Desalination and Water Treatment
www.deswater.com
doi: 10.5004/dwt.2022.29119

280 (2022) 240–250
December

Overview of chemicals of potential concerns in contaminated land in Malaysia

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Received 30 December 2021; Accepted 7 October 2022

ABSTRACT

In developed countries, contamination of soil due to industrial activities and illegal toxic waste disposal has been identified as major environmental problems. Established mechanisms for identifying, prioritizing, characterizing, assessing, and improving soil conditions have been implemented to reduce risks to human health and environmental receptors. However, the Contaminated Land Management System (CLMS) and the practices for the management of this contaminated land in Malaysia, including the enforcement of legislation are ineffective. The objective of this study is to discuss an overview of potential chemical substances, especially regarding its existence in contaminated soil in Malaysia. The report also examines the parameters of several heavy metals especially arsenic and mercury found in contaminated soil areas. In addition, this study is an explanatory effort to assess the level and characteristics of illegal disposal including current enforcement practices in Malaysia after three guidelines related to contaminated land management were developed by the Department of Environment (DOE) Malaysia in 2009.

Keywords: Contaminated land management system; Potential chemical substances; Environmental Quality Act 1974

1. Introduction

Initially, the Environmental Quality Act 1974 (EQA 1974) was specifically enforced through the implementation of the Environmental Quality (Scheduled Waste) Regulations in 1989. Nonetheless, it has been replaced by the enforcement of the Environmental Quality Regulations (Scheduled Waste) in 2005 and is still in effect today [1]. Fundamentally, this document has laid out a basis for planning the management of hazardous waste from the point of origin until it is appropriately disposed-off in compliance with established legislation. The statute also categorizes each of the contaminant characteristics according to its hazardous level (infectious, toxicity, reactivity, corrosiveness and flammability) and giving the Department of Environment (DOE)

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broad powers is given to regulate waste labelling, detention, transportation and storage records, including establishing a system to permit treatment, storage, disposal and recovery facilities. Other than that, according to the acts, for each incident of illegal hazardous and toxic materials waste disposal for which the perpetrator is unidentified, the trust fund allocations can be utilized to cover the expense of cleaning and disposal, as well as site preservation and conservation studies [2].

To date, it is discovered that many industrially polluted sites in Malaysia require remediation or restoration before they can be reused [3–7]. Previously, it was found that no legislation has addressed brownfield assessment methodology or target remedial values. It triggered the DOE to create a recommendation document for evaluating soil and groundwater pollution mainly for remediation purposes [8,9]. It includes several limitations on contaminants within those mediums. Moreover, land-use patterns, soil hydrological characteristics, and contamination depth are all taken into account in establishing the limit [10].

In general, it was determined that heavy metals accumulation in soils is due to the effect of industrial activities including wastewater irrigation [11], mine tailings [12], disposal of high metal by-product [13,14], fertilizer land application [15], animal manures [16], leaded gas and paints [17], sewage sludge [18], pesticides [19], coal combustion deposits [20], petrochemical spill and atmospheric deposition [21]. It was also reported that hazardous inorganic compounds such as lead (Pb), chromium (Cr), zinc (Zn), copper (Cu), cadmium (Cd), arsenic (As), mercury (Hg), and nickel (Ni) are often abundant in contaminated areas [22–26]. As a result of these human activities, soil acts as a significant absorber of heavy metals or contaminants of potential concern (COPCs) which are then released into the environment [27,28]. Unlike organic contaminants, which most likely to be degraded to carbon (IV) oxide by microbial action, most of metals cannot be degraded via microbial or chemical action [29–32]. Furthermore, their overall concentration in soils remains stable over time.

Previous review presented the overview of contaminants in soil which undetermined COPCs problems in Malaysia, such as the review was written by Maddela et al. [33], Pullagurala et al. [34], and Li et al. [35]. Therefore, in this study, the overview of system used by the government of Malaysia that related to COPCs problem in contaminated land was discussed. In order to provide a brief overview, this paper has reviewed the basic chemistry, potential sources of contamination, and associated environmental and health risks that related to heavy metals as well as several methodologies applied by the government in order to cope with the problem. This review can be useful for the future research that require a revision on the system used in Malaysia. Several data that were discussed in this paper were obtained by the DOE and available to the public through their official website (https://www.doe.gov.my).

2. Sources of pollution

2.1. Untreated wastewater

Almost hundreds of years ago, municipal and industrial wastewater, as well as associated effluents, have been utilized for land irrigation and widespread in many parts of the world [36]. Around the world, wastewater is used to irrigate 20 million ha of arable land [37]. According to studies, wastewater irrigation agriculture produces 50% of the vegetable supply in a number of Asian and African cities' metropolitan areas. Previous studies in Malaysia showed the utilization of industrial and municipal wastewater as a resource of irrigation water [38,39]. For industrial wastewater, the level of metal was tolerable up to the optimum concentrations of 5% and 25% for the elongation of roots and shoots in *L. purpureus* and *B. chinensis*. Farmers' primary goal is growing yields and profits, on the other hand disregard environmental concerns. While concentrations of metals in sewage effluents are normally low, irrigation of land over time can lead to significant level of metal deposition in the soil [40]. Thus, it needs to remove wastewater sludge from the river for reducing the significant level of metal deposition. Fig. 1 demonstrates how DOE removes wastewater sludge from the river on a regular basis.

To resolve the problem, the Malaysian government has established Water Quality Index (WQI) to regulate the quality of river waters [41]. The standards are classified into six categories, from preserving the natural environment to drinking water treatment and irrigation for agriculture [42]. Also, water quality standards are measured in nearly seventy parameters, including chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), ammonia nitrogen, and several number of bacteria coliforms, as well as a large number of pesticides and heavy metals [43,44]. Although no specific environmental standard exists for ponds and lakes, a proposed interim standard for coastal waters is currently being reviewed.

In Malaysia, wastewater standards have been specified in the 2009 environmental quality regulations especially for industrial effluents and sewage where the standards are applied to industrial wastewater and domestic wastewater [45]. The wastewater standards are prescribed in the form of a series of national standard uniforms and divided into two classes: Standard A and B. Standard A applies to intake points of upstream, while Standard B applies to downstream areas. Standard A is much more restrictive than

Fig. 1. Removing wastewater sludge from the river [15].

Standard B and each standard has included 23 parameters, such as BOD_5, COD, SS, pH, temperature, CFU/100 mL, and various types of heavy metals.

2.2. Milling processes, metal mining, and industrial wastes

Metal ore's excavation and grinding, as well as other industries, have contaminated the soil in a number of countries [46]. Tailing, a dense and large particulate, settle in the aeration basin during mining. Then, it is released into existing sinkholes, including onsite wetlands, resulting in heightened concentrations of pollutants. Other materials are discharged in a range of industries, including textiles, tanning, petrochemicals, insecticides, and pharmaceutical facilities, and their compositions are quite diverse [47,48]. Fig. 2 shows an industrial leftover that was abandoned leaving behind contaminated site and required a clean-up.

3. Heavy metals and their potential risks

Analyzing and forecasting pollution-related consequences entails identifying and determining a variety of potential risk sources, estimating a variety of risk factors that come into contact with human-environment boundaries, estimating levels of exposure via identifying routes of exposure to a target organism, and quantifying health risks associated with this exposure. In order of abundance accordingly, Pb, Cr, As, Zn, Cd, Cu, and Hg are the most often reported heavy metals found in the sites [49]. Additionally, two metals found to be highly toxic, for instance arsenic (As) and mercury (Hg), that required an extensive treatment. It was mentioned that the presence of contaminants in excess of the permissible limits set by regulatory authorities, such as the World Health Organization (WHO), DOEs not automatically imply a risk to human health. Consequently, the United States Environmental Protection Agency's (USEPA) target hazard quotient (THQ) technique can also be utilized to assess potential health concerns associated with long-term exposure to heavy metals [22].

3.1. Arsenic

Arsenic has been classified as a confirmed carcinogenic substance to humans by the International Agency for Research on Cancer (IARC). A measurable amount of arsenic in the human body is required to categorize human carcinogenic levels. Multiple human populations have an increase in lung cancer mortality primarily owing to inhalation, an increase in mortality from internal organ malignancies (liver, kidney, lung and bladder), and in the incidence of skin cancer, especially due to drinking water containing arsenic [50]. The global impacts of arsenic level are projected in Fig. 3 with the level of affections.

The International Agency for Research on Cancer has classified inorganic arsenic as carcinogenic to humans

Fig. 2. Illegal industry discharges the accumulation of COPCs [15].

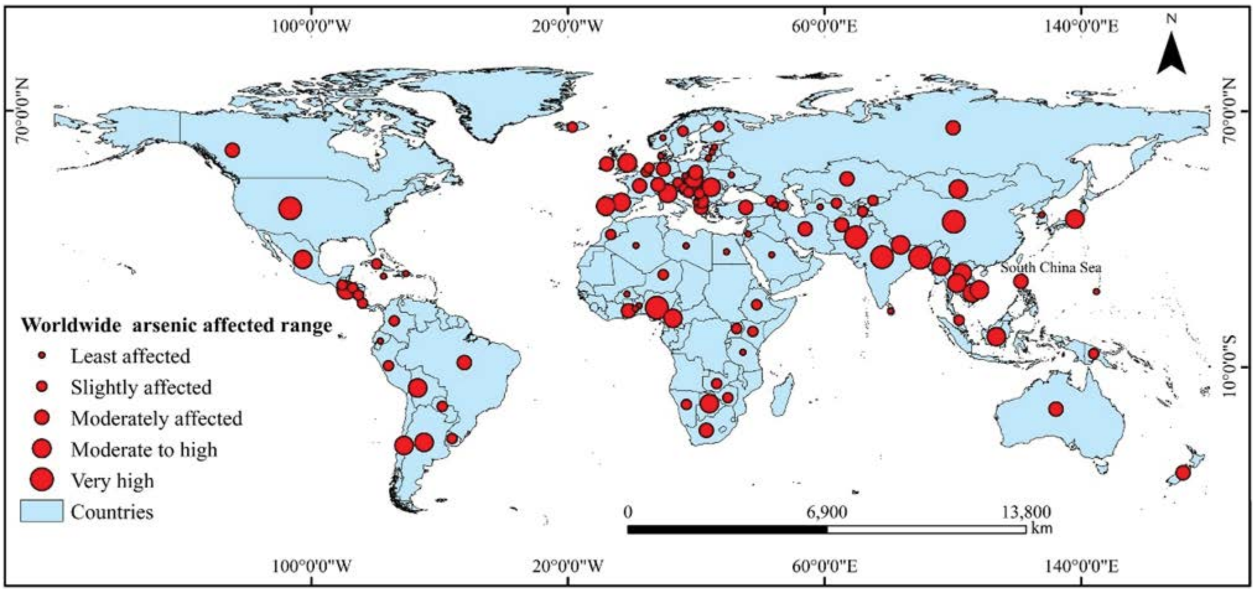

Fig. 3. Arsenic seems to have a global impact, as indicated by the scale of the plots [21].

Group 1 and carcinogenicity Category A [51]. Organic arsenic is classed as a "possibly carcinogenic to humans" chemical [52]. Arsenic is a metalloid belonging to the periodic table's group VA and period 4 that can be mined from ores that primarily containing copper, lead, zinc, silver, and gold. It occurs naturally in a range of minerals, most notably as As_2O_3, and is found in a variety of minerals as As_2O_3. Additionally, it also is found in coal ash remains.

3.2. Mercury

Mercury is a highly lethal and hazardous heavy metal. It may emerge from a variety of natural and man-made sources. Mercury appears in three forms in the environment: elemental, inorganic and organic (methylmercury) [53]. The toxicity of the substance is determined by its availability in the environment and its reaction with human exposure [54]. Mercury is transported in a complex cycle through land, water, and the atmosphere [55]. Numerous natural and anthropogenic activities are mercury sources, including the presence of mercury in cinnabar, natural weathering of rocks, episodic mercury release from volcanoes, small-scale gold mining, coal-fired power plants burning medical waste, numerous daily-use devices in household activities, and fungicide. Mercury exposure occurs when people consume shellfish, fish containing methylmercury, or inhale mercury released accidentally when a substance or gadget degrades [56]. Mercury can react with inorganic salts such as chlorine, sulfur, and other elements to generate inorganic salts [57].

The USEPA has established guidelines to enhance consistency in the implementation and communication of risk assessments [58]. These criteria cover to the assessment of developmental effects, germ cell mutagenicity, carcinogenicity, and the exposure and consequences of chemical combinations. The guidelines for evaluating reproductive effects are already in place, as well as the guidelines for evaluating effects on other organ systems are being developed. Despite the existence of recommendations for assessing a variety of end goals, until recently, the emphasis was on carcinogenicity, sometimes at the expense of other critical types of toxicity [59,60]. Mercury is a member of the same periodic table family as zinc and cadmium. It is the only liquid metal at STP.

Mercury has natural two forms: as a dimeric cation mercury (I) (Hg^{2+} mercuric ion) and as mercury (II) (Hg^{+} mercuric ion). Mercury (II) is the principal pollutant which poses a significant risk to humans due to its affinity for amino acids [61]. Mercury comes in various forms that can expose human health. Organic or high mercury has been discovered to induce a variety of neurological and cardiovascular problems and, in certain cases, reproductive and immune system dysfunction [62].

The nervous system is one of the most sensitive organs exposed to methylmercury and metallic mercury fumes, which lead direct cell damage. Entering the brain, methylmercury can provoke the neurological system to malfunction. Increased exposure to all types of mercury can permanently injury the brain and kidneys, along with affect a developing fetus in the womb [63].

3.3. Others

Heavy metals are found in soils in a variety of chemical forms which is directly related to their mobility and biological availability. Water contamination with heavy metals is practically unavoidable in certain areas due to natural causes (rock erosion) and anthropogenic activity (industries, agriculture and households) [64]. Wastewaters from mining, the electric sector, dye manufacturing, and chemical laboratories frequently contain the significant amounts of heavy metals such as cadmium (Cd), copper (Cu), and lead (Pb). Agricultural soils become contaminated with heavy metals as a result of wastewater irrigation that has severe impact on public health [65]. Certain heavy metals, such as Fe, Zn, Cu, and Se, are necessary for humans in certain amounts [7]. However, since they are non-biodegradable, they rapidly accumulate to dangerous levels in biological media and have negative repercussions in animals, plants, and humans in a certain excessive concentration [66]. The negative impacts of metal contents in human internal organs and organ systems are determined in term of the percentage of health risks as seen in Table 1.

4. Classification of chemical's carcinogenic

The USEPA in 1986 released guidelines with categories and requirements on the classification of chemicals with carcinogenic potential based on a weighted evidence scheme, as seen in Table 2 [67].

5. Contaminated land management standard in Malaysia

Under the contaminated land management framework, there are two types of land classifications specified. It is either by establishing contact with the responsible party or land with no known guilty party or government-owned land with contamination that is not cleanable under current conditions due to a lack of resources. Only landfill, former mining property, agricultural land, dumping sites, and orphan land are exempt from this rule [8]. The flow of standard process is illustrated in Fig. 4.

5.1. Site screening levels

The Malaysian Recommended site screening levels were developed using the USEPA site screening levels to assess subsurface contamination that identified to pose an unacceptable human health risk [8]. The degrees of site screening will aid in the assessment and management of hazardous sites in Malaysia. The site screening levels are the criterion for determining if a piece of land is polluted, determining the need for remediation, and developing remediation objectives, such as target clean-up concentrations of COPCs at contaminated sites [68]. Previous study assessed the ecological and health risks of several metals, such as Cd, Cu, Ni, Zn, Cd, and Ni, in the top soils of different land, in Peninsular Malaysia [69]. The study showed that the ranges of the metals in the soils (mg/kg, dry weight) of this study were 0.24–12.43 for Cd (mean: 1.94), 4.66–2,363 for Cu (mean: 228), 2,576–116,344 for Fe (mean: 32,618), 2.38–75.67 for Ni (mean:

Table 1
Hazard index for heavy metals that have a significant influence on the organs and human systems [12]

Critical organs/system	Group	HI_{max}	HI_{mean}	Contribution made by specific metals into risk, %					
				Zn	Cd	Cr	Cu	Ni	Pb
Central nervous system	Adults	1.7	0.24						100
	Children	2.4	0.34						100
Cardiovascular system	Adults	22.5	3.21					100	
	Children	31.5	4.50					100	
Digestive system	Adults	8.9	1.27		80.90				9.10
	Children	12.5	1.78		80.90				9.10
Kidneys	Adults	33.61	4.79			0.09	32.97	66.94	
	Children	47.14	6.74			0.08	33.16	66.76	
Blood	Adults	14.11	1.23	16.01	83.63	0.36			
	Children	22.81	1.71	15.91	83.73	0.36			
Development	Adults	40.29	3.46					92.93	7.07
	Children	64.70	4.84					92.97	7.03
Reproductive system	Adults	1.7	0.24						100
	Children	2.4	0.34						100

Note: The term of HI refers to the Hazard Index, established to assess potential health hazards to consumers as a result of exposure to multiple potentially harmful substances.

Table 2
List of categories for chemicals with carcinogenic potential [67]

Category	Group	Requirement
Human carcinogen	A	Epidemiology studies have found enough evidence to indicate a causal link between exposure to the chemical and human cancer
Probable human carcinogen	B	In animals, there is sufficient evidence carcinogenicity, but in humans, there is either minimal (Group B1) or inadequate (Group B2) evidence
Potentially carcinogenic to humans	C	In the absence of human data, there is scant evidence of carcinogenicity in animals
Not classified as carcinogenic to humans	D	There is insufficient evidence of carcinogenicity in humans and animals, or no data is available
Evidence of Non-carcinogenicity in humans	E	In at least two adequate animal tests in separate species, as well as in both epidemiology and animal investigations, there is no evidence of carcinogenicity

16.04), 7.22–969 for Pb (mean: 115) and 11.03–3,820 for Zn (mean: 512) and there was no serious impact on children's and adults' health from the six land uses from Peninsular Malaysia.

5.2. Risk-based site management

The process of risk assessment is used to quantify the extent and likelihood of negative health and environmental effects, as well as other problems, linked with exposure to potentially dangerous substances. Environmental professionals can use risk assessment frameworks and tools to make informed decisions about the type and severity of risks associated with chemical emissions, as well as the best ways to manage those risks. Over the last three decades, scientific concepts and procedures that form the basis of such tools have been developed and widely adopted in several countries. These scientific concepts and procedures released risk assessment recommendations and developed international drinking water quality criteria using a risk-based approach [27].

5.3. Conceptual Site Models

A Conceptual Site Model (CSM) is used to underpin environmental risk assessment and management by outlining realistic processes through which chemicals can migrate through the ecosystem and potentially harm receptors [70]. The CSM is most typically used to organize site investigation operations (such as COPCS selection or sample collection and analysis), and then, if unacceptable risks are discovered, it is used to lead the development of a suitable risk management strategy. For example, a comparison of mass reduction-based remediation vs containment, institutional or administrative controls to remove each whole Source–Pathway–Receptor relationship.

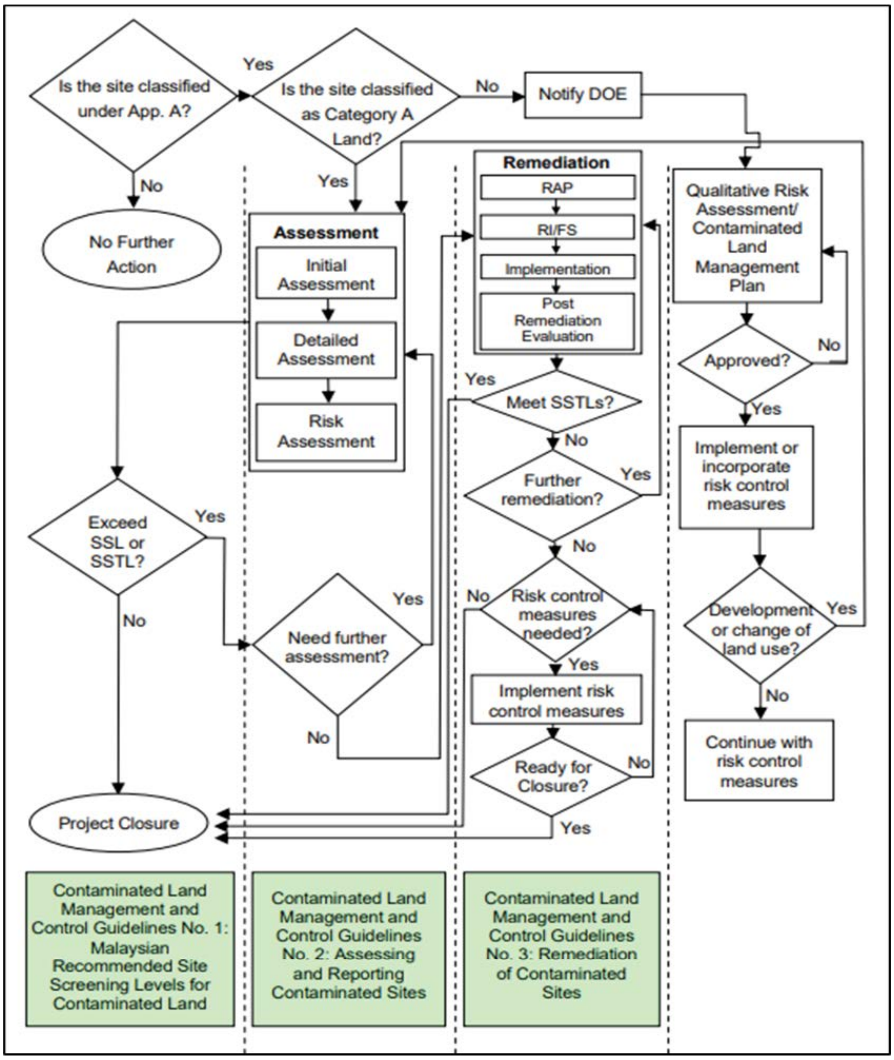

Fig. 4. Flowchart for the overall framework for contaminated land management.

A CSM is a written or graphic description of an environmental system and the biological, physical, and chemical processes that determine the movement of pollutants from sources to environmental receptors in the system [71]. A system diagram that shows pollutant sources, routes of exposure (pathways), and the receptors that are impacted by contaminants travel along those pathways. 'Source-pathway-target (receptor) conceptualization' is a simple way of putting it. In addition, it serves as a communication tool for members of the site assessment team, discipline experts, consultants and clients, clients and regulators and stakeholder groups. A decent test of a CSM is whether you would grasp essentially what is going on at the site if you were given the CSM [72].

5.4. Remediation of contaminated soils

Any soil remediation approach should become its main goal where the creation of a system that is safe for people and the environment, such as biochar application, microbiomes technique, and advanced oxidation process. Since there are no statutory requirements as well as where standards are advisory, remediation is frequently susceptible to various legislative criteria and may also be guided by assessments of human health and environmental concerns. Typically, regulatory bodies will authorize remediation schemes that focus on reducing metal bioavailability only if lower metal bioavailability is associated with decreased risk and the bioavailability reductions are proven to be long-term. The physical and chemical characteristics of the heavy metal contamination in soil heavily influence the technique of heavy metal remediation [47]. In general, remediation technologies applied for contaminated land in Malaysia is shown in Fig. 5 [73].

The applied technologies include soil vapour extraction, bio-remediation, remedial natural attenuation, containment, solidification and stabilization, contaminated soil excavation, and phytoremediation. It is noted that the predominant industry that conducted contaminated land remediation in Malaysia is the petroleum-based industry. Research on the development of effective methods for contaminated land remediation in Malaysia is still

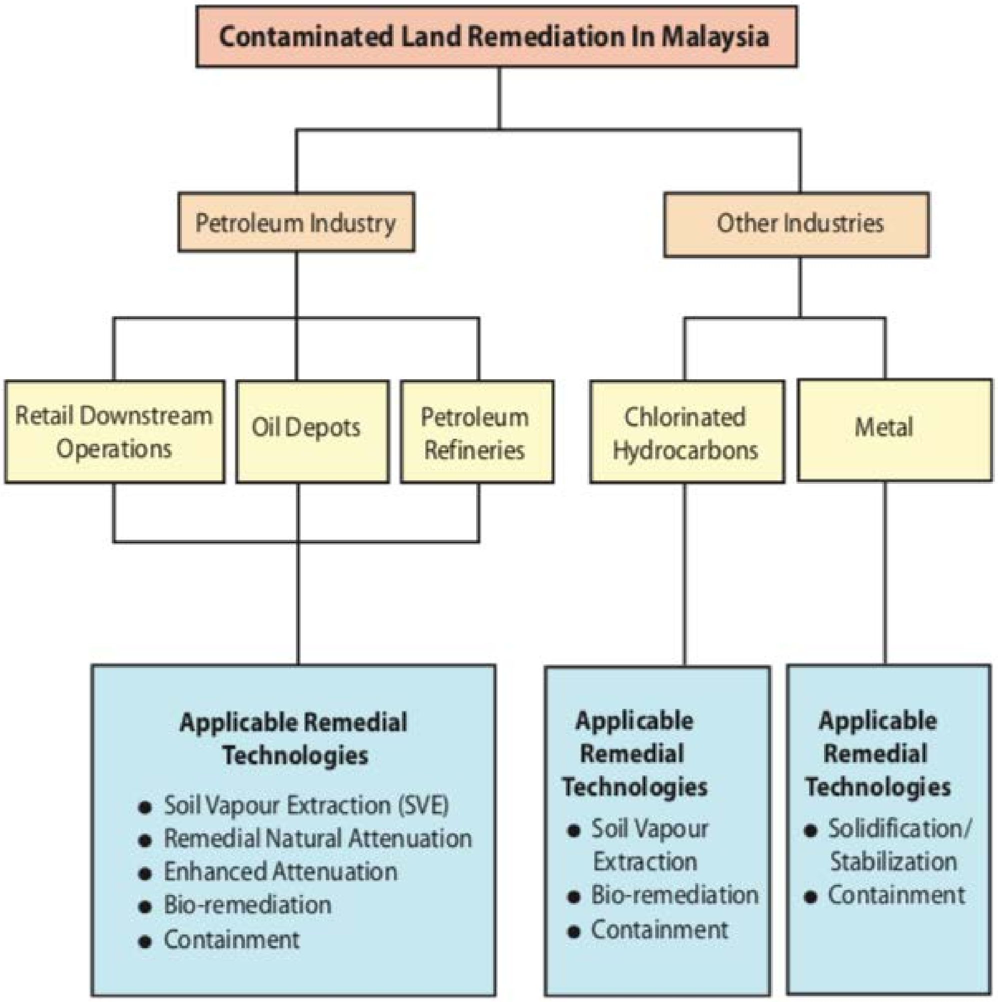

Fig. 5. Remediation technologies applied for contaminated land in Malaysia [73].

continuously conducted. For instance, the use of sugarcane bagasse (SCB) can be used for contaminated soil by Pb [74]. Alternatively, coconut flakes and plantation of *Centella asiatica* and *Chrysopogon zizanioides* can also be used not only for soil contamination but also for soil erosion control [75]. Electrokinetic-Bioremediation (Ek-Bio) by using by using 50 V/m of electrical gradient and *Lysinibacillus fusiformis* bacteria was found to be effective for reduction of approximately up to 78% of mercury concentration for the landfill soil [76].

5.5. Dose-response assessment

Site screening levels (SSLs) are the soil and groundwater criteria, or concentrations adopted under the contaminated land management framework that define if a land has a potential soil and groundwater contamination concern. Natural metal concentrations in soil and groundwater, on the other hand, can be caused by natural mineralization, weathering, or any other naturally occurring chemical processes of minerals that are accommodated in the soil matrix [8].

5.6. Selection of an appropriate set of COPCs

Indicator chemicals, also known as COPCs, are often chosen as the first step in a site-specific risk assessment to describe the site and focus assessment activities on the compounds that may pose the greatest potential harm to humans. In most cases, all detected chemicals are included in the original list used to choose COPCs. Only a few pollutants were quantitatively tested in surface waste material at WSS due to project financial constraints, and only these limited data could be used to determine risk. As a result, based on archival data on the chemical composition of waste on the site, indicator compounds were proposed for this risk assessment. Cadmium, copper, iron, manganese, lead, and zinc were among the heavy metals found. The choice of COPCs is a critical first stage in the site assessment and risk management process, as it ensures that the risk assessment detects any unacceptable risks and allows the assessor to successfully manage such risks. COPCs are the specific target analytes that need to be investigated in affected environmental media like soil, groundwater, surface water (if used for potable water supply), or soil gas

Table 3
Standard limit of SSLs analysis for each of related COPCs [8]

Analyte	CAS No.	Residential soil	Key	Industrial soil	Key	Residential air	Key	Industrial air	Key	Ground-water	Key
		mg/kg		mg/kg		ug/m³		ug/m³		ug/L	
Arsenic	7440-38-2	6.8×10^{-1}	C**R	3.0×10^{1}	c**R	6.5×10^{-4}	C**	6.6×10^{-3}	n	5.2×10^{-2}	c*
Cadmium	7440-43-9					1.0×10^{-3}	n	4.4×10^{-3}	n	9.2×10^{-1}	n
Chromium	18540-29-9	3.0×10^{-1}	c*	6.3×10^{1}	c**	1.2×10^{-5}	c	1.5×10^{-3}	c*	3.5×10^{-2}	c
Copper	7440-50-8	3.1×10^{2}	n	4.7×10^{3}	n					8.0×10^{1}	n
Lead acetate	301-04-2	1.9	c	8.2×10^{1}	c	3.5×10^{-2}	c	1.5	c	2.8×10^{-1}	c
Lead chromate	7758-97-6	3.0×10^{1}	c	6.2×10^{1}	c*	6.8×10^{-6}	c	8.2×10^{-4}	c	4.1×10^{-2}	c
Lead compound	7439-92-1	4.0×10^{2}		8.0×10^{2}	L	1.5×10^{-1}	L			1.5×10^{1}	L
Lead phosphate	7446-27-7	8.2×10^{1}	c	3.8×10^{3}	c*	2.3×10^{-1}	c	1.0×10^{1}	c	9.1	c
Lead subacetate	1335-32-6	6.4×10^{1}	c	2.7×10^{3}	c	2.3×10^{-1}	c	1.0×10^{1}	c	9.2	c
Mercury	439-97-6	9.4×10^{-1}	n	4.0	ns	3.1×10^{-2}	n	1.3×10^{-1}	n	6.3×10^{-2}	n
Mercury chloride	7487-94-7	2.3	n	3.5×10^{1}	n	3.1×10^{-2}	n	1.3×10^{-1}	n	5.7×10^{-1}	n
Methylmercury	22967-92-6	7.8×10^{-1}	n	1.2×10^{1}	n					2.0×10^{-1}	n
Nickel acetate	373-02-4	6.7×10^{1}	n	8.1×10^{2}	n	1.5×10^{-3}	n	6.1×10^{-3}	n	2.2×10^{1}	n
Nickel carbonate	333-67-3	6.7×10^{1}	n	8.1×10^{2}	n	1.5×10^{-3}	n	6.1×10^{-3}	n	2.2×10^{1}	n
Nickel carbonyl	13463-39-3	8.2×10^{1}	n	1.1×10^{3}	n	1.5×10^{-3}	n	6.1×10^{-3}	n	2.9×10^{-3}	n
Nickel hydroxide	12054-48-7	8.2×10^{1}	n	1.1×10^{3}	n	1.5×10^{-3}	n	6.1×10^{-3}	n	2.0×10^{1}	n
Nickel oxide	1313-99-1	8.4×10^{1}	n	1.2×10^{3}	n	2.1×10^{-3}	n	8.8×10^{-3}	n	2.0×10^{1}	n
Nickel refinery dust	N/A	8.2×10^{1}	n	1.1×10^{3}	n	1.5×10^{-3}	n	6.1×10^{-3}	n	2.2×10^{1}	n
Nickel salt	7440-02-0	1.5×10^{2}	n	2.2×10^{3}	n	9.4×10^{-3}	n	3.9×10^{-2}	n	3.9×10^{1}	n
Nickel subsulfide	12035-72-2	4.1×10^{-1}	c	1.9×10^{1}	c*	1.5×10^{-3}	n	6.1×10^{-3}	n	4.5×10^{-2}	c
Zinc	7440-66-6	2.3×10^{3}	n	3.5×10^{4}	n					6.0×10^{2}	n
Zinc phosphide	1314-84-7	2.3	n	3.5×10^{1}	ns					6.0×10^{-1}	N

(via vapor intrusion or exposure in confined spaces) to adequately manage risks to human health and the environment. Table 3 shows generics SSLs summary for related COPCs obtained from DOE analysis. COPCs selection should also consider the possibility of corrective treatment to adequately limit any actual risks and inform remedial system design. COPCs should then be assessed as part of a risk assessment to identify any unacceptable hazards to human health or the environment, as well as to support an effective risk management approach [77].

6. Conclusions

The most important clinically relevant finding was the system used by the government of Malaysia that related to COPCs problem in contaminated land. Effective law enforcement tactics must be implemented promptly to combat the illegal disposal of toxic waste. Secondly, a framework for the management of contaminated land must be devised and maintained. This is because toxic waste disposal activities have become increasingly prevalent in recent years. Some take place in industrial settings, while others take place in more rural places. With the year-over-year increase in occurrences, responsible enforcement authorities must redouble their efforts and enhance their overall oversight and innovation capacity. Understanding the nature, composition, and possible hazards of toxic heavy metals in contaminated soils is critical for successful treatment methods selection. Restoration of heavy metal-contaminated soil is important to mitigate associated dangers, make land resources available for agricultural growth, boost food security, and address communal land concerns. While immobilization, soil washing, and phytoremediation are widely promoted as some of the most effective readily available treatments for removing heavy metals from soils, their effectiveness has been proved exclusively in industrialized countries. These technologies are recommended for field use and commercialization in underdeveloped countries where agriculture, urbanization, and industry have wreaked havoc on the environment.

Funding

This research received no external funding.

Acknowledgements

The authors are grateful for all resources provided by Department of Environment, Malaysia.

Conflicts of interest

The authors declare no conflict of interest.

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