REVIEW ARTICLE

Remediation Technology Inventions for Soil and Groundwater Contamination

MUHAMMAD HILMI M, SHARIFAH SAFFINAS SS, UMMI MIRZA B, ZALEHA MI

Department of Community Health, Faculty of Medicine, Universiti Kebangsaan Malaysia Medical Centre, Jalan Yaacob Latif, Bandar Tun Razak, 56000 Cheras, Kuala Lumpur, Malaysia

ABSTRAK

Kemerosotan kualiti air bawah tanah berpunca dari pelepasan akibat kemalangan dan basuhan tanah yang mengakibatkan impak kesihatan yang meluas. Air bawah tanah memainkan peranan yang penting dalam membekalkan sumber air minum yang utama kepada populasi manusia. Pencemaran air bawah tanah yang teruk mendesak kepada tindakan pemulihan oleh banyak pihak untuk mengawal kemusnahan. Tinjauan naratif ini akan cuba untuk membentangkan status semasa teknologi pemulihan bagi pencemaran tanah dan air bawah tanah yang dilakukan untuk mencegah kerosakan yang lebih teruk ke atas biodiversiti ekosistem persekitaran. Beberapa komponen berkaitan dengan setiap teknologi in-situ dan ex-situ dibincangkan dengan terperinci untuk disesuaikan dengan ciri-ciri tapak pencemaran. Penemuan teknologi pemulihan in-situ yang boleh dipercayai untuk membuang bahan cemar adalah satu lagi pencapaian bagi kelestarian persekitaran hijau. Oleh itu, pengetahuan yang mencukupi tentang ciri-ciri tapak pencemaran, pemahaman tentang keadaan aliran air bawah tanah, penilaian tapak dan aktiviti pengangkutan bahan cemar adalah penting untuk perancangan teknologi pemulihan masa hadapan.

Kata kunci: air bawah tanah, pencemaran, pemulihan alam sekitar, tanah, tapak pembuangan sisa berbahaya

ABSTRACT

The reducing quality of groundwater resulted from accidental wastes compounded with soil leaching has become the topmost health concerns. Groundwater plays an important role in provisioning central source of drinking water to human

Address for correspondence and reprint requests: Zaleha Md Isa. Department of Community Health, Faculty of Medicine, Universiti Kebangsaan Malaysia Medical Centre, Jalan Yaacob Latif, Bandar Tun Razak, 56000 Cheras, Kuala Lumpur, Malaysia. Tel: +6019-3209456 Email: zms@ppukm.ukm.edu.my

population. The extensive contamination of ground water urges for remedial actions by many to control the damage. This narrative review will attempt to present the current state of remediation technologies for soil and groundwater contamination implemented to prevent further damage to the biodiversity of surrounding ecosystem. Components of each in-situ and ex-situ technologies were examined in detail to suit the characteristics of contamination site. The discoveries of reliable in-situ remediation technology of removing contaminants are another milestone for green environment sustainability. Therefore, adequate knowledge on characteristics of contamination site, understanding of groundwater flow conditions, site assessments and contaminant transport activities are crucial for future planning remediation technologies.

Keywords: contamination, environmental remediation, groundwater, hazardous waste sites, soil

INTRODUCTION

Groundwater refers to water that can be found naturally at the underground layer and within rocks (USEPA 2021). Various layers of rock formed on top of another with small spaces in between them allow water and other forms of fluid to pass through easily. These rock layers holding the groundwater are commonly known as aquifers (U.S. Geological Survey 2021). Precipitation absorbed through the porous substance layer continuously refills the groundwater level of the aquifer pooling into the water table. Studies in the urbanised area revealed high water quality index (WQI) reading, consistently more than 100 over the years whereas groundwater has been used as the primary source for drinking (Badeenezhad et al. 2020; Ren et al. 2021).

Generally, groundwater serves as the central provider of natural drinking water to the human population (Schmoll et al. 2006). This has resulted in the extensive use of groundwater through tube wells since several decades ago (Adeloju et al. 2021). In rural and peri-urban settings, the population relies heavily on groundwater for safe drinking water because of contaminated resources of water on the land (Masindi & Foteinis 2021). Nonetheless, rapidly developing industrialisation, the growing anthropogenic activities for new residential land area, subsurface structures, and traffic systems, leaking of gasoline from the underground petroleum storage, leachate collection containing hazardous waste from landfills, and harmful organophosphate usage in agriculture have imposed severe contamination against the soil and groundwater system (Sweileh et al. 2016; Selvakumar et al. 2017). Collectively, these detrimental harmful events lead to long-term effects that are hardly reversible and are very difficult and costly to recover (Sweileh et al. 2016). Therefore, soil and groundwater pollution implies a major environmental threat that requires urgent attention (Al Manmi et al. 2019).

Groundwater contamination contributed to the disease burden mainly through the transmission of communicable diseases and chemical hazards containing heavy metals (Oleiwi 2020). Based on the Protocol on Water and Health, a legally binding instrument by the United Nations Economic Commission for Europe (UNECE) and WHO-Europe that aims to protect human health through efficient water management, water-related diseases are defined by any significant adverse effects on human health, such as death, disability, illness or disorder, caused directly or indirectly by the condition, or changes in the quantity or quality of any waters (World Health Organization & United Nations Economic Commission for Europe 2009). A previous study reported contaminated drinking water alone had caused diarrheal disease that resulted in 2 million deaths annually and 4.1% of the total Disability Adjusted Life Year (DALY) in the last few years (Troeger et al. 2018). In line with Sustainable Development Goal 6 which is to ensure availability and sustainable management of water and sanitation for all, strategies for remediation measures to overcome such contamination are warranted.

There have been more than 140,000 new chemicals and pesticides developed since a few decades ago; a huge proportion of them can be found in the environment alone (Landrigan et al. 2018). The contaminants and their metabolites are potentially persistent in the environment causing great detrimental effects over space and time (Landrigan et al. 2018). Besides that, soil and groundwater can also be contaminated by poor land waste management systems constituting hazardous chemical waste landfills, harmful discharges from wastewater treatment plants, penetrable leaking sewers, heavy metals, radionuclide, petroleum storage, or from extensive use of agricultural pesticides (Abiriga et al. 2021; Han et al. 2016; Sizirici & Tansel 2015).

Groundwater quality deteriorates due to the impact of disposed wastes, resulting in penetration of heavy metals to the groundwater, which further contaminates the main river basin, thus becoming one of public health concern (USEPA 2009). Similarly, the contaminants absorption takes place through diffusion and adsorption in between the rock layers before resting in the groundwater (Chen et al. 2019). The interaction of groundwater contamination is commonly analysed using hydrology transport models (Selvakumar et al. 2017). Natural attenuation is one form of preventative remediation method. However, the efficacy is limited due to the long processing time, and is suitable in rural and remote areas with minimal contamination risk on ecology and public health (Andrea 2017). Considering the tremendous effects from the soil and groundwater contamination, various techniques were developed to contain the contamination site. Therefore, this review aims to give an overview of most commonly used in-situ and ex-situ remediation technologies for soil and groundwater contamination to prevent further damage to the biodiversity of the surrounding ecosystem.

HEALTH IMPACTS OF SOIL AND GROUNDWATER CONTAMINATION

Groundwater contaminants can be classified into chemical, biological and radioactive. The negative impacts on human health generally occur over a long period of time as they tend to accumulate in the human body, thus making it difficult to detect at times. For example, arsenic, a natural component of the earth's crust and a class 1 carcinogen, could be presented in groundwater as a colourless and odourless chemical, in which it is impossible to be detected without laboratory testing. Thus, arsenic is a contaminant to drinking resources. They can be presented naturally at high levels in the groundwater in some countries such as Argentina, Chile, China, India (West Bengal), Mexico, the United States of America, where approximately half of the total population is at risk of drinking arsenic-contaminated water from tube wells. In Bangladesh, about 9,100 deaths and 125,000 disability-adjusted life years (DALYs) were reported in 2001 from consumption of arsenic contaminated drinking-water (Lokuge et al. 2004). The severity of groundwater arsenic contamination is manifested in the dermatological, neurological and obstetric outcomes (Zhang et al. 2019). Consumption of arsenic contaminated water may lead to acute poisoning where urgent treatment is necessary.

Besides that, high level of nitrate exposure from contaminated drinking water, as revealed by the International Agency for Research on Cancer (IARC) classification group 2A, has caused substantial health effects when ingested such as colorectal cancer, bladder cancer and breast cancer (Ward et al. 2018). Biological contaminants include bacteria, viruses and parasites that could transmit water-borne diseases such as cholera, dysentery and typhoid fever. The wastewater containing coliform bacteria may infiltrate into the groundwater layer to contaminate the source of drinking water (Mthombeni et al. 2010).

Radionuclide contamination in groundwater sources has been commonly linked with naturally occurring radioactive materials (NORM) series; thorium, uranium and actinium (Khedr 2013). Uranium238 is nephrotoxic that the poisoning effect occurred at 20 parts per billion (ppb) and progressively developed into kidney failure at 10-fold greater concentrations. Moreover, Radium226 and Radium228 tend to accumulate in the bone which could lead to the development of bone abnormalities and bone cancer (Khedr 2013). All these forms of radionuclide formation could be present in contaminated water, exposed for domestic usage.

SOURCES OF GROUNDWATER CONTAMINANTS

Groundwater contamination may occur naturally or as secondary to manmade activities (Oleiwi 2020). The most common type of soil and groundwater contamination among the developed and developing countries can be categorised into three distinct source-based contaminants as follows.

Municipal Solid Waste Landfills

Non-hazardous solid waste disposed from municipal and commercial areas will be collected in the municipal solid waste landfill (USEPA 2017). Often, most of the older landfills do not subscribe to the sanitary landfill technologies allowing for potential groundwater source contamination (Kjeldsen & Christophersen 2001). The location of landfills situated close to the aquifers and water table enable contaminants to leach through the permeable soils (Adimalla et al. 2019). Similarly, the chemicals containing leachates in the form of precipitation and surface runoff could possibly penetrate deep down to reach the groundwater (Abiriga et al. 2021). Apart from that, certain closed landfills could also contribute to groundwater contamination threat given that they are not layered with an impermeable material before close for leaching prevention purposes (Abiriga et al. 2021).

With regards to the precaution for the contamination, continuous surveillance of the nearest groundwater quality is mandatory during the active life period of municipal solid waste and extended to the post closure care periods (USEPA 2017). According to the USEPA, the exception applies only to small landfills receiving less than 20 tons of solid waste per day and efficient landfills which are equipped with technologies able to prevent migration of hazardous constituents into the groundwater. The groundwater monitoring system shall include sample collection from the uppermost aquifer nearest to the landfills (Adimalla et al. 2019). On top of that, the surrounding environmental function area and land use need to be investigated and managed to screen for possible contamination.

Hazardous Waste Landfill

The Malaysian Environmental Quality Act (EQA) 1974 defined Environmentally Hazardous Substance (EHS) as "any natural or artificial substances including any raw material, whether in a solid, semi-solid, or liquid form, or in the form of gas or vapor, or in a mixture of at least two of these substances, or any living organism intended for any environmental protection, conservation, and control activity, which can cause pollution". Disposal of hazardous waste requires high skilled technology to prevent harmful environmental impact that includes objectionable odours, radioactivity, noise, temperature change or physical, chemical or biological change to any segment or element of the environment (Malaysia Environment Quality Act 1974). The ignorance of the public may pose salient challenges to the efforts of preventing groundwater contamination in long term. Companies using chemical substances in industrial processes should arrange for scheduled hazardous waste management system, and not to dispose in drains or rivers as they could contaminate the drinking water source. Previous study in China reported hazardous waste landfills were dominated by industrial sector dealing with heavy metal wastes in the form of fly ash, slag and sludge (Xi et al. 2021). Provided that heavy metals have stable chemical characteristics, they are also non-biodegradable, hence exposing to persistent toxicity hazard (Schmoll et al. 2006). Moreover, the formation of harmful leachate following acid rain that could potentially extend to the surrounding environment pose threat to human health in the long-term (Kjeldsen & Christophersen 2001; Tirkey et al. 2017). While in many industrial areas producing wastes of solidified fly ash and sludge containing heavy metals, these hazardous wastes must be pretreated to reach the acceptance criteria before final safe landfill (Mondal et al. 2009).

The landfill security techniques for hazardous waste disposal can be divided into the pretreatment stage and final disposal (Xi et al. 2021). In the earlier stage, hazardous wastes are first treated by means of physical, chemical or biological methods to achieve minimum toxicity and to reduce the volume for occupying limited space of landfill (Chosh 2020). Following that, the hazardous waste will be deposited in the safe landfills for the final process (Hoang & Nguyen 2020). It is during this operation that the hazardous waste may react chemically with acid rain or other substances to produce leachate that discharges contaminants beyond the landfill area (Chosh 2020). If not managed well, such leachate will contaminate groundwater sources.

Oil-contaminated Site

In oil contaminated site, the main organic compound detected in the groundwater ranges from the crude type of oil, the solvent oil, the residual type, gasoline and diesel (Al Manmi et al. 2019). These various types of oil sewage can contaminate the source of drinking water through the similar process of infiltration and penetration (Xi et al. 2021). The vadose zone extend from the surface soil, unsaturated subsurface materials and inundated capillary fringe to the regional groundwater table (Adimalla et al. 2019). In places with thinner vadose zone, the water permeability is higher, hence weaker pollution-proof capacity leading to pollution in the unconfined aquifer (Adimalla et al. 2019). This is the most common mechanism by which oil contamination takes place affecting the impurity of groundwater source (Xi et al. 2021).

Oil contaminants can penetrate the soil and groundwater during oil recovery and drilling process, where water returning movement are in close contact and accelerated with the presence of water pressure difference (Nambi et al. 2017; Xi et al. 2021). On the other hand, the deep seated aquifer may be compromised during drilling process, thus, directly contaminating the groundwater table (Al Manmi et al. 2019). The leakage in the oil collection areas is difficult to avoid without proper seepage control measures (Chosh 2020). Pollutants in the oil contaminated site consist of volatile organic compounds and polycyclic aromatic hydrocarbons, both of which harmful to human health (Xi et al. 2021). The soil pollution is prominently detected near oil tanks, oil reservoirs and oil drains (Al Manmi et al. 2019).

SOIL AND GROUNDWATER REMEDIATION

Groundwater remediation process refers to the stages of treatment aimed to effectively remove contaminants while turning the hazardous substances into less harmful form (Regenesis 2017). The remediation measures using immobilisation technique or isolation is taken to ensure safe groundwater source for drinking and containing the contaminants from intruding the surrounding area that are potential source of food owing to the bioaccumulation effect (Caliman et al. 2011; Regenesis 2017).

Strategic remedial planning is crucial from the initiation phase of setting up any industrial site until the final phase of cleaning the area from harmful substances (Reddy 2008). Groundwater remediation can be achieved by utilising many different methods. Selection of appropriate remediation method is thoroughly determined based on the environmental assessment, resources available, policy involved and cost effectiveness analysis (Caliman et al. 2011).

Types of Soil and Groundwater Remediation

Contamination of soils and groundwater has tremendous impacts on the environment that brings the utmost concern in public health. The non-degradable characteristics of heavy metal contaminants explain the persistence in the environment which further contaminates the food chain. Long term contaminated food or water consumption poses serious adverse effects to the general wellbeing of human health, particularly the younger age group and during reproductive years (Zhang 2019).

It is quite impossible to clean up the polluted site completely. However, prompt action is required to reduce the contamination risk to a level that is tolerable for both short- and long-term environmental exposures. The reduction plan should return to a containment approach, taking into account land use policy controls and active soil and groundwater remediation efforts. The remediation procedure can be performed alone or in conjunction with additional actions. Similarly, when deciding on the optimal remediation strategy, the approach to dealing with soil and groundwater contamination should be holistic, weighing the benefits and drawbacks of a number of significant aspects such as time, location, cost, sustainability, and the severity of the condition (Department of Environment Malaysia 2009).

Generally, there are two types of groundwater remediation, namely in-situ (in place or on-site) and ex-situ (off-site) (Caliman et al. 2011; Reddy 2008; Regenesis 2017). Instead of removing and transferring it to another location for treatment, in-situ remediation entails treating areas where it is currently located. This kind of remediation is far less expensive than ex-situ remediation, which often entails excavating and transporting the polluted site to another location while avoiding off-site contamination (Regenesis 2017). Although the procedure can avoid future damage on site, the total cost of transportation and eradication is extremely high. When the capacity of in-situ remediation is exhausted, ex-situ remediation is applied. Biological, chemical, and physical therapy strategies have all been discovered as options for remediation. Physical separation, source pump and treat, recycling, thermal treatment, solidification and stabilisation, off-site incineration, aeration, and chemical and bioremediation procedures are examples of ex-situ techniques (Reddy 2008; Regenesis 2017; USEPA 2020). Out of all, physical separation is the most common technique used in ex-situ treatment (USEPA 2020). Sifting, sieving, and sorting solid media to separate components; dewatering; and decontamination are all examples of physical separation. According to several sources, the optimum remediation strategy for leachate or liquid waste media is extraction and ex-situ treatment, which often includes carbon adsorption, neutralisation, aeration, evaporation, or bioremediation during the process (USEPA 2020).

In-situ remediation is a type of remediation that involves removing contaminants on-site. When the remediation process involves a larger/deeper contamination site with a lower cost than excavation, the in-situ approach is recommended. This chosen remediation strategy is well-suited to a variety of materials i.e. (Kuppusamy et al. 2016): (i) Soil/sludge/sediment treatment: Chemical extraction, flushing, thermal desorption, vitrification, bioaugmentation, bio-stimulation, phytoremediation, and electrokinetic separation are examples of technology-based approaches; (ii) Groundwater/fresh water/leachate treatment: Dual-phase extraction, air sparging, bio slurping, natural attenuation, and air stripping are all common techniques; (iii) Other remediation containment: Physical barriers and reactive treatment walls; (iv) Hazardous gas emission treatment: Chemical oxidation, membrane bioreactors and bio filtration.

The risk management application, the physicochemical characteristics of contaminants, the available remedial approach, the location of the process to take place, the strategic system to be applied with, implementation, and outcome are some of the factors to consider when selecting the most suitable remedial approaches for remediation technique (Kuppusamy et al. 2016; Reddy 2010). The vast majority of today's soil and groundwater remediation approaches are driven by the development of an integrated approach plan that is implemented on site for cost savings and convenience.

In-situ Remediation Technology

In-situ remediation is classified into two, existing technology, and emerging technology. Existing technology consists of heating, fracturing, soil flushing, electrokinetic separation, physical barriers, multi-phase extraction, air-sparging, soil vapor extraction, natural attenuation, bioaugmentation, bioventing, bio-stimulation and phytoremediation. Microbial fuel cells, nano-remediation, genetic engineering, and phyto-hetero microbial systems are examples of new approaches including pump and treat technique, nano treatment technique, in-situ soil vapor extraction (SVE), in-situ chemical treatment technique, in-situ thermal treatment technique (ISTT), permeable reactive barriers and bioremediation treatment technique (Kisku et al. 2015). In the United States of America, the most prevalent in-situ approach has been SVE, ISTT, bioremediation, and chemical treatment including in-situ chemical oxidation (ISCO) and in-situ chemical reduction (ISCR) (USEPA 2020). Frequently, more than one techniques have been utilised according to the site and type of contaminants (USEPA 2020). Summary of the remediation techniques is available in Table 1.

(i) Heating

The heating procedure includes methods for raising the temperature, lowering viscosity and adsorption, and increasing solubility to facilitate the recovery of volatile organic compound (VOC) (Jarvie et al. 2019) and semi-volatile compound (SVC). Heating is suitable to remediate those non-aqueous phase liquid (NAPLs) and dense-non-aqueous phase liquid (DNAPLs) (Heron et al. 2008). The contaminants can be easily remediated by soil vapor extraction, air sparging, and bioremediation by changing their density, viscosity, surface tension, and solubility. Electrical heating (hot air/steam injection, thermal conductive heating, thermal decontamination) is commonly used. Pneumatic and hydraulic control should be achieved for effective remedial treatment, since it is critical throughout the heating stage, and a clear path for the generated vapors to an extraction system must be given (Heron et al. 2000). Furthermore, heating is a procedure that improves other remediation technology, reducing the time and cost of the entire remediation process when used together.

For the remediation of oil from petroleum reserves, hot air/steam injection is the best option. The contaminated ground surface will be injected with hot air/steam. The contaminated soil will then evaporate and be trapped in a containment tank as a result of the hot air/steam. Physical displacement, co-distillation, vacuum extraction, or improved desorption will be used to recover the contaminant in the next phase (Chen et al. 2001).

Electrical resistance heating is a technique for creating electrical resistance by placing an electrode in low-permeability zones. This method heats the soils and converts semi-VOC and VOC to steam. The steam would be condensed and extracted VOCs are then to be treated conventionally into granular activated carbon (GAC) or being oxidised. This type of technology improves the speed and efficiency

Table 1: Summary of the remediation techniques available

No	Method	Indication	Advantages	Disadvantages
1	Heating	1. Non-aqueous phase liquid (NAPLs) 2. Dense-non-aqueous phase liquid (DNAPLs) 3. Volatile organic compound (Jarvie et al.) 4. Semi-volatile compound (SVC)	1. Improves other remediation technology 2. Reducing the time and cost of the entire remediation process when used together	Require extraction system to catch generated vapours
2	Soil flushing	Organic waste	1. Simple and easy method 2. The recovered fluids are re-usable 3. The method does not involve excavation or predisposal concerns 4. Able to remove organic waste on a large scale	Longer duration of time needed for remediation
3	Physical barriers	Chemicals: 1. Halogenated organics 2. Hydrocarbons 3. Chlorinated solvents 4. Radionuclides 5. Metals	1. Reduce the volume of harmful contaminant residues 2. Permanently restricting contaminant migration into non-contaminated areas	1. Barrier wall materials must be made from appropriate reactive materials 2. The wall must be large to catch all the pollutants 3. Longer duration needed for clean-up process to be completed
4	Soil vapor extraction (SVE) and air sparging	1. Areas with a low water table (>1 meter below ground level) 2. Volatile chemicals	1. Able to treat large volume of soil with little soil disturbances 2. Fair cost 3. Shorter time of remediation	1. Requirement for air emission licenses 2. The need for costly treatment of extracted vapor released into the atmosphere 3. Treatment of only unsaturated soil zones 4. Require integration with other technologies that can lower contamination concentrations to more than 90%
5	Fracturing (Pneumatic/ Blast-Enhanced / Hydro)	Designed to increase the efficiency of removal and in-situ treatment techniques	1. Increasing the efficiency of current in-situ technologies 2. Increase cost-effectiveness 3. Help to reduce the number of extraction wells, manpower, and material expenses	1. Time consuming process 2. May change the soil pH
6	Electrokinetic remediation	1. Slurries and heavy metals 2. Radionuclides 3. Mixed inorganic species 4. Some organic molecules	1. Less expensive 2. Target a specific area 3. Applicable for a wide range of contaminants	1. Time consuming process 2. May change the soil pH

No	Method	Indication	Advantages	Disadvantages
7	Natural attenuation	A preventative remediation method	1. Authenticating and monitoring the natural cleaning process 2. Non-halogenated volatile organic compounds (VOCs), semi volatile organic compounds (SVOCs), herbicides, fuels, and pesticides can be removed from aquifers and soils 3. The efficacy of natural processes is evaluated first before choosing the site for restoration	1. The procedure takes a longer time 2. A remote location away from potential receptors need to be identified to reduce the risk to ecological and public health
8	Phytoremediation	1. Petroleum hydrocarbons 2. Organophosphate insecticides 3. Heavy metals 4. Radionuclides 5. Non-aromatic chlorinated solvents 6. Surplus mineral 7. Explosives 8. Nitrotoluene ammunition wastes	Takes advantage of the natural processes of plants	1. Disposal of plants used can be a problem 2. Limited to shallow soils, streams, and groundwater
9	Nano-remediation	1. Trichloroethylene 2. Trichloroethane	1. Eco-friendly technology 2. Clean-up large contaminated sites 3. Reducing clean up time	Problem of unknown toxicity and safety
10	Pump and treat technique	1. Chlorinated VOCs 2. Non-chlorinated VOCs (TCE, chlorobenzenes, xylene)	Effective for free phase contamination	1. Expensive 2. Longer period of time needed 3. High cost of maintenance

with which contaminants are removed (USEPA 2012).

(ii) Soil Flushing

This method is used to remove organic waste on a large scale. Aqueous solution was flooded or sprayed over the contaminated surface in this method. The contaminating fluids will then be collected in trenches or wells and flushed to the surface for removal, treatment, recirculation, or reinjection on-site. The extracted fluids shall be disposed in accordance with the water quality standard for the environment. Despite its simplicity and ease of use, this technology takes longer to achieve the clean-up criteria. The recovered fluids are re-usable, and the method does not involve excavation or predisposal concerns, which are two major benefits of this remediation technique (Trellu et al. 2016).

The flushing solution can be divided into three; water only, water and additives (acids, bases or surfactant), and organic solvent. It is necessary to choose a solution that is easily soluble in water. Metals and organics are removed using an acidic solution, for example, zinc contamination from the plating process. A basic solution is a solution made up of water and a base (sodium hydroxide) that is widely used to treat phenols and metals. A surfactant is a type of detergent or emulsifier that binds to unmixed substances like oil and water. Paint strippers and nail polish removers are examples of organic solvents that dissolve substances that cannot be removed by water (USEPA 1992). The efficacy of soil flushing treatment varies based on the soil's hydraulic conductivity, the flushing solution's contact with the contaminants, and the flushing solution's suitability (Kuppusamy et al. 2016).

(iii) Physical Barriers: Treatment Walls / Permeable Reactive Barriers

This technology is effective for a series of chemicals (halogenated organics, hydrocarbons, chlorinated solvents, radionuclides and metals). The treatment may reduce the volume of harmful contaminant residues by permanently restricting contaminant migration into non-contaminated areas. The efficiency of this approach is governed by the barrier qualities used (Shukla & Srivastava 2019).

In the business world, subsurface vertical barriers are often employed to control groundwater seepage. This technology is currently being used as a primary and supplemental remedial option for hazardous waste sites, as well as a method of preventing toxic contamination of groundwater resources. Active containment system (e.g. ground-water extraction to control hydraulic gradient) and passive containment system (e.g. physical barriers only) are typically used in tandem depending on the remediation objectives and the complexity of the pollution sites (Shackelford 2013). Low permeability vertical barriers (walls) get into an underlying floor surface, as well as a low permeability cover (cap) to prevent precipitation infiltration, extraction and/or injection wells, trenches, and a network of monitoring wells (Beljin 2005).

Groundwater remediation can be accomplished passively using permeable reactive barriers (PRBs) with a suitable reactive material. A permeable wall would be built across the course of a contamination plume, filtering or degrading the toxins as the contaminated water that passes through it (Reddy 2008). The wall must be made of proper reactive material and be large enough to intercept the whole pollutant plume while also allowing enough time for clean-up to take place within the wall.

(iv) Soil Vapor Extraction (SVE) and Air Sparging

Soil vapour extraction (SVE) uses vacuum to produce a concentration gradient, which causes gas phase volatiles to be extracted from the soil. The vapour of volatile elements will be removed using extraction wells and then treated with carbon absorption before being discharged into the atmosphere or reinjected into the subsurface. This method for treating contaminated groundwater has also been employed in air stripping and groundwater pumping. Petroleum residues, for example, can be treated by combining SVE with steam injections, bioventing, and radio frequency heating procedures, aided by the heavier contaminant's volatility, which is accelerated by hot air injections (Fernández Rodríguez et al. 2014).

Soil vapor extraction has shown its ability to treat vast volumes of soil with little soil disturbances at a fair cost and in a short amount of time. However, it is only useful in areas with a low water table (>1 meter below ground level) and volatile chemicals. By restricting air movement through the soil pores, low permeability, high moisture content, and preferred flow in a layered pattern might prolong the restorative period. Other constraints include the requirement for air emission licenses, the need for costly treatment of extracted vapour released into the atmosphere, treatment of only unsaturated soil zones, and integration with other technologies that can lower contamination concentrations to more than 90% (Kuppusamy et al. 2016).

To speed up the process of contaminant volatilisation, air sparging involves injecting gas under pressure into the saturated subsurface zone. Air sparging in groundwater raises the concentration of oxygen in the subsurface. The extracted air and pollutant vapour are sometimes referred to as "off-gases", which is another way of saying "contaminant removal". The off-gases are routed from the extraction wells to an air-water separator to eliminate any moisture that could interfere with the treatment process. By pushing the vapour through activated carbon canisters, the vapour was separated from the air. The chemicals are then trapped between the carbon while clean air will be emitted to the atmosphere (Wilson et al. 2002). This strategy is more cost-effective and efficient, particularly when paired with other traditional remediation strategies (such as SVE or volatilisation/biodegradation mechanisms) (Kuppusamy et al. 2016).

The United States has been practising SVE for decades (USEPA 2020). It allows for the elimination of VOCs that have been absorbed into the unsaturated (vadose) soil. To remove VOCs from the soil and transport the vapour to ex-situ treatment systems for destruction or recovery, air will be taken from and injected into the vadose zone. Soil vapor extraction is commonly used to remove VOC sources by regulating and diverting vapour migration from the source region to a compliance point. Where the soil or contaminants are not suitable to SVE treatment, vapours will be stripped from VOC-contaminated soil utilising conventional soil treatment methods such as electrical resistance heating in-situ.

Air sparging, which involves injecting air into contaminated groundwater to move volatile and semi-volatile contaminants into the underlying vadose zone through the volatilisation process, is also beneficial in treating VOCs. To remove the generated vapor-phase contaminants from the vadose zone, SVE is commonly used in conjunction with air sparging.

(v) Fracturing (Pneumatic/Blast-enhanced/Hydro)

By generating more new cracks, these fracturing strategies may improve contaminant mass transfer. The generated fracture will aid in increasing the efficiency and cost effectiveness of current in-situ technologies by increasing wall permeability and altering liquid flow. Aside from that, fracturing will help to reduce the number of extraction wells, manpower, and material expenses associated with contaminated site treatment. In terms of blast-enhancing fracturing, the drilled boreholes create additional fractures, which are subsequently filled with the explosion and detonation. In the presence of fractured bedrock formation, this in-situ approach can be used. Furthermore, the use of SVE technology in conjunction with hydraulic fracturing systems will improve overall contaminant recovery (USEPA 2021).

(vi) Electrokinetic Remediation

Electric current is used to remediate slurries and heavy metals in electrokinetic remediation. This method has also been utilised to handle radionuclides, as well as mixed inorganic species and some organic molecules. Acid is created in the anode compartment once the electrical current is supplied, and it is carried through the soils, desorbing contaminants from the soil surface. In low permeable medium soil composed of clays and silt mixtures, the electrodes' electroosmosis and electrolysis processes will perform well. The transport medium served as the foundation for the basic reaction (such as electroosmosis with water, electrophoresis in pH gradient, electromigration in ions transportation, and electrooxidation-oxidation of contaminants). Electrokinetic is costly, necessitating the utilisation of machinery on site. To treat heavy metal contaminants such as lead (Pb), chromium (Cr), zinc (Zn), iron (Fe), mercury (Hg), magnesium (Mg), and cadmium (Cd), as well as radionuclides – thorium (Th), radium (Ra) and uranyl (UO_2), a combination of electrokinetic and bioremediation is required; involving nonpolar compounds (benzene, toluene, ethylene and xylene) and polar organic compounds (acetic acid and phenol) (Hansen 2016).

(vii) Natural Attenuation

Natural attenuation is a preventative remediation method. Rather than using the "walk away" methodology, the clean-up method focuses on authenticating and monitoring the natural cleaning process. Non-halogenated volatile organic compounds (VOCs) and semi volatile organic compounds (SVOCs), herbicides, fuels, and pesticides are removed from aquifers and soils using bio-attenuation. The efficacy of natural processes will be evaluated before the site for this restoration method is chosen. Because the procedure takes longer, a remote location away from potential receptors is a key consideration, maybe to reduce the risk to ecological and public health (Andrea 2017).

(viii) Phytoremediation

Plant/vegetation, microbes, and enzymes are used in phytoremediation to remove, eliminate, immobilise, or contain contaminants from polluted media. The plants utilised in this process, known as "hyperaccumulators," have the ability to collect a large amount of heavy metals. Phytoremediation is further divided into five types: phytotransformation (plant metabolism used to treat both water and soil pollution), rhizofiltration (pollutants accumulated at plant roots), phytostimulation (microbe degradation stimulated at root zone), phytoextraction (contaminant uptake from soil), and phytostabilisation (halting migration of contaminant using plant). Phytoremediation is expected to treat various pollutants such as polycyclic aromatic hydrocarbon (PAHs), polychlorinated biphenyls (PCBs), petroleum hydrocarbons, organophosphate insecticides, heavy metals, radionuclides, non-aromatic chlorinated solvents, BTEX, surplus mineral, explosives and nitrotoluene ammunition wastes (Shukla & Srivastava 2019).

(ix) Nano-remediation

This approach uses reactive materials with a size range of $1x10^{-9}$ meter to $1x10^{-7}$ meter. Through catalysis and chemical reduction, this procedure will aid in the detoxification and transformation of contaminants. Despite the fact that many other reactive chemicals, such as titanium dioxide, metal oxides, nanotubes, and noble metals, have been studied, nanoscale zero-valent iron (nZVI) is often used in groundwater remediation. Furthermore, in-situ nanotechnology applications such as nano-sized oxides have been shown to aid in the reduction of NAPLs from subsurface oil tanks (Ingle et al. 2014).

(x) Pump and Treat Technique

This technique requires a simple machine which is effective for free phase contamination. In this process, polluted ground water is physically pumped out from aquifers using a vacuum pump, then treated using filter or activated carbon process to absorb the contaminant and injected again in aquifers (Kisku et al. 2015; Reddy 2008; Regenesis 2017). Due to the nature of the technology and the nature of pollutant transport in the subsurface, this technique frequently operates for long periods of time, in some cases decades (USEPA 2009). The downside of this method is that it has a high cost of operation and maintenance, as well as residual pollution from tailing and/ or rebound (Reddy 2008).

CONCLUSION

The remediation technology for soil and groundwater contaminants have been in place for a long time. Many reviews have been published by scholars highlighting the emerging needs of technologies to contain the ecological impacts of the contamination. Clearly, although there are several technologies that can be executed to clear the contamination site, some of the important factors such as containment approach, considering national land use policy controls, resources availability, and geographic issues should be considered in depth to properly suit the success and sustainability of the remedial measures. The discoveries of reliable in-situ remediation technology of removing contaminants are another milestone for green environment sustainability. Remediation technologies depends on type of hazards (from soil analysis and groundwater analysis), cost available for the development of remediation technologies and maintenance, type of soil, depth of groundwater, the flow of groundwater, the status of groundwater whether it is used for drinking water or not, etc. By completing this review, perhaps it will greatly benefit those in the government and private environmental agencies, politicians, developers, manufacturers and local authorities.

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