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Report

Feasibility Studies of Soil Remediation for Kenya

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Abstract: Soil remediation technologies have been developed to remediate the contaminated soil. There are several types which categorized into physical/chemical, biological and thermal methods. Physical/chemical method involves physical removal and uses of chemical to destroy, separate, or contain the contaminations, biological method uses plants and some microorganisms to degrade pollutants accumulated in the soil, while thermal uses heat energy to treat contaminated land. The main objective of this report is to analyze the remediation technologies that are feasible to be implemented in Kenya by the use of summarized studies done by environmental expertise in UK. By comparing cost and time used to implement each of the technologies, the study found out that eight technologies are most feasible technologies identified after analysis. These technologies are soil washing & separation, soil flushing (In situ), Vitrification (In situ), chemical oxidation and reduction (Ex situ), vitrification (Ex situ), phytoremediation (In situ), permeable reactive barrier (In situ) and thermal treatment (Ex situ) that likely to work well for the remediation of contaminated soil in Kenya.

Keywords: Soil Contamination, Remediation Technologies, Kenya's Soil, Selection Criteria, Soil Remediation

1. Introduction

Soil is considered as a critical component of the earth's life support system, as well precious resource and an important factor of production in economic systems. Nonetheless, historical industrial operations have resulted in large areas of contaminated land that are only slowly being remediated [1]. The anthropogenic activities lead to the release of contaminants to the soil resulting in ecological damaged. Soils are a major sink for these toxic metals and unlike organic contaminants which are oxidised to Carbon (IV) oxide by microbial action, most metals do not undergo microbial or chemical degradation [2].

Soil contamination in Kenya is increasing because of intensive anthropogenic activities, low inputs and poor management of land. This is because of growing population; hence, there is a need to assess the status of soil and the trends of its quality degradation. Thus suggesting incentive and remediation technologies for restoring back to normal [3]. Reconstructing the soils is difficult because soils comprises both organic and inorganic components that have weathered in situ for a very long time. Remediation is needed to reverse the barren land to dynamic soil quality which is normally referred to as soil health [3].

There are many existing techniques of remediating contaminated soils; they are categorized into physical, chemical, biological, and thermal [4]. Physical/ chemical treatment uses the physical/chemical properties of the contaminated medium to destroy, separate, or contain the contamination. Biological treatment is a process whereby contaminants in soil are transformed or degraded into harmless substance such as, carbon dioxide, water, fatty acids, and biomass through the action of microbial metabolism. Thermal processes use heat to increase the volatility, to burn, decompose, destroy or melt the contaminants. Thermal treatments offer quick cleanup type but are typically the most costly treatment than other techniques.

Each category of these can be classified as ex-situ (where remediation is done off-site) or in-situ (remediation of contaminated soil is done on-site) [4]. The detail information about available technologies and their capability for treating contaminated soil are in Table 1. Some of the examples of physical and chemical methods are; permeable reactive barriers, solidification & stabilisation, electro-remediation, virification, vapour extraction, soil washing and flushing. These types of technologies are expensive and do not make the soil suitable for plant growth [5]. Bioremediation encourages the establishment of plants on polluted soil and is therefore environmentally friendly approach because it is achieved via natural processes.

Table 1. *Available technologies for treating contaminated soil and their cost of using based on UK experience adapted from Defra [4]; Nathanail [6].*

Methods	Available technologies	Capability	Timescale (year) & cost (£)
	In situ		
Physical	Soil flushing*	Heavy metals, VOCs & SVOCs	1-3 (20 to 168/m^3)
	Electro-remediation	Heavy metals	1-3 (8 to 45/m^3)
	Stabilization & Solidification	Heavy metals	< 1 (14 to 500/m^3)
	Vitrification*	Heavy metals, PCBs, Pesticides/ herbicides, Dioxins/furans	< 1 (40 to 280/m^3)
	Permeable reactive barriers*	Heavy metals, VOCs & SVOCs	> 10 (10 to 150/m^3)
Chemical	Chemical oxidation and reduction	PCBs, VOCs and SVOCs	< 1 (12 to 500)/m^3
	Electro-remediation	Heavy metals	1-3 (8 to 45/m^3)
	Stabilization/Solidification	Heavy metals	< 1 (14 to 500/m^3)
	Vitrification*	Heavy metals, PCBs, Pesticides/ herbicides, Dioxins/furans	< 1 (40 to 280/m^3)
	Permeable reactive barriers	Heavy metals, VOCs & SVOCs	> 10 (10 to 150/m^3)
Biological	Phytoremediation*	Heavy metals, VOCs & SVOCs, PCBs, Pesticides/herbicides, Dioxins/furans	> 10 (20 to 50/ m^3)
	Permeable reactive barriers*	Heavy metals, VOCs & SVOCs	> 10 (10 to 150/m^3)
Thermal	Thermal treatment	SVOCs	< 1 (20 to 168/m^3)
	Vitrification*	Heavy metals, PCBs, Pesticides/ herbicides, Dioxins/furans	< 1 (40 to 280/m^3)

Table 2. *Continue.*

Methods	Available technologies	Capability	Timescale (year) & cost (£)
	Ex situ		
Physical	Soil washing and separation*	Heavy metals, PCBs, VOCs & SVOCs	< 0.5 (6 to 200)/m^3
	Stabilization & Solidification	Heavy metals	< 0.5 (3 to 150/m^3)
	Vitrification*	Heavy metals, PCBs, Pesticides/ herbicide, Dioxins/furans	< 0.5 (60 to 300/m^3)
Chemical	Chemical oxidation and reduction*	Heavy metals, PCBs, VOCs & SVOCs	< 0.5 (15 to 200)/m^3
	Stabilization & Solidification	Heavy metals	< 0.5 (3 to 150/m^3)
	Vitrification*	Heavy metals, PCBs, Pesticides/ herbicide, Dioxins/furans	< 0.5 (60 to 300/m^3)
Biological	Biological treatment	VOCs & SVOCs	< 0.5 – 3 (12 to 125/m^3)
Thermal	Thermal treatment*	Heavy metals, PCBs, Pesticides/ herbicides, Dioxins/furans	< 0.5 (55 to 280/m^3)
	Vitrification*	Heavy metals, PCBs, Pesticides/ herbicides, Dioxins/furans	< 0.5 (60 to 300/m^3)

The star sign* against technologies in Table 1 are the one that has wide range of applications (These types are used to remediate the soil contaminated with organics and inorganics at the same time).

2. Physical/Chemical Treatment Method

This method involves physical removal of top soil and is perhaps the oldest remediation method for contaminated soil; Figure 1 shows how it is done. It is still in use at many locations around the world, especially in developed countries. Physical/chemical method can be applied in-situ as well as ex-situ [4]. Technologies use in in situ are (soil flushing, stabilization/solidification, vitrification, electro remediation, and permeable reactive barriers), and ex situ are (soil washing & separation, stabilization/solidification and vitrification).

Advantages of excavation include the complete removal of the contaminants, degrade semi-volatile organic compounds (SVOCs) & nonvolatile organic, and require low maintenance and the relatively rapid cleanup of a contaminated site [7]. The soil replacements are divided into three types, including soil replacement, soil spading and new soil importing [8].

The limitations of using physical method include the fact that the contaminants are simply moved to a different place, where they must be monitored hence the risk of spreading contaminated soil and dust particles during removal and transport of contaminated soil; and again the cost is relatively high [9]. It also requires sufficient nutrients, moisture, active indigenous microbial population, and pH of 6-9 to degrade contaminant [7]. Excavation can be the most expensive option when large amounts of soil must be removed or disposal as hazardous or toxic waste is required.

The chemical treatment method, on the other hand, is that soil reclamation aims to degrade the pollutants accumulated in the soil or make such changes to their physicochemical properties to reduce their ecological hazard [5]. This method initially developed based on the following chemical processes; oxidation and reduction, extraction, precipitation of sparingly soluble chemical compounds, and pH stabilization. These are the main advantages of chemical treatment technology; (i) the broad spectrum of applicability, (ii) high efficiency, and (iii) high specificity of application for individual pollutants. The limitations and disadvantages are (i) usually high costs of application, (ii) production of many wastes, including hazardous waste, and (iii) problems of process control, especially in the case of in-situ techniques [8].

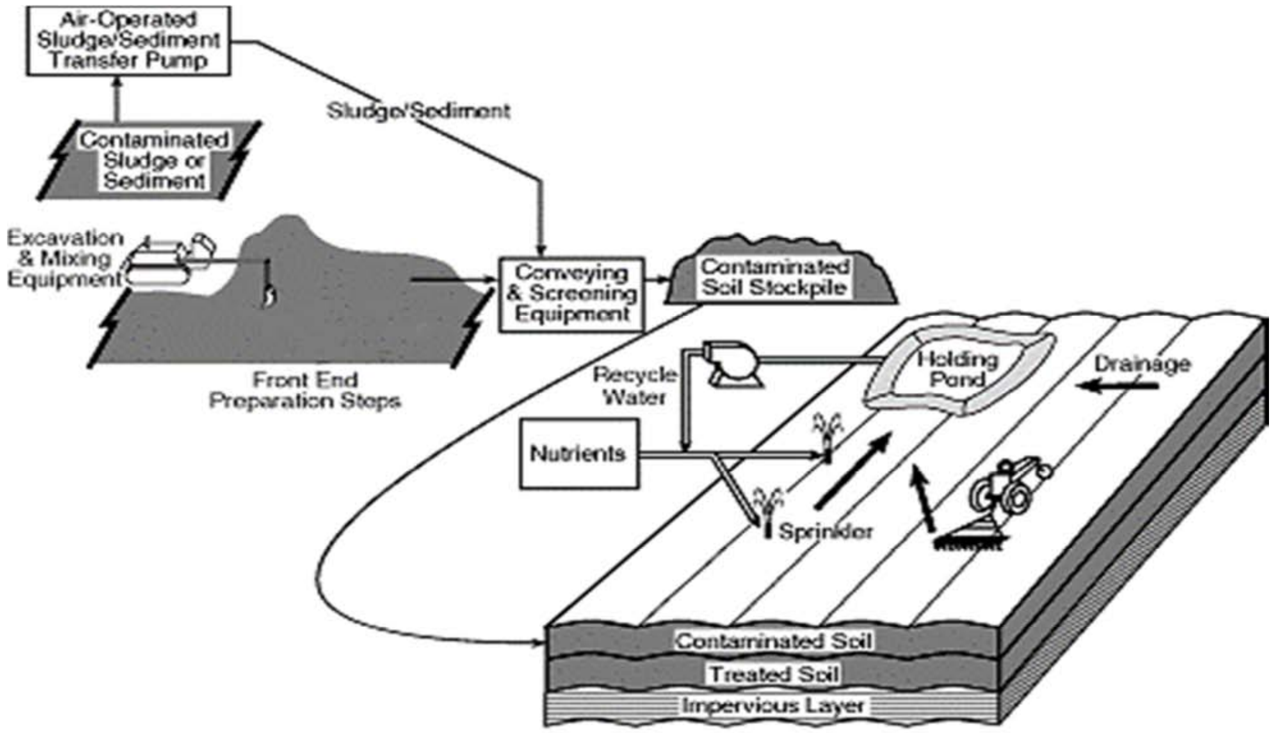

Figure 1. *Evacuation technology for treating contaminated land FRTR [10].*

3. Biological Treatment Method

Biological treatment is widely recognized as soil reclamation technology that is based on the biological activity of microorganism and higher plants, which have the ability to degrade pollutants accumulated in the soil, including their mineralization, immobilization or removal [11].

The advantages of biological methods of soil reclamation are; it has wide application range, high efficiency but only in a limited concentration range (the concentrations could not exceed a tolerance level of organisms used for this purpose); and cost-efficiency and simplicity during the initiation and process operation. While disadvantages are; this method has a dependency of process efficiency on bioavailability and contents of removing contaminants; sometimes, a long time is needed to obtain the expected effect; and in some cases, production of highly toxic wastes [11].

Phytoremediation has been applied to a number of contaminants in a small-scale field. These contaminants include heavy metals, radionuclides, chlorinated solvents, petroleum hydrocarbons, PCBs, PAHs, organophosphate insecticides, explosives, and surfactants [11].

4. Thermal Treatment Method

Thermal treatment method usually applied in two stages, low-temperature thermal desorption followed by secondary treatment or in a single stage (incineration) [4]. The process of Low-temperature thermal desorption uses heat to separate organic contaminants from soil. Its treatment units typically designed to heat soils to temperatures up to 600°C.

Incineration plant involves a thermal destruction of contaminants in a combustion chamber at high temperatures up to 1300°C. The most common type of incinerator is a rotary kiln design, but fluidized beds and infrared systems have also been developed [4]. The higher operating temperature, compared with thermal desorption, means that incinerators can successfully treat a wider range of contaminated materials, higher concentrations of contaminants and those that are harder to treat.

Thermal treatment technology is more applicable in either soil that has a sand particle of 0.06 to 2mm or clay that has particle less than 2μm. The advantages of this technology are; one it is applicable to a wide range of organic and some inorganic contaminants and two it has a high potential for contaminant removals and three it offer quick cleanup times but are typically the most expensive than other treatment methods [4]. The disadvantages includes (i) it is expensive since incineration uses more power, (ii) may result in loss of organic matter in the soil which restricts its use post-treatment and (iii) emissions must be carefully controlled in case incomplete combustion products (e.g dioxins and furans) are formed, particularly for thermal desorption [4].

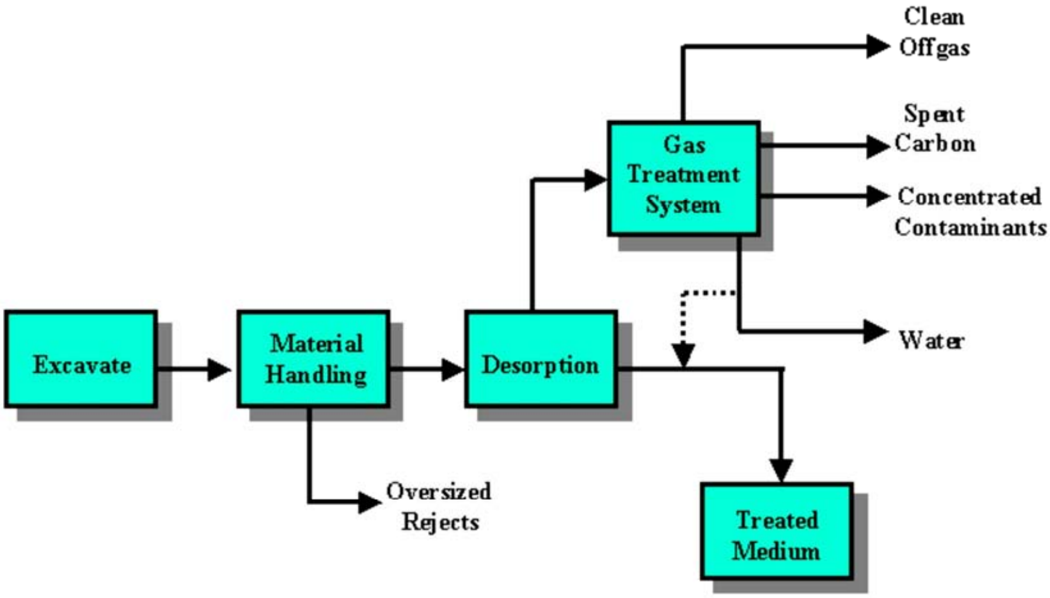

Figure 2. *Thermal treatment technology FRTR [10].*

5. Selection Criteria for Soil Remediation Technologies for Kenya

There are few things to consider when choosing feasibility of soil remediation technology most feasible in Kenya. Environment implication of using the method cost for the maintenance and operation of the technology chosen, and land used consideration of the treated land. Table 1 contains the cost of soil treating with different technologies in the United Kingdom [6]. The cost may vary depending on the level and nature of the risk independent of the proposed use of the land and the sensitivity of the environment [12]. This paper review soil remediation technologies currently implemented in Nigeria and South Africa.

The study carried in Alaba International Market in Nigeria whereby there is an indication of the presence of a significant concentration of Cr, Zn, Cd, Pd, and Ni in soils in the e-waste dumpsites and residences area [13]. The report further revealed that there is a higher possibility and potential of using a type of vegetable plant called *Amaranthus spinosus* as a plant for environmental monitoring and soil remediation of land contaminated with heavy metals.

Another study carried out in Cape Town South Africa by Ochonogor & Atagana [14], revealed *Psoralea pinnata* plant can accumulate heavy metal in their leaves. The results of the experiment show that *Psoralea pinnata* accumulated chromium highly in their leaves and roots.

Kenya and South African have similarities of some resources found in the soil. The ground is called laterite and is a clay that has been enriched with iron and aluminum that has been developed over long periods by heavy rainfalls and intense heat [15]. Some of the plants such as Bambara bean (*Vigna subterranea*) are a leguminous plant that can do well in tropical areas in both countries. This plant is grown in Nigeria, South African, and Kenya [16]. Therefore, the same technology that was applied in South Africa and Nigeria for treating contaminated soil is more likely to be feasible to be implemented in Kenya.

A Recent study also conducted in Kenya using three plants (*P. senegalensis, A. hybridus and E. crassipes*) on the effectiveness of absorption heavy metals [17]. It was concluded that the mean concentration values of the elements in the plants decrease according to the sequence Zn>Cu>Cd. Again, *P. senegalensis* plant recorded the highest mean concentration uptake, followed by *A. hybridus* and *E. crassipes* in that sequence.

6. Selection of Feasible Soil Remediation Technologies for Kenya

The study carried in the UK on the time scale and cost of using different technologies to treat contaminated soil as indicated in Table 1. This survey was done by comprising technology vendors, environmental experts, and remediation practitioners [4]. This study enables to summarize Table 2 below, which contain technologies that have the potential of treating combined contaminants (e.g. organics and inorganics) in the soil. These are some of the most feasible technologies identified after analysis as in Figure 3 (Soil washing & Separation, Vitrification (In situ), Chemical oxidation and reduction (Ex situ), Vitrification (Ex situ), Phytoremediation (In situ), and Thermal treatment (Ex situ)) that likely to work well for the remediation of contaminated soil in Kenya. Taking into account the cost of treating using each technology, the biological method considered as an economically friendly since Kenya is developing a nation. The selection of the above technologies was analyzed based on time scale and cost shown in Table 1.

Table 2. *Time and cost scale analysis for feasible remediation technologies of Kenya*.

Method	Technology	Time scale (year)	Cost (£)	Feasibility
Physical	Soil washing & Separation	V. efficient	Expensive	Good
	Soil Flushing (In situ)	Efficient	Expensive	Fair
	Vitrification (In situ)	V. efficient	V. expensive	Fair
Chemical	Chemical oxidation and reduction (Ex situ)	V. efficient	Expensive	Good
	Vitrification (Ex situ)	V. efficient	V. expensive	Fair
Biological	Phytoremediation (In situ)	Not efficient	Less expensive	Good
	Permeable reactive barrier (In situ)	Not efficient	Less expensive	Good
Thermal	Thermal treatment (Ex situ)	V. efficient	V. expensive	Fair

V. efficient = Very efficient, and V. expensive = Very expensive, Fair= reasonably good

	Soil flushing	Soil washing	Vitrification (In Situ)	Phytoremediation	Permeable reactive barrier	Vitrification (Ex Situ)	Thermal treatment	Chemical oxidation and reduction
Cost (£)/m3	94	103	180	35	80	160	167.5	107.5
Time (Months)	24	3	3	120	120	12	3	3

Figure 3. *Cost and time scale analysis for feasible remediation technologies for Kenya.*

6.1. Feasible Physical/Chemical Method

Soil washing, Vitrification (in situ), soil flushing and chemical oxidation and reduction take the shortest time of all the other techniques according to the analysis done in Table 2 and Figure 3 above. These techniques are suitable for the owners of land that need to develop as soon as possible, but only for other applications apart from agriculture activities. There are detrimental factors for each of the technologies discussed in the previous sections of this chapter. For instance, vitrificataion require a lot of energy during application, hence making it very expensive. Kenya currently may not be able to sustained since approximately 64% of Kenya households do not have electricity [18]. On the other hand, soil washing technique is uneconomical to treat small volumes and sometimes may need further treatment, therefore, making it expensive to apply this technique [4]. Whereas chemical oxidation and reduction may require large volumes of reagents [4], this increase the cost of application. Soil flushing also has a risk of a worsening situation by producing more toxic or mobile compounds [4].

6.2. Feasible Biological Method

Biological method especially phytoremediation and permeable reactive barrier are not expensive and environment friendly as compared with other techniques according to analysis as in Figure 3. This therefore is the good option for Kenya especially when applied on a site where farming activities are taking place. For instance, in situ methods are those that take place in the subsurface, without excavation of the contaminated soil or abstraction of groundwater. Taking into account the main advantages of in situ methods are, they can often avoid excessive environmental impacts, there is no costs associated with excavation and abstraction, and they can typically be implemented on operational sites [4]. On the other, the main limitations of ex situ remediation are, the high cost of excavation and pumping, the cost of safety materials for handling considering the exposure of workers to the contaminants, and additional land is required on site for the operation [4]. Again, this method is not suitable for land that needs to be reclaimed in a short period. Despite the fact that biological method takes longer time when used as in situ, it is the best for environment-friendly when reclaiming the contaminated land. Bioremediation enables appropriate reuse of the treated soil and minimizes disposal of waste soil to landfill, hence providing adequate protection of human health and the environment [19].

Biological remediation method is most suitable that can be applied in Kenya because of the following factors (i) Cost of managing and monitoring is lower than the other technologies, due to that this technology has no cost for electricity and again most people have a small piece of land. In phytoremediation, the use of plants to remove or degrade contamination from soils and surface waters has been proposed as a cheap, sustainable, effective, and environmentally friendly alternative to conventional remediation technologies [20]. (ii) Most plants such as tobacco shrub, rape plant and soya bean that has been studied to show the effectiveness of treating contaminated land can do well in almost everywhere in Kenya. Tobacco shrub (*Nicotiana glauca*) transformed with the *phytochelatin*, shows very high levels of accumulation of zinc, lead, cadmium, nickel, and boron, and produces high biomass [20]. Also, there is indication that duckweed is a good accumulator for Cd and Cu, but his result was unable to establish potential plant for abstracting Cr from the soil [14]., (iii) Soil properties in Kenya are good for the application of biological remediation technology. Again, there is availability of natural additives (e.g. mineral clay and organic manure) for process of phytostabilization of heavy metal (iv) This technology has wide range of remediating contaminated land, (v) This technology can preserve soil structure, and also soil can often be reused onsite. It is environmentally friendly; hence, there is a high level of community acceptance [4]. Therefore, this technology can be of beneficial to many farmers in Kenya who are planning to reuse the remediated land.

6.3. Feasible Thermal Treatment Method

Thermal treatment technology takes the shortest time as possible, hence it is appropriate for the clients who are purposing to make use of land in short period of time. However, this type of treatment requires a lot of energy during application, therefore, making it very expensive to sustain.

7. Future Lessons for Kenya on Soil Reclamations Procedures

Soil remediation has not been counted as more of concern in Kenya, despite the fact that various researchers compiled in this report have confirmed the present of different contaminants in soil across Kenya. Some of the researchers they have done their research in and around dumpsites in the cities and major towns, have reported having the highest concentrations of heavy metals and other POPs (e.g. Dioxins and Furans). [21]; [22]; [23].

Therefore, Kenya should learn from other countries for example UK and China who have implemented the remediation technologies, since Kenya economy is growing fast with a number of industries, and populations are increasing. In the near future, Kenya's soil most likely to have different types of contaminants.

8. Conclusion and Recommendations

Soil contamination has become more prevalent in Kenya due to many anthropogenic activities such as industrial, agricultural and improper waste disposal. Therefore, Kenya should undertake measures to adapt soil remediation technologies implementation to restore the polluted land, implement effective legal framework and prevent further contamination.

Soil washing & separation and Chemical oxidation & reduction technologies are counted as effective since it takes shortest time to remediated contaminated land though it is more expensive. An effectiveness of using these two technologies has been shown to remove heavy metals, PCBs, VOCs and SVOCs from the treated land. On the other hand, it is evident from the data that the phytoremediation is most reliable since it is cheapest and does not interfere with ecosystems. Phytoremediation is an emerging technology that can remove, contain, or render harmless such environmental contaminants as heavy metals, trace elements, organic compounds, and radioactive compounds in soil.

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