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Implementation of Soil Washing in Remediation of Contaminated Soil

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ABSTRACT: Many human anthropogenic activities, including as deforestation, fossil fuel combustion, industrialisation, and solid waste production, have contaminated and endangered the entire environmental ecosystem in this age of pollution. Recently, heavy metal contamination in soil particles has attracted the attention of governments around the world, as many agricultural farmlands are contaminated with heavy metal pollutants such as copper, nickel, cobalt, iron, and lead, which have negatively impacted crop development. In addition, long-term exposure of the human body to heavy metals will cause severe illnesses, including neurological disorders, cardiovascular diseases, and chronic diseases. These contaminated soils are extremely tough and demanding to remediate. Soil washing is one of the most effective, rapid, and straightforward ways for decontaminating heavy metal-contaminated soil. The primary purpose of soil washing is to clean the sand and gravel fractions while concentrating contaminants in the clay and silt fractions. This will aid in the removal of heavy metal particles from the soil and their transfer to the washing solution. This study will examine the fate and transport of heavy metal contaminants as well as the many forms of soil washing mechanisms. In addition, the obstacles of implementing soil washing as well as its advantages and disadvantages were explored. Further research and possibly new directions, in addition to the possibility of soil washing, would also be discussed.

KEYWORDS: Soil washing; soil type; remediation; heavy metal

1. Introduction

As a result of the continual expansion of industrial and agricultural development around the globe, environmental considerations and concerns surrounding sustainable development are becoming of the utmost importance. Currently, these concerns addressing environmental sustainability are taken into account in the industrial, political, and economic decision-making processes [1]. Yet, despite the fact that the worldwide pollution of air, water, and atmosphere is still steadily increasing [2, 3], many of these restrictions intended to limit the escalation of pollution have yet to have a substantial effect. At the turn of the century, soil pollution has become a globally pervasive issue caused by human activities such as intensive soil exploitation, widespread use of fertilizers and pesticides in agricultural activities, urban discharges, and significant mining and metallurgical operations [4, 5]. In the past few years, heavy metals, petroleum hydrocarbons, polycyclic aromatic hydrocarbons, and polychlorobiphenyls have caused the most prevalent soil contaminations [5, 6]. According to a study, among the 10 million most polluted areas in the world, 50% of the soil contamination was caused by heavy metals. Globally, the agriculture sector loses an estimated 20 billion US dollars per year due to heavy metal soil contamination [4, 7]. In addition, exposure to heavy metals may offer severe health hazards, including cardiovascular ailments, neurological disorders, and acute and chronic diseases. Hence, soil remediation is essential for the elimination of pollutants and contaminants [8].

Heavy metal contaminated soil has been treated with a variety of remediation methods in recent years, including soil substitution, electrokinetic remediation, soil washing, thermal treatment, and phytoextraction. Based on a few prior investigations, these studies have favored the use of soil washing as a rapid and effective method for removing heavy metals from soil [5, 7]. Essentially, soil washing is the extraction of heavy metals from soil using several reagents and extractants. During this procedure, filthy soil is excavated and mixed with an appropriate reagent for a predetermined amount of time. Many studies [7, 9] have proven the effectiveness of a variety of organic and inorganic soil-washing solutions. Prior research indicates that with a liquid-solid ratio of 10:1 and the specified washing duration of 25 minutes, hydrochloric acid has the potential to recover 67% of zinc heavy metals from the soil. Other studies found that 24.5% of arsenic metal may be recovered using a phosphate solution containing 0.5 mol/l and a predetermined period of 120 minutes [10, 11]. Concerns exist, however, that the use of these washing solutions may alter soil features such as microbial variety, physiochemical properties, and enzymatic soil reactions [12]. Thus, the purpose of this study is to analyze the fate and transport of heavy metal pollutants and to determine if the application of soil washing on heavy metal pollutants is the most advantageous strategy compared to other soil remediation strategies.

2. Fate and transport of heavy metal pollutants

Heavy metals are a generic term for the group of metals and metalloids whose atomic densities are typically greater than 4000 kg/m3. They may be differentiated readily because their atomic densities are typically greater than 4000 kg/m3. Even at low quantities, the vast majority of heavy metals are hazardous to humans. Excessive exposure of the human body to heavy metals can result in a variety of debilitating diseases, and in extreme cases, death [13, 14]. Boron, arsenic, iron, zinc, copper, mercury, lead, and cobalt are examples of heavy metals. Heavy metals such as copper, zinc, iron, nickel, and boron are essential to the maturation of plants, but when their concentrations surpass the acceptable limits, they are harmful to the plants. Heavy metals are generated by natural processes such as volcanic eruptions, sea-salt sprays, rock weathering, and forest fires [14]. Fate of heavy metals in the environment is shown in Figure 1. Numerous soil locations are becoming contaminated with heavy metals as a result of anthropogenic activities such as industrial wastewater, agricultural fertilizers, mining discharges, urban discharges, and the application of treated wastewater within land use [15, 16].

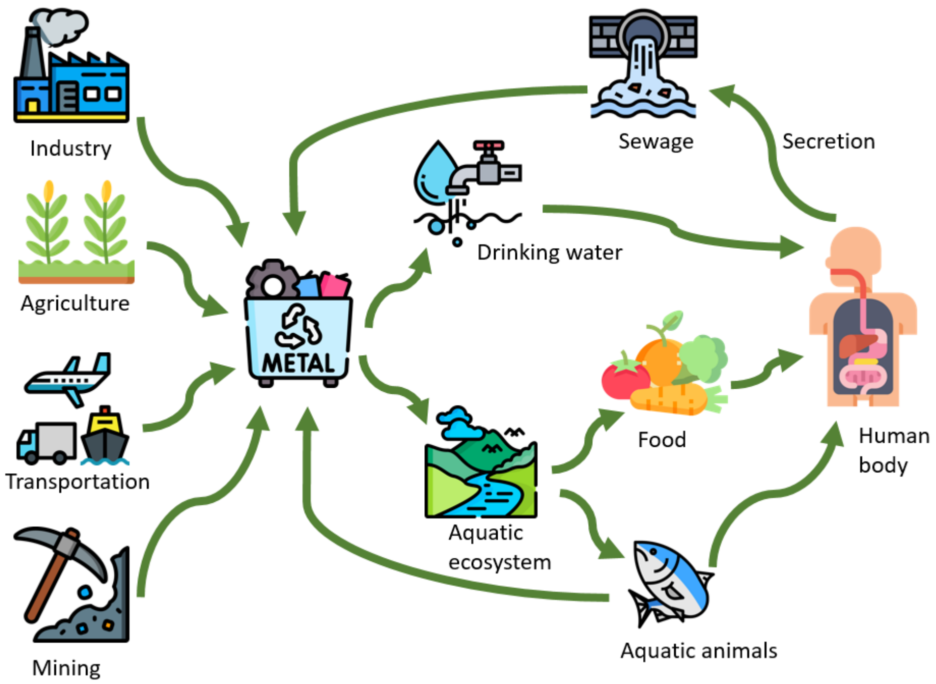

Figure 1. Fate of heavy metals in the environment [Icon from Flaticon Basic License CC3.0 (Creative Commons)].

Heavy metal soil contamination is often caused by either diffuse or point pollution sources, with the primary difference being the transit of heavy metal contaminants within the soil. Industrial manufacturing and landfills that primarily use the soil as a support system are considered point sources because they are associated with activities that directly transfer heavy metal pollutants into the soil, whereas diffusion sources are associated with natural occurrences such as sedimentation by surface water, atmospheric deposition, and long-distance transport, with agricultural fertiliser runoffs, wastewater runoffs, and mining operations categorized as diffusion sources. The most significant anthropogenic causes of heavy metal contamination include automobile exhaust emission, which releases lead; pesticides, which emits arsenic; and fossil fuel burning, which emits tin, nickel, and vanadium. Based on prior research, it was discovered that the fate and transport of heavy metals within the soil were also influenced by pH, as the solubility of heavy metals tended to decrease at higher pH values [17–19]. This is because the precipitation of solid phases in alkaline conditions reduces the concentration of metal ions. Another study revealed that the fate and transport of heavy metal pollutants depended on the redox potential, as the reduction-oxidation reactions within the soil were governed by the aqueous free electron activity pE or Eh redox potential. Temperature influences the breakdown of organic compounds, which in turn influences the mobilization of organo-metal complexes [17, 19]. Analysis reveals that the majority of heavy metal pollution originates from anthropogenic sources, such as industry, cars, agricultural runoffs, and mining operations, with pH, redox potential, and soil temperature also influencing the fate and transit of heavy metal contamination.

3. Mechanisms of soil washing

Several research [1, 5, 9, 10] have concluded that soil washing is the most effective and widely used procedure worldwide for soil remediation. Mechanisms scematic of soil washing technology is shown in Figure 2.

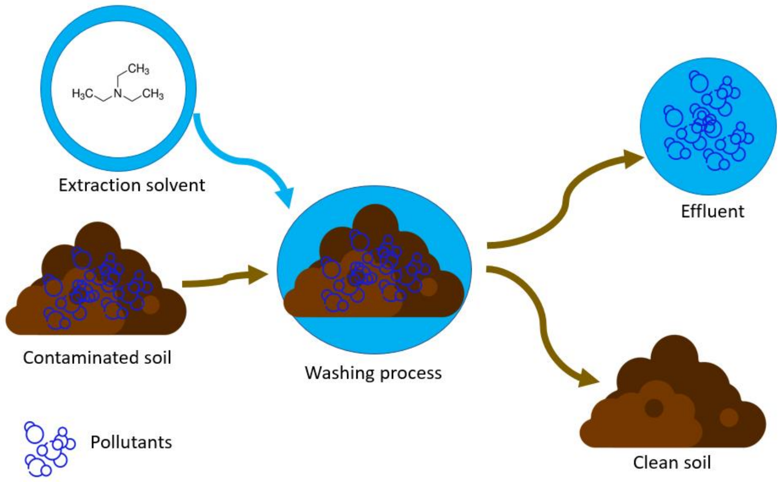

Figure 2. Mechanisms scematic of soil washing technology [Icon from Flaticon Basic License CC3.0 (Creative Commons)].

Table 1 demonstrates the various soil cleansing mechanisms and their efficiency. Soil washing with chelators, a recently discovered technology, was determined to be the simplest, quickest, and most effective method for eliminating soil polluted with contaminants, particularly heavy metals. This method uses physical procedures to remove contaminated soil particles and chemical separation methods with chelators to form coordinating bonds with heavy metal pollutants, allowing for the solubilization of heavy metal contaminants from solid to solution [20, 21]. Due to its strong metal separation capability, high solubility, and high thermodynamic stability of the metal-complex synthesis, ethylenediaminetetraacetic acid (EDTA) has attracted the attention of numerous scientists in recent years as the ideal washing agent. However, it was noted that this chelating agent had a substantial downside in the form of biodegradability restrictions and persistence in soil particles, which may have detrimental impacts on soil quality and function [21, 22].

Table 1. Different soil washing processes and their effectiveness.

Soil Washing Processes	Removal Efficiency	Adverse Impacts Towards Soil Properties	Economical	Reference
Ethylenediaminetetraacetic acid (EDTA)	High	High	No	[22]
Ethylenediaminedisuccinic acid (EEDS)	High on zinc, cadmium and copper only	Low	No	[23]
Glucomonocarbonic acid (GCA)	High on zinc, cadmium and copper only	Low	Yes	[12]
Polyaspartic acid (PASP)	High on zinc, cadmium and copper only however less effective when compared to GCA and ISA	Low	Yes	[12]
Iminodisuccinic acid (ISA)	High on zinc, cadmium and copper only	Low	Yes	[12]
Physical washing	Low	High	Yes	[25]

Many scientists today advocate ethylenediaminedisuccinic acid (EDDS), a biodegradable chelator, as an alternative to ethylenediaminetetraacetic acid (EDTA) in the soil washing mechanism due to its fewer negative effects on the soil environment. Upon comparison and analysis, EDDS has negligible effects on plants, near-zero toxicity to soil microorganisms, and good biodegradability with short half-lives of four to seven days. According to earlier research, it has been demonstrated that heavy metals such as zinc, cadmium, and copper can be effectively separated by EDDS, hence reducing their bioavailability and leaching in remediated soils [15, 23]. In the event of lead heavy metal contamination, EDDS was much less effective than EDTA due to EDTA's significantly greater stability constant (log KPb–EDTA = 17.9 > log KPb–EDDS = 12.7) [23]. In addition, EDDS is an expensive alternative compared to EDTA, costing between $2,000 and $5,000 per ton, which hinders its adoption for the treatment of heavy metal-contaminated soil. As a result, biodegradable chelates such as glucomonocarbonic acid (GCA), polyaspartic acid (PASP), and iminodisuccinic acid (ISA) have been introduced as replacements to EDTA and EEDS. According to numerous research studies, these different additional biodegradable chelates are non-toxic, have high water solubility, and have superior biodegradability within 28 days, which may aid in mitigating the negative effects of soil washing on soil attributes [12, 24]. Moreover, GCA, PASP, and ISA are generated commercially using green chemistry techniques relating to heat polymerization and fermentation [12]. It is unknown if biodegradable chelates are as successful as EDTA and EEDS at removing other forms of heavy metal compounds, despite the fact that they are more environmentally friendly and economical. Several variables, such as pH levels, duration, and concentration, have the ability to influence the efficiency of removing heavy metal pollutants from soil. There have been instances of physically washing heavy metal-polluted soil with water alone; however, the removal efficiency of heavy metal pollutants was very poor, and the excessive energy generated by the high-pressure water washing has the potential to damage the ecological environment and soil structure [12, 25].

4. Case studies in Malaysia

The soil contamination in Johor was caused by an accidental spill of petroleum from a storage tank farm. The contamination posed a serious threat to the environment and human health. Therefore, a soil washing plant was set up in Johor to remediate the contaminated soil. Contamination situation: The soil samples collected from the contaminated site were found to have high levels of total petroleum hydrocarbons (TPH), specifically in the range of 2,100 to 3,300 mg/kg. The high levels of TPH suggested that the soil was heavily contaminated with oil. The soil washing process involved a series of steps, including screening, washing, and separation. Initially, the contaminated soil was screened to remove large debris, stones, and gravel. The soil was then washed with a mixture of water and surfactant to remove the oil. The contaminated water was separated from the soil using a sedimentation tank. The clean soil was dried and screened again to remove any remaining debris. After the remediation process, the treated soil was tested for TPH levels, and it was found to have a range of 20 to 100 mg/kg, which was well below the regulatory limit of 1,000 mg/kg. The treated soil was then reused for landscaping and road construction, demonstrating a sustainable approach to the remediation of contaminated soil [25].

The soil contamination in Selangor, Malaysia was due to the discharge of industrial wastewater containing heavy metals such as lead, cadmium, and nickel. The soil samples collected from the contaminated site were found to have high levels of heavy metals, with lead levels ranging from 144 to 592 mg/kg, cadmium levels ranging from 1.4 to 4.7 mg/kg, and nickel levels ranging from 165 to 397 mg/kg. Soil washing using a series of steps including screening, washing with an acidic solution, and separation was employed to remediate the contaminated soil. The treated soil was tested and the heavy metal levels decreased to well below the regulatory limit for contaminated soil, with lead levels ranging from 26 to 34 mg/kg, cadmium levels below the detection limit of 0.05 mg/kg, and nickel levels ranging from 11 to 16 mg/kg. The treated soil was reused for land restoration, showcasing a sustainable approach to soil remediation [26–28]. Another case study in Selangor, Malaysia showed that a former landfill site was contaminated with various pollutants including heavy metals, volatile organic compounds (VOCs), and polycyclic aromatic hydrocarbons (PAHs), which posed a significant risk to the environment and human health. To clean up the site, the contaminated soil was excavated and transported to a soil washing plant where it was treated with various chemicals to remove the pollutants. The treated soil was then tested to ensure that the pollutant levels were safe, and then transported back to the site for land reclamation. The remediation process helped to reduce the risk to the environment and human health, making the site safer for the community [29–31].

In Perak, Malaysia, a former tin mining site was found to be contaminated with heavy metals like lead, arsenic, and cadmium. The contamination was a result of mining activity that left behind polluted soil and tailings, which posed a threat to the environment and human health. To remedy this, the contaminated soil was taken to a soil washing plant, where it underwent treatment using chemicals to remove the heavy metals. Once the treated soil met the acceptable limits, it was transported back to the site for land reclamation [32]. Similarly, in Johor, Malaysia, a site was contaminated with petroleum hydrocarbons due to a leaking underground storage tank. This contamination posed a serious risk to the environment and human health. To remediate the site, soil washing was chosen as the technology of choice. The polluted soil was transported to a soil washing plant where it was treated with surfactants and solvents to remove the petroleum hydrocarbons. The treated soil was tested to ensure that the levels were safe, and then used for land reclamation purposes [33].

4. Challenges faced implementing soil washing

Soil washing has emerged as an effective remediation technology for contaminated soil in Malaysia, but it faces several challenges in its implementation in Malaysia. Firstly, soil washing can be a costly process, particularly for large-scale remediation projects. This cost includes not only the equipment and materials used in the process but also the disposal of the contaminants removed from the soil. The cost of soil washing could be a major challenge for many organizations, particularly in Malaysia, where the environmental budget for soil remediation projects is often limited. Secondly, soil washing requires a significant amount of water, which can be a concern in areas where water resources are limited. The use of large volumes of water in the process can also generate contaminated wastewater, which must be treated before discharge to avoid further contamination. Thirdly, the selection of the appropriate surfactant and solvent to remove the contaminants from the soil can be challenging.

The effectiveness of the process is highly dependent on the selection of the appropriate chemicals and their concentration, and this selection can vary depending on the type and concentration of the contaminants present in the soil [34–36].

Although though soil washing appears to be a very effective and environmentally sustainable method for removing heavy metal contaminants from the soil, there are still obstacles to be addressed before this technique can be considered the most effective heavy metal soil remediation method. While biodegradable chelates like EEDS, GCA, PASP, and ISA have negligible negative effects on the soil after washing, they are ineffective against heavy metal pollution, except for zinc, cadmium, and copper. On the other hand, EDTA is the most effective heavy metal extractor, but it can alter the natural soil structure, harming the ecosystem [12, 22–34]. Therefore, most studies refrain from using EDTA. Biodegradable chelates are a greener alternative to conventional chelating agents like EDTA and EEDS, but further research is necessary to evaluate their efficacy in removing heavy metals, especially for GCA, PASP, and ISA, which are new green chelating agents. The effectiveness of soil washing is also influenced by pH value, time, concentration, and soil extraction efficiency. A lack of information about these factors may lead to a decrease in heavy metal extraction efficiency. For example, heavy metals are less soluble in alkaline conditions, which would impact the rate of removal and efficiency during soil washing [37–38].

5. Advantages and disadvantages of soil washing

Although soil washing appears to be a very effective and environmentally sustainable process for eliminating heavy metal contamination from the soil, there are still difficulties to overcome before it can be deemed the most effective heavy metal soil remediation technology. With the exception of zinc, cadmium, and copper, biodegradable chelates such as EEDS, GCA, PASP, and ISA are ineffective against all heavy metal pollutions, despite their low detrimental effects on the soil after washing. EDTA, on the other hand, is the most efficient heavy metal pollution extractor; nonetheless, it has the ability to modify the natural soil structure, so hurting the ecosystem [22]. In the absence of EDTA, soil washing has a minimal impact on a few heavy metal pollutants. Yet, based on previous research, the vast majority of studies avoid employing EDTA since it may cause harmful changes to the underlying soil structure [12, 23, 24]. While biodegradable chelates are a green alternative to conventional chelating agents such as EDTA and EEDS [39], there is a need for more research on the efficacy of biodegradable chelates in dirt removal, particularly for the novel green chelating agents GCA, PASP, and ISA. The absence of information regarding the relationships between pH value, time, concentration, and soil extraction efficiency necessitates further study, given that the application of soil washing is influenced by the aforementioned factors, the absence of which may result in a decrease in heavy metal extraction efficiency. For example, according to a study, heavy metals were less soluble in alkaline circumstances, which would impact the rate of removal and efficiency of soil washing, hence decreasing performance. Due to the necessity to excavate and replenish the soil after washing, soil washing is more costly than other methods of soil restoration [37-39]. Given that the cost of the soil washing cleanup process includes excavation fees, scientists may prefer alternate soil remediation methods.

6. Conclusion, future research and prospect in Malaysia

In conclusion, soil washing is a promising technology for the remediation of contaminated soil in Malaysia. However, its implementation is not without challenges, including cost, water usage, and chemical selection. To overcome these challenges, further research is needed to identify more cost-effective methods of soil washing, as well as to explore alternative methods that require less water and fewer chemicals. One area for future research is the development of more environmentally friendly surfactants and solvents. Currently, many of the chemicals used in soil washing are not biodegradable and can contribute to further contamination. Therefore, the development of greener alternatives would be beneficial for the environment and human health. EEDS, a biodegradable chelate, has no negative side effects following soil remediation, but is only effective for heavy metal contaminants like zinc, cadmium, and copper. In addition, EEDS was more expensive than alternative remediation strategies. Other biodegradable chelates, such as GCA, PASP, and ISA, cost significantly less than EEDS and have no negative impact on the soil following remediation. While these biodegradable chelates are still relatively new alternatives to conventional chelates, their ability to remove heavy metal contaminants other than zinc, cadmium, and copper is mostly unknown. Due to a lack of evidence and confidence, this will discourage other scientists from using the soil washing procedure. Another area for future research is the optimization of soil washing processes based on the specific contaminants present in the soil. As mentioned earlier, the effectiveness of soil washing is highly dependent on the selection of appropriate chemicals and their concentration, and this can vary depending on the type and concentration of the contaminants present. Therefore, further research is needed to optimize the process for different types of contaminants, to ensure maximum effectiveness and cost efficiency.

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Conflicts of Interest

The authors declare no conflict of interest.

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