Framework for Preliminary Risk Assessment of Brownfield Sites

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1 Abstract

The complexity of hazards, risk and environmental legislation surrounding the reuse of brownfield sites necessitates a preliminary risk assessment prior to their redevelopment. Most prevailing efforts have been targeted at indepth site investigations, which are often costly, time–consuming, and may not be required at the early stages of a site development. However, there is a collective absence of knowledge, methods and computer models that can present a complete framework to carry out a preliminary risk assessment that is simpler, quicker and sufficient, not only for risk assessor but also effectively communicative for a diverse range of stakeholders with or without risk assessment expertise. Therefore, this study aims to bridge this gap by designing and creating an framework, by not only identifying hazards but also exposing the degree of presence. Sixty-five potential hazards have been identified from a comprehensive literature review. A questionnaire survey was then shared with brownfield site experts (n=76) that asked then to rank the priority of the potential hazards. Kendall's W test and Kruskal–Wallis H test were subsequently conducted to determine the level of agreement among the respondents. Mean weightings were calculated by using the Voting Analytic Hierarchy Process (VAHP) to prioritize the potential hazards from 'more likely' to 'least likely'. Based on this information, the framework has been developed. It is anticipated that the framework can assist

professionals to conduct a preliminary assessment of brownfield sites, which enables them to gain informative and rapid guidance on any potential liabilities or risks related to a site's suitability for acquisition or redevelopment. In this context, the framework outlines a systematic structure to collect appropriate data and information in the three main categories which are sources, pathways and receptors.

Keywords: Brownfield sites, Contaminated sites, VAHP, Statistical analysis, Hazard identification, Risk assessment, Risk model.

2 Introduction

Constraints on the use of green spaces for development purposes has meant brownfield sites have become increasingly popular for redevelopment in recent years, especially in places where demand for residential and commercial property is high (De Sousa, 2000; Gray, 2019). Since the late 1990s the reuse of brownfield lands has been a significant policy objective across many countries with industrial legacies (Schulze Bäing and Wong, 2012), aimed at reducing urban sprawl and minimising greenfield development, as well as contributing to a more compact form of urban development. This approach also supports the United Nations SDGs (sustainable development goals), namely SDG–11 'Indicators for Sustainable Cities and Communities', which requires the best information and communication technologies (Pierce, 2018). Moreover, the sustainable development agenda promotes using as little previously undeveloped land for new development as possible.

Brownfield sites are often amongst the most technically challenging and expensive sites to bring forward. In the case of a former industrial site, there could be more than a century's worth of chemicals and unpleasant contamination lingering in the soil (Wiley and Asadi, 2002; Jera, Ncube and Kanda, 2017). As a minimum, a preliminary risk assessment is necessary to determine whether a brownfield site is contaminated and, if so, ensuring any redevelopment is safe and suitable for its proposed use

(Environment Agency, 2008). Due to limited financial resources in many cases not all the identified risks to health, safety and environment can be reduced (Marzocchini *et al.*, 2019; Pizzol *et al.*, 2011). Thus, Pizzol *et al.* (2011) highlight the need to develop methodologies that rank risks in terms of their likelihhod to select those to be investigated more thoroughly or in order to prioritize the remediation actions. The European Environment Agency (EEA, 2004) published a critical review of the available relative risk assessment methodologies. The reviewed methodologies are generally applied to rank potential contaminated sites based on existing data to develop priority actions plans in terms of detailed site investigation and remediation. The reviewed approaches adopt a qualitative method to assess the risks posed by potentially contaminated sites. They define the three components of a risk assessment model (i.e., source, pathway and receptor) in terms of scores to rate associate risks, rather than absolute estimates of health/environmental impacts (Zabeo *et al.*, 2011; Pizzol *et al.*, 2011).

Redevelopment of brownfield sites has often significant market risks. Indeed, the revitalisation of contaminated land has been associated with stigmatisation and market value reductions (Schädler *et al.*, 2011). A study conducted by Bartke, (2011) found that areas that have been properly decontaminated on average still have a depressed market value of 12.25%. Moreover, results indicate that environmental contamination more than doubles the negative influence commercial properties have on neighboring residential home values (Taylor, Phaneuf and Liu, 2016).

There are a plethora of challenges facing developers and other stakeholders in conducting preliminary assessment of brownfield sites (Mahammedi *et al.*, 2020a, 2020b; Butt *et al.*, 2020). Amongst the difficulties facing brownfield site assessors is the very strict protocols and standards adopted for risk assessment of such sites. These can be expensive and time–consuming, which can in turn have serious impacts on a project's viability (Parry, 2018). In addition, it is possible that the number of potential risks on the redevelopment of brownfield site could be far greater than assessors can expect to identify

(Kovalick and Montgomery, 2017). This generally results in a rise in site redevelopment costs and an extended period of design and site works. Therefore, it is imperative that the correct information needed at the preliminary stage to develop such a site is collected and used in the most cost–effective manner (Martin and Toll, 2006). According to the Environmental Agency (2008), lack of information increases uncertainties in identifying and assessing hazards, which leads to poor communication between stakeholders, and it is possible that different suitable qualified stakeholders could form different conclusions even when presented with the same information. However, excessive detail should be avoided, and the level of detail should be no more than is needed for robust decisions to be taken (Butt, Mair and Oduyemi, 2006; Butt *et al.*, 2016, 2017). Another challenge in the assessment of brownfield sites is commonly required expertise and knowledge from many disciplines, ranging from geotechnical engineers to geochemical scientist to provide an independent professional report about the risks to human health and the built environment, by identifying actual or potential hazards of the site (Nathanail and Bardos, 2005; Nathanail, Bardos and Nathanail, 2011). Therefore, these limitations reveal the need to take a holistic approach to the development of a framework to assist assessors and other stakeholders in identifying and prioritising potential hazards associated with brownfield sites.

Prioritization methodologies, including the Multi–Criteria Decision–Making (MCDM) method, have been proposed in a range of multidisciplinary applications as an approach for improving judgement forecasts, including application to many engineering and management decision problems (Belton and Goodwin, 1996; Ghodsypour and O'Brien, 1998; Hajeeh and Al–Othman, 2005). Literature shows several ways to solve Multiple–criteria decision–making (MCDM) issues, including the Analytical Hierarchy Process (AHP) and the Voting Analytical Hierarchy Process (VAHP). The AHP was designed by Wind and Saaty, (1980) as a decision–making aid. It is suitable for complex decisions that require the comparison of decision elements that are difficult to quantify (Kabir and Hasin, 2011). Basically, AHP is an approach to solve unstructured complex problems involving multiple–criteria, using three principles for problem–solving: *(i)* decomposition; *(ii)* comparative judgement and *(iii)* logical consistency (Saaty, 1987). While VAHP was proposed in a study by Liu and Hai (2005) as a novel easier weighting procedure in place of AHP's paired comparison. The Hadi–Vencheh and Niazi–Motlagh model (HN model) combines the AHP with a new voting data envelopment analysis (DEA) model and propose an integrated VAHP–DEA methodology (Hadi-Vencheh and Niazi-Motlagh, 2011). The VAHP maintained AHP's main concept that a comprehensive analysis of the problem is required along with identification of the important system elements involved. After the hierarchy model was established in the VAHP, the weights of criteria are calculated through voting instead of using the paired comparisons of the AHP (Liu and Hai, 2005).

The analytical hierarchy process (AHP) for brownfield sites regeneration has already been proposed in the literature. They focus on different aspects and phases of the regeneration process, including the application of AHP for conservation forest (Wolfslehner, Vacik and Lexer, 2005; Laxmi et al., 2012), landfill site selection (Wang et al., 2009; Donevska et al., 2012), site selection (Chen, 2006; Vahidnia, Alesheikh and Alimohammadi, 2009) and remediation techniques for contaminated and brownfield sites (Zhang *et al.*, 2012; Pizzol *et al.*, 2016). While, the use of VAHP for brownfield redevelopment is often neglected. In fact, limited research adopting VAHP in the redevelopment of brownfield sites.

Despite significant advances in risk assessment of brownfield sites, the scope has been characterised by a lack of a comprehensive, robust and sound frameworks to assist in the identification of hazardous substances, pollutants, or contaminants, as well as guide research in this field (Mahammedi *et al.*, 2020b; Mahammedi, 2021). Laidler *et al*. (2002) stressed that the lack of robust frameworks contributed to delays in the planning process and a reluctance of some governments to redevelop brownfield sites. Searl (2012) also argued that the uncertainty underlying preliminary risk assessment of brownfield site affected stakeholders' decisions. It emerged that existing decision support systems have focused mainly on economic aspects, while neglecting environmental issues (Schädler *et al.*, 2011; Morio, Schädler and Finkel, 2013).

Consequently, this study aims to bridge this knowledge gap and provides an framework that gives a theoretical foundation to the study of preliminary assessment of hazards associated with the redevelopment of brownfield sites. This aim is facilitated via the following key objectives:

1. To conduct a critical review of literature to identify potential hazards associated with brownfield site development.
2. Design and develop a questionnaire and identify appropriate target groups.
3. Apply a statistical and VAHP approach to prioritising, classifying, and generally distinguishing potential hazards from most likely to least likely.
4. Based on the results prioritise the potential hazards to inform the development of the framework.

3 Research methodology

This research design involved four phases, which were divided into seven activity stages (Figure 1). These phases are used to structure this section, before leading to the creation of the framework.

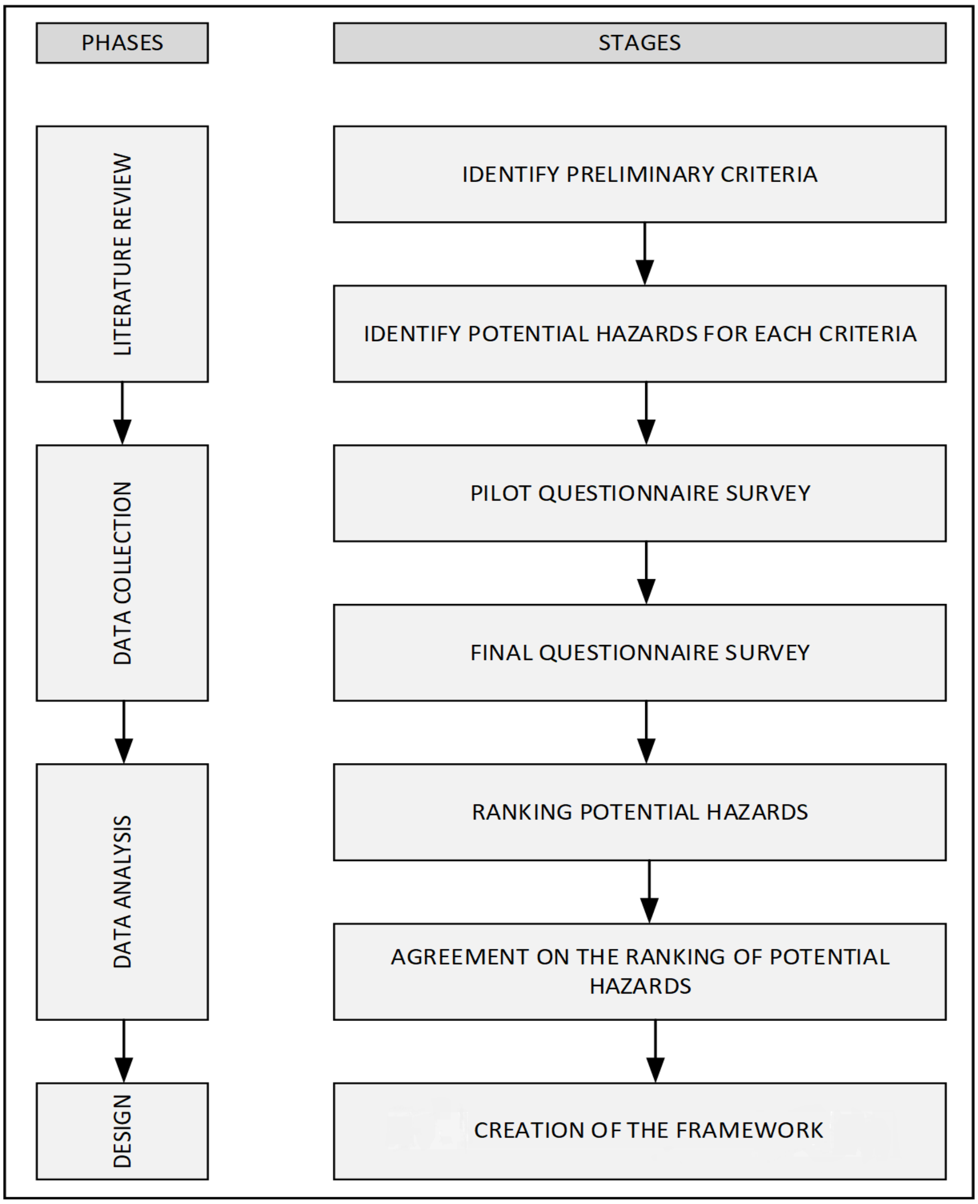

Figure 1: Research design process that enabled the framework development

3.1 LITERATURE REVIEW

A number of strategies were undertaken in order to select and ensure that a comprehensive approach to investigating the literature in the field of brownfield sites and hazards, is applied. Firstly, an online search of electronic databases was conducted, including Science Direct, Scopus, Web of Science, American Society of Civil Engineers (ASCE) and other similar leading search facilities. This was expanded further by examining the grey literature such as government reports, technical reports (e.g.

Department of Environment, industry profile) etc. Using a variety of databases increased the sensitivity of the search, ensuring that an extensive assortment of literature was explored. Secondly, to identify relevant articles a number of key words and phrases were used to search the databases including (“Hazards identification” OR “Risks” OR “Risk assessment”) AND (“Brownfield” OR “Contaminated site”, ”Derelict site”, “Previous used site”). The Boolean Operator ‘OR’ was used between the terms to find one term or the other, while ‘AND’ returns only results that contain all search terms (Aveyard, 2018). A total of more than 200 publications were identified relevant to the scope of the study. No automatic text analysis was applied, as manual study of the articles was adopted. Thirdly, inclusion and exclusion (eligibility) criteria were used for further narrowing down from 200 to about 1/3rd, which were also in line with the research question (Popay *et al.*, 2006). The eligible criteria dopted are: i) only works published in the English language; and ii) focus primarily on hazards in connection to brownfield sites.

3.2 DATA COLLECTION

A questionnaire survey is an effective approach to achieve quantifiable and objectiveness (Jones *et al.*, 2013). In addition to the literature review, which laid the foundation for the development of a survey questionnaire, a pilot study was conducted (phase–two) with discipline–expert professionals to ensure that the content of the questionnaire was comprehensive and clear for the participants. Based on the feedback, the questionnaire was amended and finalized. In the finalized questionnaire, the objective of the research and contact details were first presented, followed by questions meant to gather background information of the participants.

An online structured questionnaire survey was deployed via a Qualtrics (recording participant details and opinions) with a panel of industry–facing professionals. To identify appropriate target groups for the questionnaire, the survey adopted a purposive/judgement sampling technique. This technique is appropriate mainly because it requires a deliberate choice of participants (Etikan, Musa and Alkassim, 2016). The purposive sampling is used because the researcher seeks to capture solid knowledge in a particular form of expertise and become better informed about the subject at hand before engaging in tool development. In this study it is important to involve expert participants with a good understanding of issues pertaining to development of brownfield sites and hazards associated with them.

Participants were asked to rank and prioritize potential hazards associated with brownfield site from more likely hazards to the less likely. This type of questioning has the benefit of requiring respondents to identify how elements or choices compare to each other and determines the most likely ones to them. Eligibility criteria used to include participants as appropriate specialists was that they needed to be: (i) hold the minimum of a Bachelor degree qualification; and (iii) employed in the Brownfield Site sector for a minimum of one year. The profiles of participants are presented in Table 1.

Table 1: Profiles of the participants

Characteristics	**Frequency**	**Percentage (%)**
Professions		
Geotechnical Engineer	13	17
Geo–Environmental Engineer	16	21
Hydrologist	12	16
Geochemist	10	13
Geophysicist	12	16
Geologist	13	17
Years of working experience		
1–3 years	15	20
4–6 years	9	12
More than six years	52	68
Years of working experience in the redevelopment of brownfield sites		
1–3 years	11	14
4–6 years	19	25
More than six years	46	61

3.3 DATA ANALYSIS

3.3.1 AGREEMENTS ON THE RANKING OF THE POTENTIAL HAZARDS

To verify the level of agreement among the participants regarding the ranking of the potential hazards associated with brownfield sites, Kendall's coefficient of concordance (also known as Kendall's W) test was conducted. Kendall's W test is a non–parametric statistic. It is a normalization of the statistic of the Friedman test and can be used for assessing agreement amongst participants (Rasli, 2006). Kendall's *W* tests the null hypothesis that "no agreement exists among the rankings given by the participants in a particular group". It ranges from 0 (no agreement) to 1 (complete agreement) (Lewis and Johnson, 1971).

3.3.2 AGREEMENTS ACROSS PROFESSIONS

As the participants were from different discipline backgrounds (Geotechnical engineers, Geologists, Hydrologists, etc.), it was fundamental to check whether there were significant differences between respondents by applying intergroup comparisons. To conduct the intergroup comparisons, two different statistical methods were considered, ANOVA and the Kruskal–Wallis H test, where the ANOVA test is the parametric equivalent of the Kruskal–Wallis H test (Hecke, 2012). The normality of the data was tested using the Shapiro–Wilk test. The results indicate the data collected are not normally distributed, as all the p–values produced by the test were <0.05. Hence, the Kruskal Wallis H test was adopted for inter–group comparison. Briefly, the Kruskal-Wallis is a non–parametric statistical test that assesses the differences among three or more independently sampled groups on a single, non–normally distributed continuous variable. Non–normally distributed data (e.g. ordinal or rank data) are suitable for the Kruskal–Wallis test (McKight and Najab, 2010).

3.3.3 VOTING ANALYTIC HIERARCHY PROCESS

The Voting Hierarchy Process adopted in this study consists of the following steps:

Step 1: *Determine framework criteria.* In the initial step, the framework criteria can be obtained from the existing literature or through other methodologies.

Step 2: *Structure the hierarchy of the criteria,* in the second step, developing multi–level hierarchy model, which will provide the user with a better understanding of the inter–relationship of the entire assessment framework

Step 3: *Vote on the importance of criteria and sub–criteria.* In this step, it is required to rank order the criteria by experts based on their importance.

Step 4: *Derive the importance ratings of criteria and sub–criteria.* In the fourth step, Liu and Hai (2005) have adopted a DEA approach to determine the weight of criteria and sub–criteria by using the following model:

$$\theta_{rr} = \max \textstyle\sum_{(s=1\sim S)} U_{rsX_{rs}},$$

$$\theta_{rp} \textstyle\sum_{(s=1\sim S)} U_{rsX_{ps}} \leq 1(\rho = 1,2,\ldots.R), \qquad \textit{Equation 1}$$

$$U_{r1} \geq 2U_{r2} \geq 3U_{r3} \geq \cdots \geq SU_{rs},$$

$$U_{rs} \geq \varepsilon = 1/((1+2+\cdots+S)*n)$$

$$= \frac{2}{n*S(S+1)}$$

Where S_{rs}=the total votes for the *r*th criteria for *l*th place by *n* voters. α is the constraint which stands for the difference in weights between sth place and (s+1) th place

Step 5: *Measurement of the performance of alternatives*. In the fifth step, the performance of the alternatives is measured against those criteria and sub–criteria that are represented in the criteria hierarchy. Liu and Hai (2005) provide a detailed explanation of how these measurements have been applied in their case study, which involved both factual data and qualitative judgements.

Step 6: *Identification of the priority of alternatives*. In the sixth step, the total weight obtained in Stage 5 through the summing of criterion weights.

$$w_1 \geq 2w_2 \geq 3w_3 \geq \cdots . \geq Sw_s \qquad \text{Equation 2}$$

$$\sum_{s=1}^{S} w_s = 1$$

$$\alpha \leq \theta_r = \sum_{s=1}^{S} x_{rs} w_s \;\; r = 1,2, \ldots , R \qquad \text{Equation 3}$$

Where x_{rs} is the total votes of the *r*th criteria for the *s*th place.

4 Framework development and discussion

The framework development started from an idea based on the literature review that there is a strong need for a framework that will enable assessors in conducting preliminary risk assessment (Mahammedi *et al.*, 2020b). The components of the framework were determined from a critical review of the literature. It is composed of three components: (*i*) pollutant linkage model, (*ii*) site characteristics and (*iii*) potential hazards.

4.1 RISK ASSESSMENT MODEL

The assessment and management of land contamination risks management have been adopted in many European countries based on the pollutant linkage concept, including a contaminant source, a pathway along which the contaminant can move to a receptor that may be affected (Vik *et al.*, 2001). These are the three fundamental components to any risk assessment in many countries (Vik and Bardos, 2003), in which this concept is used in the UK Model Procedures (CLR11) in the context of risks assessment and management to health and the environment from contaminated lands. This information will enable the local planning authority to determine whether more detailed investigations are required, or whether any proposed remediations are appropriate (Ministry of Housing, 2014).

Figure 2: Risk assessment model (derived from Environmental Agency, 2008)

This concept is limited to contaminated sites with chemical contamination, while this research study illustrates that the term brownfield site has been widely adopted to describe previously developed land. Therefore, the pollutant linkage concept can be extended to be adopted for brownfield sites.

4.2 SITE CHARACTERISTICS

Site characteristics are required for conducting preliminary risk assessments. With this criteria potential hazards are identified and behaviours can be confidently determined, before allowing solutions to be managed (Mulligan *et al.*, 2001; Liu *et al.*, 2018). As already mentioned, this research conducted a review of academic databases and grey literature to identify the necessary criteria to develop a comprehensive understanding of the potential hazards associated with brownfield sites. As indicated by the review findings, the following criteria are essential to identify potential hazards (Environment Agency, 2008):

1. History of the site
2. Surrounding area
3. Buildings and other structures
4. Underground services
5. Storage of materials and old tanks
6. Previous mining activities
7. Presence of radon
8. Invasive species
9. Made ground
10. Site geology
11. Site hydrology/hydrogeology
12. Site topography
13. Future end–use
14. Building materials

4.3 IDENTIFY THE POTENTIAL HAZARDS

The hazard identification process involves highlighting substances/chemicals, biological and physical entities which can or have the potential to cause harms to human health and the built environment (Charles and Skinner, 2004; Skinner, Charles and Tedd, 2005). In view of this definition, the relevant literature was comprehensively reviewed to identify hazards and risks. For example, the main industries and activities that cause brownfield sites have been identified by the Environment Agency (2008), which illustrates a comprehensive list of contaminants associated with each industry and/or activity. Moreover, the data related to the past use of the site, as manufacturing processes of past industries are well documented. Such hazards include buried tanks, deep foundations, effluent lagoons etc. The identified hazards are presented in Table 2.

Table 2: List of potential hazards identified from the literature

Criteria	Code	Potential hazards	References
	PH1	Physical hazards (e.g. tanks, storages, etc.)	

History of the site	PH2	Chemical contaminants	(Departement of the Environment, 1995; Environment Agency, 2008)
	PH3	Biological contaminants	
Surrounding area (Industrial/Commercial)	PH4	Pollutants migration from industrial/commercial site to adjacent sites (e.g. in the period of heavy rainfall or snowmelt.)	(Environment Agency, 2008; Bougherira *et al.*, 2014)
	PH5	Excavation of the industrial/commercial site may disturb contaminates and releasing them into water course and water supplies which may pose risk to neighbour residential.	(Leach and Goodger, 1991; Fent, 2003; Billington, 2007; Watts and Charles, 2015)
Surrounding area (Residential)	PH6	Pollutants migration from brownfield sites to neighbour residential (.e.g. in the period of heavy rainfall or snowmelt)	(Leach and Goodger, 1991; Fent, 2003; Billington, 2007)
	PH7	Excavation of brownfield site may disturb contaminates and releasing them into water course and water supplies which may pose risk to neighbour residential	(Environment Agency, 2008; Mouri *et al.*, 2014; Cole and Marney, 2012)
Buildings and other structures	PH8	Hazards related to demolition activities of existing buildings and other structures.	(Charles *et al.*, 2002; Skinner, Charles and Tedd, 2005; HSE, 2006)
	PH9	Old foundations failure due to chemical soil attack that lead to foundations degradation	(Charles *et al.*, 2002; Skinner, Charles and Tedd, 2005; Hertlein and Walton, 2007)
	PH10	Hazards from sharp objects (e.g. glass, metallic objects)	(Fleming, 2015)
Underground services (water pipes and sewers)	PH11	Damage to water pipes and sewers may cause floods	(Mi, 2007; Noh *et al.*, 2016)
	PH12	Contaminants in the ground can pose a risk to potable water supply by permeating plastic water	(Hill, Slade and Steeds, 2001; LeChevallier *et al.*, 2003)
	PH13	Leaks of water from underground pipes can affect adjacent services and reduce support for other structures	(Charles *et al.*, 2002; Charles, 2005)
	PH14	Damage to a sewer pose risks to the health of workers from exposure to raw sewage.	(HSE, 2006, 2013a)
Underground services (Gas pipes)	PH15	Risk of fire and explosion due to flammable gases.	(HSE, 2006; Shin *et al.*, 2018)
	PH16	Risk of leakage due to damage of connections.	(HSE, 2006; Best, 2007; Department for Communities and Local Government, 2008)
	PH17	Risk of asphyxiation due to inert gases such as nitrogen and argon.	(HSE, 2006; Peterson, 2015)

	PH18	Risk of poisoning due to toxic gases	(Leach and Goodger, 1991; Ong and Teugels, 2016)
	PH19	Risk of release contents due to elevated pressure	(British Standard Institution, 2004a, 2004b)
Underground services (Electricity cables)	PH20	Explosive, fire or flames that may result when a live cable is penetrated by a sharp object.	(HSE, 2006; Wilkinson and David, 2009; HSE, 2013b)
	PH21	Damage of electricity cables may pose risk to nearly services	(HSE, 2006, 2013b)
	PH22	Hazards of electrical cables to burn hands, face and body	(Timmons, 1981; HSE, 2013b)
	PH23	Cables which have been damaged but left unreported and unrepaired, or which have deteriorated with age.	(HSE, 2006, 2013b, 2013a)
Underground services (Telecommunication cables)	PH24	The possibility of flammable and toxic gases migration through telecommunication cables.	(HSE, 2013a, 2017)
Storage of materials and old tanks	PH25	Chemicals and other liquid raw materials stored in tanks and silos	(Barry, 1991; Leach and Goodger, 1991; Watts and Charles, 2015)
	PH26	Ground instability related to removing tanks and underground storages	(Barry, 1991; Leach and Goodger, 1991; Charles, 2005; Watts and Charles, 2015)
Previous mining activities	PH27	Pollution incidents resulting from mine water and contaminated shaft fill	(Lee, Chon and Kim, 2005; Li and Ji, 2017; Nikolaidis, 2018)
	PH 28	Subsidence and collapsing of voids due to the presence of large voids at shallow depth.	(Charles, 2005; Kelm and Wylie, 2007; Watts and Charles, 2015)
	PH 29	Emission of noxious or asphyxiating mine gases	(Ramirez–andreotta *et al.*, 2013; Argyll Environmental Ltd, 2018; Kim *et al.*, 2019)
	PH 30	Spontaneous combustion of coal by exposure to atmospheric conditions	(Charles, 2005; Li *et al.*, 2009; Qi *et al.*, 2019)
Presence of radon	PH31	Radon may migrate into buildings, which may cause lung cancer, particularly for smokers and ex–smokers	(Hampson *et al.*, 2000; Tracy *et al.*, 2006; Zielinski *et al.*, 2006)
Invasive plants	PH32	Aggressive plant may cause damage to the structure of a building such as drains, services, and walls.	(Maerz, Blossey and Nuzzo, 2005; Payne *et al.*, 2012)
	PH33	Invasive plants may cause immense landslides and soil erosion	
	PH34	Health issues due to contact (e.g. dermal contact, swallowing) with invasive plants	(Batish *et al.*, 2004; Culliney, 2005; D'hondt *et al.*, 2015)

Invasive animals	PH35	Transmission of viruses to humans	(Mazza *et al.*, 2013)
Made ground	PH36	Failure of construction materials, because of their vulnerability to aggressive ground conditions	(Bartarya, 2013; Seeley and Winfield, 2015; Baker, 1980)
	PH37	Hazards for buildings and occupants, arising from combustion	(Richards, 1998; Blight, 2009; Kim *et al.*, 2013)
	PH38	The migration of contaminants from landfill site over time increase the possibility of groundwater to be contaminated.	(Jensen, Ledin and Christensen, 1999; Broholm *et al.*, 1998; JACOBS, 2017; Augustsson *et al.*, 2016; Smith, 2005)
	PH39	Damage to buildings due to volume changes in fill caused by physical, chemical or biological reactions	(Watts and Charles, 2015; Skinner, Charles and Tedd, 2005; Lucian, 2006; Charles and Skinner, 2004)
	PH40	The generation of methane and carbon dioxide with volatile organic compounds (VOC) as result to microbial activity	(Talaiekhozani *et al.*, 2018; Maheshwari, Gupta and Das, 2015; Bouazza and Kavajanzian, 2001; Jonidi jafari and Talaiekhozani, 2010; Ohimain and Izah, 2017)
Site geology (Homogeneous clay)	PH41	Because of the impermeable features of homogeneous clay, the migration of the contaminants is practically excluded. which creates a persistent, secondary source of contamination that is difficult to remediate.	(Carter, 1983; Miller *et al.*, 2011)
Site geology (Silts, fine sands, clay)	PH42	Because of the poor permeability, the soil underlying the site slows down the migration of contaminants, which creates a persistent, secondary source of contamination that is difficult to remediate.	(Carter, 1983; Westcott, Smith and Lean, 2003; Nathanail, Bardos and Nathanail, 2011)
Site geology (Clean sands, sand and gravel mixture)	PH43	The soil underlying the site accelerates the migration of contaminants for groundwater, nearby surface water and adjacent sites.	(Carter, 1983; Westcott, Smith and Lean, 2003; Nathanail, Bardos and Nathanail, 2011)
Site geology (Clean gravel)	PH44	The soil underlying the site accelerates the migration of contaminants for groundwater, nearby surface water and adjacent sites.	(Carter, 1983; Westcott, Smith and Lean, 2003; Nathanail, Bardos and Nathanail, 2011)
Site geology (Very thickly)	PH45	A very thin layer accelerates the migration of contaminants for groundwater, nearby surface water and adjacent sites.	(Carter, 1983; Martin and Toll, 2006)

Site geology (Tickly)	PH46	A tickly layer accelerates the migration of contaminants for groundwater, nearby surface water and adjacent sites.	
Site geology (Medium)	PH47	Medium layer the soil underlying the site slows down the migration of contaminants, which creates a persistent, secondary source of contamination that is difficult to remediate	
Site geology (Very thinly)	PH48	Very thinly layer the soil underlying the site slows down the migration of contaminants, which creates a persistent, secondary source of contamination that is difficult to remediate	
Presence of groundwater	PH49	Presence of groundwater increase the movement of contaminants to adjacent sites and/or surface water systems. Which rise risks to human health and aggressive attack to building materials.	(Kawai, Yamaji and Shinmi, 2005; Bartarya, 2013; Ahmad *et al.*, 2013; Hadigheh, Gravina and Smith, 2017; Naveen, Sumalatha and Malik, 2018)
Site hydrology (Presence of surface water)	PH50	Presence of surface water increase the movement of contaminants to adjacent sites and/or groundwater. Which rise risks to human health and aggressive attack to building materials.	
Site hydrology (Flooding zone)	PH51	The upwards movement of contaminants in groundwater following flooding or excessive rainfall.	(Environment Agency, 2008)
Site topography (Steep site)	PH52	Spreading of contaminants as result of slope failures	(Salgado *et al.*, 2013; Boulding, 2017; Environment Agency, 2008)
	PH53	Migration of contaminants in the direction of the slope	(Salgado *et al.*, 2013; Boulding, 2017; Environment Agency, 2008)
Site topography (Flat site)	PH54	Horizontal sites increase infiltration and vertical movement of accumulated contaminants towards groundwater.	(Gurunadha Rao and Gupta, 2000; Burgos *et al.*, 2008)
	PH55	Horizontal sites reduce contaminants flow which creates a source of contamination that increase environment pollution	(Galletti, Verlicchi and Ranieri, 2010)
Future end use (Residential with consumption of homegrown produce)	PH56	Health issues which can be exposed through: • Direct ingestion of soil • Ingestion of home–grown produce • Ingestion of soil attached to home–grown • Inhalation of indoor and outdoor dust	(Environment Agency, 2009; Nathanail, Bardos and Nathanail, 2011)

		• Inhalation of indoor and outdoor vapours • Dermal contact with soils and dust	
Future end use (Residential without consumption of homegrown produce)	PH57	Health issues which can be exposed through: • Direct ingestion of soil, • Inhalation of indoor and outdoor dust, • Inhalation of indoor and outdoor vapours, • Dermal contact with soils • Dermal contact with dust (Indoors)	
Future end use (Commercial)	PH58	Health issues which can be exposed through • Direct ingestion of soil • In halation of indoor and outdoor dust • Inhalation of indoor and outdoor vapours • Dermal contact with soils • Dermal contact with dust	
Future end use (Public open space)	PH59	Health issues which can be exposed through: • Direct ingestion of soil • Inhalation outdoor of dust, • Inhalation outdoor of vapours • Dermal contact with soils	
Building materials (Concrete)	PH60	Contaminants contact with concrete cause damage leading to loss of strength, stiffness and cracking.	(Building Research Establishment (BRE), 1991, 2005)
Building materials (Reinforced concrete)	PH61	Reinforced corrosion may happen either of corrosion ions, for example attack by chlorides, or as a result of reduction in the PH of concrete through carbonation.	(Asrar *et al.*, 1999; Building Research Establishment (BRE), 2005; Poursaee, 2016)
Building materials (Asbestos cement)	PH62	Asbestos cement is highly durable material, can be considered as strong resistant to contaminants. Otherwise, certain contaminants such as Sulphate the asbestos cement show less resistant.	(British Standard Institution, 1988; Garvin *et al.*, 1999)
Building materials (Metal)	PH63	Many metals such as cast iron, stainless steel, galvanised and aluminium are used in substructure. All these metals can deteriorate through corrosion process.	(Lankes, 1981; Galka and Yates, 1984)
Building materials (Organic Materials (.i.e	PH64	Plastics deteriorate by degradation of their polymeric constituent. Damage of plasticiser and change the physical properties and characteristics of polymeric materials.	(Crathrone *et al.*, 1987; Shimao, 2001)

Plastic Membranes and Geotextiles)			
Building materials (Clay Brick)	PH65	Although the characteristics of clay bricks to resist to chemical attack, but their permeability will let them at high risk from salt crystallisation.	(Somsiri, Zsembery and Ferguson, 1985; Hansen and Kung, 1988)

4.4 RANKING POTENTIAL HAZARDS

VAHP aims to prioritize the potential hazards associated with brownfield sites, which will help to identify and select the most appropriate hazards to eventually be investigated in the next stage of the risk assessment. It should be noted that the potential hazards associated with the 'history of the site', 'underground services (telecommunication cables)', 'presence of radon', 'invasive species (animals)', 'geology' receptor were excluded from the VAHP analysis since it contained only one potential hazard that was identified in this study.

4.4.1 POTENTIAL HAZARDS ASSOCIATED WITH SURROUNDING AREAS

The weightings of hazards was calculated based on data collected from the survey. The same procedure was followed for all potential hazards. However, the steps to calculate the weightings of potential hazards are presented only in this section to avoid repetition. The steps are presented as mention in section 3.3.3 as follows:

Step 1: calculate w_s: For example, the potential hazards associated with residential surrounding areas consists of two potential hazards: "Excavation of the brownfield site…" and "Pollutants migration from brownfield..". the coefficient w_s are different and calculated based on Equation (2). As result w_s will be: $w_1 = 0.5454$, $w_2 = 0.2727$

Step 2: weights and rank hazards by using the VAHP Equation 3. Subsequent to the calculation of weights, the obtained weights for the potential hazards were normalised so that they add up to one. Similarly, the obtained weightings for the attributes in hazard were normalised. The result of this process can be seen in Table 3.

Table 3: The ranking of the potential hazards associated with surrounding areas

Surrounding areas	Potential hazards	Weight	Normal	Rank	Kruskal–Wallis H		Kendall's coefficient of concordance		
					X^2	***P–value***	**W**	***X^2***	***P–value***
Residential	PH 5	41.667	0.548	1	5.239	0.387[a]	0.169[b]	25.658	<0.001
	PH 4	34.332	0.451	2	.545	0.990[a]			
Industrial/Commercial	PH 7	40.333	0.530	1	5.128	0.382	0.178	26.079	<0.001
	PH 6	35.666	0.469	2	.523	0.930			

This outcome indicates that excavation in brownfield sites is the most likely hazards associated with surrounding criteria. This observation agrees with the findings of previous studies (Leach and Goodger, 1991; Wood, 2015; Liu *et al.*, 2018) carried out in the context of remedial treatment of contaminated sites, where excavation contaminants would be a positive way of preventing contact of contaminants (i.e. chemical and biological) with surface targets and the aquifer, but the disturbance of contaminants can create a high risk that migrating contaminants into groundwater or adjacent sites. The second, the respondents ranked, was pollutant migration to adjacent sites. This finding is in agreement with (Leach and Goodger, 1991), which indicates that important phenomena in the site containing contamination are the long term transport of pollutants to adjacent sites. For instance, contaminant could migrate in the direction of steep contaminated site. Besides, many studies (Mouri *et al.*, 2014; Hadigheh *et al.*, 2017) highlight that heavy rainfall or snowmelt may cause chemical leaching to neighbours.

4.4.2 POTENTIAL HAZARDS ASSOCIATED WITH BUILDINGS AND OTHER STRUCTURES

In terms of buildings and other structures, participants were asked to rank potential hazards from 'most' to 'least' in terms of occurrence. This outcome (Table 4) is in great agreement with earlier studies (Barry, 1991; Leach & Goodger, 1991; Sarsby, 2000; Charles, 2005), which mention that structures and buildings that exist in previously used land may present an additional source of hazards during demolition activities. For instance, due to historical poor practices, it is commonplace on most brownfield sites to discover asbestos contamination within the soil when demolition has been completed. Furthermore, buildings originally sited on brownfield land are likely to have contained high levels of contaminants. For instance, the US Environmental Protection Agency (2012) suggest there was potential widespread use of Asbestos, PCB–containing building materials, Asbestos, Microbiological, Synthetic mineral fibres in schools and other buildings constructed or renovated between about 1950 and 1979.

Table 4: Ranking the potential hazards associated with buildings and other structures

Potential hazards	**Weight**	**Normal**	**Rank**	**Kruskal–Wallis H**		**Kendall's coefficient of concordance**		
				X^2	***P–value***	**W**	X^2	***P–value***
PH 8	31.727	0.417	1	4.407	0.492	0.144	21.868	<0.001
PH 10	23.545	0.309	2	1.913	0.861			

PH 9	20.727	0.272	3	3.129	0.680

4.4.3 POTENTIAL HAZARDS ASSOCIATED WITH UNDERGROUND SERVICES

Participants were asked to rank potential hazards related to underground services. Firstly, the ranking order of potential hazards related to water pipes (Table 5). Water leaks ranked first with the highest weight of 22.84, followed by damages to water pipes and sewers that may occur during the redevelopment of brownfield sites, and which may cause flooding. While migration of contaminants through permeating water pipes ranked third (weight of 17.80), followed by the damage to sewerage, which may pose a risk to site works by weight of 17.32.

Secondly, Table 5 shows the ranking order of potential hazards related to gas pipes, where the damage to gas pipes ranked first (weight of 24.30). This is perhaps an expected result as any damage or accidents to gas pipes during the redevelopment of brownfield sites may lead to explosion and fires. Gas pipes also raise concerns of leakage due to damage or lack of maintenance, which may pose a risk for site workers or future occupants. However, this hazard ranked second (weight of 17.72). Otherwise, some gases such as chlorine, phosgene, sulphur dioxide, hydrogen sulphide, nitrogen dioxide, and ammonia which may severely toxic to human health. This potential hazard was ranked third (weight of 13.94). While the risk related to release contents due to elevated pressure ranked fourth (weight of 11.06). The fifth rank was awarded to asphyxiation hazards due to inert gases, such as nitrogen and argon, by a weight of 8.93.

Thirdly, incidents (e.g. penetrated by a sharp object) during the redevelopment of brownfield sites may lead to an explosive, fire or flames associated with electricity cables ranked first (weight of 25.24). This is understandable as the Health and Safety Executive (2010) reported that each year about 1000 accidents at work involve electric shock or burns. Followed by cables that have been damaged but left unreported and unrepaired, or have deteriorated with age. This hazard ranked second (weight of 18.92). While the risk to near services as result of damages of electricity cables ranked fourth (weight of 13.84).

Table 5: Ranking the potential hazards associated with underground services

Underground services	Potential hazards	Weight	Normal	Rank	Kruskal–Wallis H		Kendall's coefficient of concordance		
					X^2	***P–value***	**W**	X^2	***P–value***
Water pipes	PH 13	22.84	0.300	1	5.387	0.371	0.300	0.041	0.026
	PH 11	18.04	0.237	2	3.053	0.692			
	PH 12	17.80	0.234	3	1.543	0.908			
	PH 14	17.32	0.227	4	2.134	0.830			
Gas pipes	PH 15	24.30	0.319	1	1.800	0.876	0.405	123.000	<0.001
	PH 16	17.72	0.233	2	2.455	0.783			
	PH 18	13.94	0.183	3	7.328	0.197			
	PH 19	11.07	0.145	4	6.053	0.301			
	PH 17	8.93	0.117	5	2.023	0.846			
Electricity cables	PH 20	25.24	0.332	1	3.287	0.656	0.122	27.900	<0.001
	PH 23	18.92	0.248	2	6.802	0.236			
	PH 22	18.00	0.236	3	4.407	0.492			
	PH 21	13.84	0.182	4	4.055	0.542			

4.4.4 POTENTIAL HAZARDS ASSOCIATED WITH STORAGE AND OTHER MATERIALS AND OLD TANKS

The participants were asked to rank potential hazards related to storage of materials and old tanks criteria. Table 6 shows "Chemicals and other liquid…" was ranked first with the highest weight of 42.33. Second was "Ground instability…" with a weight of 33.65.

Table 6: Ranking the potential hazards associated with storage of materials and old tanks

Potential hazards	Weight	Normal	Rank	Kruskal–Wallis H		Kendall's coefficient of concordance		
				X^2	*P–value*	W	X^2	*P–value*
PH 25	42.334	0.557	1	4.610	0.465	0.117	8.895	0.003
PH 26	33.650	0.443	2	4.610	0.645			

It was perhaps not surprising that chemicals and other liquid raw materials stored in tanks had the highest level of importance, which has been demonstrated in many studies as one of the main causes of soil and groundwater contamination due to leakage from piping, from underground storage tanks. Syms (2007) outlined also the responsibility of the storage of materials in soil pollution, that delivery and storage facilities are responsible for contaminants to be absorbed on to soil, where contaminants could be dissolved in water and readily migrate through soil and reaching groundwater. Ground instability was ranked second, this hazard was highlighted in studies (Skinner *et al*., 2005; Watts and Charles, 2015), where the ground stability issues are most likely to occur on removal of storages and tanks.

4.4.5 POTENTIAL HAZARDS ASSOCIATED WITH PREVIOUS MINING ACTIVITIES

The VAHP analysis shows "Subsidence and collapsing of voids…" was ranked first with the highest weight of 28.88. Expectedly, the hazards related to subsidence of voids in previous mining sites ranked first, this finding could be due to the wide range of mining subsidence incidents that occurred in sites with mining history. The second, as the respondents ranked, was "Emission of noxious or asphyxiating …" with a weight of 20.96. This finding is consistent with existing research by Greenwood and Kuhn (2014), who warned of gas seeping from an abandoned mine. "Spontaneous combustion of coal" ranked third most likely hazards with weight of 15.08, as this hazard is a well–known phenomenon.

Serious incidents of spontaneous combustion have been reported as a result of the self–heating of reactive coal shales. Finally, 'Pollution incidents…" had the lowest weight amongst all hazards, as ranked fourth with weight of 11.20 (Table 7).

Table 7: Ranking the potential hazards associated with previous mining activities

Potential hazards	**Weight**	**Normal**	**Rank**	**Kruskal–Wallis H**		**Kendall's coefficient of concordance**		
				X^2	***P–value***	**W**	***X^2***	***P–value***
PH 28	28.88	0.380	1	8.329	0.139	0.522	119.103	<0.001
PH 29	20.96	0.275	2	4.307	0.506			
PH 30	15.08	0.198	3	8.845	0.115			
PH 27	11.20	0.147	4	3.994	0.550			

4.4.6 POTENTIAL HAZARDS ASSOCIATED WITH INVASIVE SPECIES (PLANTS)

The VAHP analysis shows "Health issues due to contact …" was ranked first (weight of 35.46). Hence, it is understandable because some plant leaves contain toxins that may affect human health, for example, physical contact with the leaves may cause skin irritation. The second, as the participants ranked, was "Aggressive plant that can cause damage…" with a weight of 21.36. These findings were highlighted by by Payne *et al.* (2012), who discussed the dangers of Japanese Knotweed to buildings. Besides, Warren (2019) demonstrate that vegetation is difficult to remove once established and can regenerate rapidly from small pieces. Moreover, the presence of Japanese Knotweed must be declared by the seller during conveyancing and some mortgage companies require eradication backed by warranty before they will lend money on a property. Finally, ground movement due to species of plants was ranked third (weight of 19.10), where the literature shows that areas recently supporting invasive plants, such as Himalayan Balsam (HB), recorded significantly higher erosion rates than nearby uninvaded areas (Table 8).

Table 8: Ranking the potential hazards associated with invasive species (plants)

Potential hazards	Weight	Normal	Rank	Kruskal–Wallis H		Kendall's coefficient of concordance		
				X^2	***P–value***	**W**	***X^2***	***P–value***
PH 34	35.46	0.467	1	4.780	0.443			
PH 32	21.36	0.281	2	3.423	0.635	0.648	147.742	<0.001
PH 33	19.10	0.251	3	6.835	0.233			

4.4.7 POTENTIAL HAZARDS ASSOCIATED WITH MADE GROUND

Results indicate contaminants from landfill are the most likely hazards (weight of 24.28) associated with made grounds (Table 9). Leach and Goodger (1991) indicate that hazardous leaching from made ground is troublesome and has prompted many studies into the consequence of contaminants leaching on groundwater aquifers. The generation of methane from landfill ranked high with a weight of 19.72. This result provides a useful reminder to assessors that hazardous gas may be present in brownfield sites containing made ground. Compton *et al.* (1999) indicated that 250–400 m^3 of landfill gas can be generated from one ton of biodegradable waste. Made ground combustion ranked third with a weight of 11.96. This hazard may result from the oxidation of organic materials and carbonaceous minerals (e.g. coal residues, solvent oils, etc.), as well as non–carboniferous materials (e.g. as sulphur, zinc blende iron, pyrite and spent oxide in gas work residues). Thus, whenever combustion materials are found a caution must be contemplated.

Made ground may also raise concerns related to settlement, which gives rise to serious problems for building development on made ground, even where suitable remedial measures are taken. In addition, gassing and combustibility hazards may affect the stability of the site. This hazard was ranked fourth by weight of 11.76. Failure of construction materials because of their vulnerability to aggressive ground conditions ranked fifth (weight of 8.26). This is understandable because aggressive ground conditions on made ground may be less intense than on an industrial contaminated site, due to lower concentrations of contaminants.

Table 9: Ranking the potential hazards associated with made ground

Potential hazards	**Weight**	**Normal**	**Rank**	**Kruskal–Wallis H**		**Kendall's coefficient of concordance**		
				X^2	***P–value***	**W**	***X^2***	***P–value***
PH 38	24.28	0.319	1	3.423	0.635			
PH 40	19.72	0.259	2	2.250	0.814			
PH 37	11.96	0.157	3	8.379	0.137	0.438	133.021	<0.001
PH 39	11.75	0.154	4	7.057	0.216			
PH 36	8.263	0.108	5	8.969	0.110			

4.4.8 POTENTIAL HAZARDS ASSOCIATED WITH SITE TOPOGRAPHY

The VAHP analysis of potential hazards associated with site topography are presented in Table 10. Results of flat sites shows that vertical movement of accumulated contaminants due to flat sites ranked first by weight of 43.33. Gurunadha *et al*. (2000) indicated that horizontal sites increase infiltration and downward movement of accumulated contaminants towards groundwater. Further, horizontal sites may also create a source of contamination due to low movement of pollutants. This hazard ranked second by weight of 32.65. Whereas, results associated with steep site show that migration of contaminants in the direction of slope, which may pose a risk to adjacent sites, ranked first with a weight of 41.67. In addition, the potential of spreading of contaminants due to slope failure ranked second by weight of 34.34.

Table 10: Ranking the potential hazards associated with site topography

Site topography	Potential hazards	Weight	Normal	Rank	Kruskal–Wallis H		Kendall's coefficient of concordance		
					X^2	*P–value*	W	X^2	*P–value*
Steep site	PH 53	41.67	0.548	1	4.668	0.458	0.284	6.368	<0.001
	PH 52	34.34	0.451	2	4.668	0.458			
Flat site	PH 54	43.33	0.430	1	3.725	0.590	0.177	13.474	<0.001
	PH 55	32.65	0.570	2	3.725	0.590			

4.5 AGREEMENT ON THE RANKING OF THE POTENTIAL HAZARDS

Shapiro–Wilk test results indicate the data collected are not normally distributed because all the *p*–values produced by the test were < 0.05. From the Kruskal–Wallis H test results, it could be inferred that differences in opinions were not statistically significant as the *p*–values of all the potential hazards were > 0.05 (Table 3–10). In addition, Kendall's W test was performed to calculate the coefficient of concordance. The results show most coefficients have p values < 0.001, indicating that a significant degree of agreement exists among all of the participants in a certain group regarding the ranking of potential hazards associated with surrounding areas (Table 3–10). This result is further corroborated by the finding from the Kendall's *W* test that the respondents had a significant degree of agreement regarding the ranking of the potential hazards associated with brownfield sites.

5 Framework for preliminary risk assessment of brownfield site

The proposed framework (Figure 3, with its legend in Table 11) has been developed to assist professionals to assess brownfield sites at an early stage, enabling them to obtain a prompt, informed opinion on any potential liabilities or risks related to the suitability of a brownfield site for redevelopment and possession, and yet in a cost effective, less time consuming and less effort requiring manner. In this context, the framework outlines the suitable criteria to identify the three components of the pollutant linkage model (Source–Pathway–Receptor). They can then be used to determine the potential hazards related to each essential criteria. A 'triple-level' approach was developed to classify the hazards into three individual clusters/categories, which are level 1 pollutant linkages, level 2 site characteristics, and level 3 potential hazards (Figure 3). Level 1 group are associated with the Source, Pathway and Receptors. Level 1 hazards are further divided into respective groups in the form of site characteristics (level 2). Level 1 and level 2 classifications provide the basis for identifying the potential of the existence of a given hazard more effectively (level 3). For instance, a brownfield site is contaminated with hydrocarbons which can be considered as a source of the hazards (level 1). Based on the history of the site, it emerged that it was previously used as gas/petrol station for 50 years, before becoming a derelict land. This historical feature is deemed as a site characteristic (level 2). Based on levels 1 and 2, the potential of hazards in the brownfield site can be determined (level 3). Similarly, this 'triple-level' approach can be applied to identifying hazards in other brownfield sites. Following this, the preliminary risk assessment can inform the detail risk assessment in which optimal and appropriate risk remediation measures can be determined to manage risks (Algreen, Trapp and Rein, 2014; Algreen *et al.*, 2015; Osman *et al.*, 2015; Limasset *et al.*, 2018).

Table 11: Legend table of the framework

Abbreviation	**Definition**	**Abbreviation**	**Definition**
ANI	Animals	PH	Potential hazards
ASC	Asbestos cement	PLA	Plants
BUM	Building materials	POO	Poor permeable
BUS	Buildings and other structures	PRI	Impermeable
C/IN	Commercial/Industrial	PRM	Previous mining activities
COM	Commercial	PRR	Presence of radon
CON	Concrete	RC	Residential with consumption of homegrown produce

ELC	Underground services –Electricity cables	RCO	Reinforced concrete
FLA	Topography–Flat site	RES	Residential
FUS	Future end user	RWC	Residential with consumption of homegrown produce
GAP	Underground services –Gas pipes	SOT	Storages of materials and old tanks
GEO	Site Geology	STE	Topography–Steep site
GOO	Good permeability	SUA	Surrounding areas
HIS	History of the site	TEC	Underground services –Telecommunication cables
HUH	Human health	THC	Tickly
HYD	Site hydrology	THI	Soil Thickness
INS	Invasive species	TOP	Site topography
MAG	Made ground	UNS	Underground services
MAS	Masonry	VEN	Very thinly
MED	Medium thickness	VER	Very good permeable
MET	Metal	VET	Very thickly
ORM	Organic materials	WAP	Underground services –Water pipes
PER	Soil Permeable		

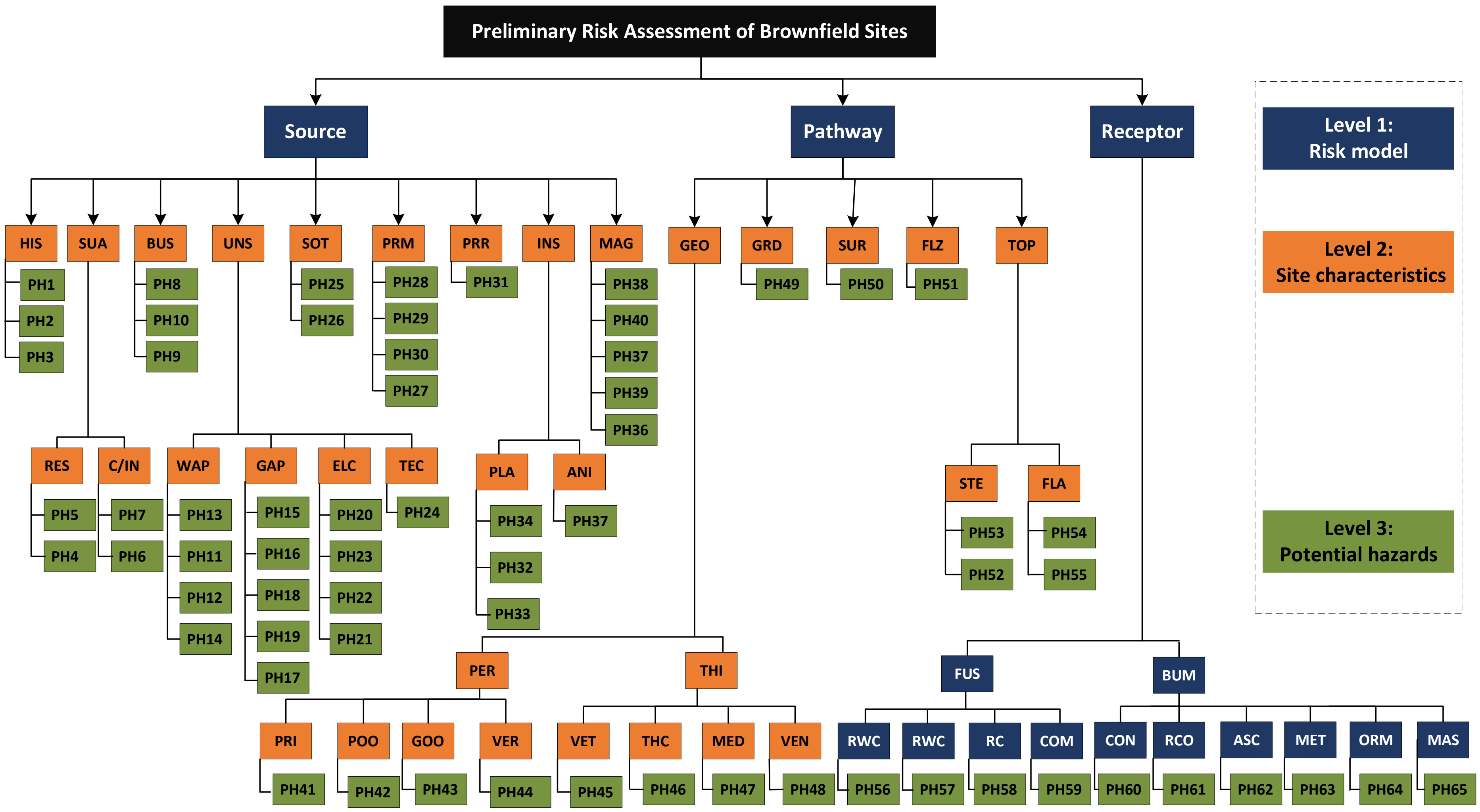

Figure 3: Framework for preliminary risk assessment of brownfield sites

The framework consists of fourteen steps that are adopted to conduct a preliminary risk assessment for brownfield sites. These steps are established to identify and assess the potential sources, pathways and receptors ('pollutant/ contaminant linkages'), before a final report is generated. They can be used to determine potential hazards related to each essential information. In this way, depending on the user's selection, different hazards are generated and, therefore, provides an informed basis for decision–making.

Source: steps 1-9 provide a good indication of potential sources and types of hazards likely to be found on site. It starts with determining the site history, surrounding area, building and old structures, underground services, storage materials and old tanks, previous mining activities, presence of radon, invasive species and made ground.

Pathway: steps 10-12 allow the user to determine the pathways within the preliminary risk assessment involves locating possible routes for migration of contaminants within site. On consultation of the technical literature, three major parameters were identified to affect the pathway of contaminants: site geology, site hydrogeology/ hydrology and the topography of the site.

Receptor: step 13 presents the receptors of hazards in brownfield sites. In reviewing the future land use, the assessor seeks to identify the types of people using the site, and in particular, the critical receptors, who are the most people likely to be exposed or susceptible to the presence of soil contamination. While step 14 identifies the impact of the site conditions son the building materials.

6 Conclusions and future research

This study has proposed a comprehensive and easy–to–use framework for preliminary risk assessment of brownfield sites. The components of the framework were identified through a critical review of the literature. These components are: (i) pollutant linkage model, (ii) site characteristics and (iii) potential hazards. The study revealed 65 known potential hazards associated with brownfield sites, which have been prioritised and classified by experts, before interrogation by VAHP. These priorities established amongst the potential hazards can help developers, planners and other stakeholders when assessing and developing brownfield sites. In such situations, the priorities can be used to identify and inform the direction of the next stages of any future risk assessment.

The contributions of this study are two–fold: Firstly, it enables preliminary risk assessment exercise to be not only more holistic and integrated, as well as reduces the uncertainty in the risk assessment process by ensuring all eventualities, along with their respective significance, have been identified at the initial stage of a risk assessment. This may represent a strong starting point to successfully conduct more detailed risk assessment and remediation. Secondly, potential hazards resulting from this study can enhance effective environmental communication between stakeholders, which should speed–up the planning process and assist in the development of brownfield sites more efficiently and effectively; while, preserving the natural environment.

Based on this study, it is proposed that future work could utilise the framework to integrate available databases with a web–based Decision Support System (DSS) to make them accessible through a single online platform. This may provide those who deal with abandoned field sites the opportunity to identify and prioritise potential hazards, and in doing so, highlight challenges facing those stakeholders dealing with the decision-making on redevelopments options. Moreover, it will enable them to promote sustainable redevelopment and minimise the risks to future occupants of brownfield sites and neighbouring lands.

7 Reference

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