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PHYTOREMEDIATION OF HEAVY METAL POLLUTED SOILS USING LOCAL PLANTS IN THE MSIMBAZI RIVER CATCHMENT, TANZANIA

A MINOR FIELD STUDY

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This study has been carried out within the framework of the Minor Field Studies Scholarship Programme, MFS, which is funded by the Swedish International Development Cooperation Agency, Sida.

The MFS Scholarship Programme offers Swedish university students an opportunity to carry out two months' field work, usually the student's final degree project, in a country in Africa, Asia or Latin America. The results of the work are presented in an MFS report which is also the student's Master of Science Thesis. Minor Field Studies are primarily conducted within subject areas of importance from a development perspective and in a country where Swedish international cooperation is ongoing.

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SUMMARY IN SWEDISH

Detta examensarbete omfattar två huvudsakliga delar.

Den första delen är en genomgång av de *in situ* jordtvättsmetoder som existerar idag för att få en uppfattning av vilka metoder som verkar praktiskt användbara i Dar es Salaam i Tanzania. Av de 14 metoder som genomgås framstår phytoremediation, dvs. rening med hjälp av växter, och reactive zone remediation, stabilisering av föroreningar så att de inte utgör ett hot, som de två mest lämpade. Resultatet kan dock behöva revideras allteftersom jordtvättningsmetoderna ifråga utvecklas.

Den andra delen i arbetet består av en fältstudie i Dar es Salaam i med syfte att ta reda på hur väl lämpad den lokala floran är som verktyg för jordtvätt genom phytoremediation. Jord- och växtprover har tagits tillsammans och analyserats efter tungmetallinnehåll. Om koncentrationen av tungmetaller i växten var hög jämfört med jorden den växte i ansågs plantan vara intressant ur ett jordreningsperpektiv. En planta, *Alternanthera sissilis* L, hade egenskaper som gör det intressant att fortsätta undersökningen huruvida den kan användas för phytoremediation.

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Eskil Österling

Stockholm, October 2011

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ABSTRACT

This master thesis is a study of the feasibility of in situ soil remediation techniques in Dar es Salaam, Tanzania. It first looks at the existing on site remediation techniques and assesses how feasible they appear in the conditions of Dar es Salaam. Two methods were interpreted as more feasible than others, namely reactive zone remediation and phytoremediation.

The feasibility of phytoremediation was assessed by sampling locally occurring plants and comparing their content of Cu, Pb and Zn with the respective content of the soil they grew in. If the content in the plants were elevated as compared to the soil content, the plant was deemed interesting from a phytoremediation point of view.

Key words: Heavy metal pollution; Remediation; Phytoremediation; Dar es Salaam; Alternanthera sissilis

1. INTRODUCTION

Heavy metal pollution of soils is a growing problem in the developed world today, and vast amounts of money are being used in order to remediate soils so that sites can be used without hazard to human health.

In the developing world of today the scenario that once took place in the now developed world is about to take place, and has to some extent already done so.

Tanzania (Fig 1) is an example of a developing country where industries have polluted the soils and are suspected of continuing to do so. The most prominent of the heavy metal polluting industries are the mining and mining related industries together with the textile dyeing industry.

In Dar es Salaam, the phenomenon of urban agriculture is well spread and a large part of the food consumed in the city is produced within the city itself. Since plants to different degrees take up heavy metals and other contaminants from the soil, it is suspected that pollutants are transferred from the soil to the food chain and further on to the people in the city, where they will cause harm to human health.

Bearing in mind the major role played by this urban agriculture sector in the provision of food for the city, stopping the production is not a feasible option. Instead, there is a need for the remediation of heavy metal polluted soils in Dar es Salaam in order to maintain the production but to stop the transfer of heavy metal pollutants transfer from the soil to humans.

The traditional ways of remediating soils, ways most often used in the developed world today, do not appear to be feasible in Dar es Salaam. The main reasons for this are the high costs involved and the limited access to functioning infrastructure.

This has brought attention to remediation by the use of plants, so called phytoremediation, which has shown promise in many studies and can be carried out at a fraction of the cost of traditional remediation.

This thesis looks into the feasibility of phytoremediation using locally occurring plants.

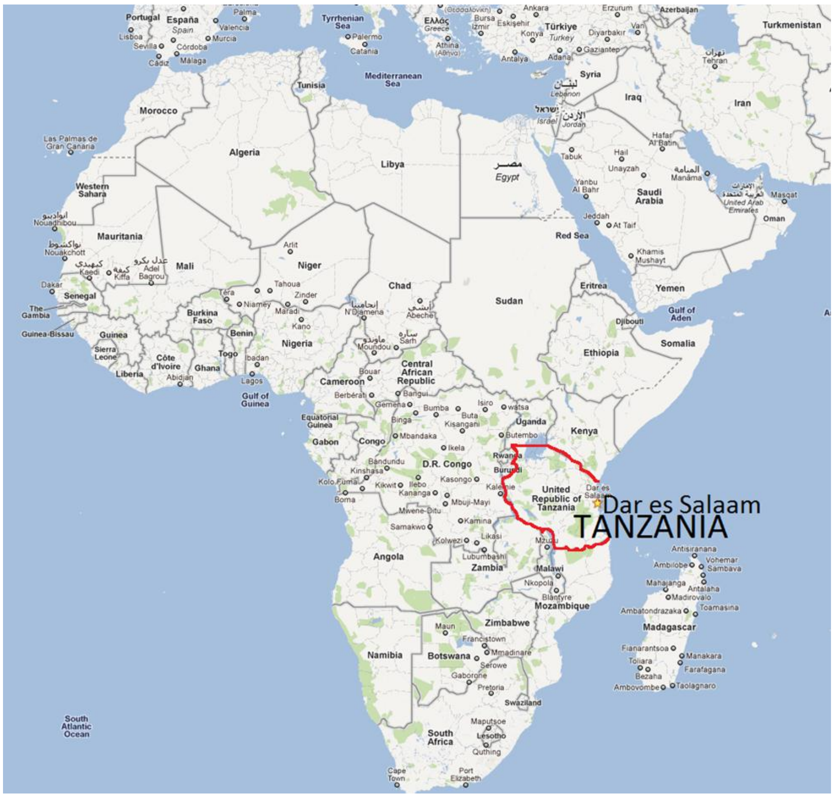

Figure 1: Tanzania and Dar es Salaam (taken from Google Maps).

1.1. Objectives

The main aim of this thesis was to assess the levels of heavy metals in soils in the Msimbazi River catchment in Dar es Salaam and to evaluate how these soils could be remediated, with a focus on the possible role of local plants. Another aim was to assess the potential health hazard of the heavy metal pollution. Specifically, the objectives were:

- To recommend what remediation techniques are most likely to perform well in Dar es Salaam
- To estimate the potential of identified plants for use in phytoremediation
- To establish the quality of agricultural soils, the potential health concerns surrounding urban agriculture and to recommend measures to be taken to avoid health problems

2. Background & State Of The Art

Heavy metals occur naturally in soil and are not always problematic. However, heavy metals in soil arising from man's polluting activities are more commonly taken up by crops to an extent that makes them unhealthy for consumption.

In comparison to organic contaminants metals do not degrade with time (United States Department of Agriculture (USDA), 2000) and are also prone to accumulate in the body of the consumer (Bahemuka & Mubofu, 1999).

2.1. Soil Treatment & Remediation

With the contamination of soils and sediments becoming problematic, methods of treating contaminated soils have developed. The most common of these is often referred to as the dig and dump method.

Figure 2: Landfill site under construction (taken from elements.geoscienceworld.org).

Dig and dump entails excavating contaminated soil so that it can be transported away, most often to be discharged as landfill (Fig 2).The excavated site can either be refurnished with new soil or simply left bare.

The recognition of the need for sustainable development has driven the development of treatments for contaminated soils. For instance the dig and dump method is slowly being abandoned and techniques for remediating soils have developed.

On site, Off site, In situ and Ex situ

When discussing remediation techniques, it is important to be familiar with some concepts:

- On site: Means that the soils are not transported away from the site
- Off site: Means that the soils are transported away from the site of origin, often by trucks, either to be remediated at another location or in order to be disposed off
- In situ: Means that the soil is not excavated
- Ex situ: Means that the soil is excavated to be treated on or off site.

The most practiced remediation technique used is a variation of dig and dump, where the contaminants are washed away from the excavated soil which can then be returned to its original site. This is often considered costly, with prices ranging from US$ 10 to US$ 100/ m^3 for on site treatment, and US$ 30 to US$ 300 / m^3 for off site treatment according to the USDA (2000). In developing countries, the cost barrier often makes this technique unfeasible.

Remediating soils does not necessarily imply removing the contaminants from it. By using areas with polluted soil for purposes other than agriculture, by stabilizing heavy metals through aeration, by using suitable crops, by changing the pH values in order for the metal contaminants to be rendered harmless in the ground (USDA, 2000) and other measures, heavy metals can be managed without removal and without causing harm. Since heavy metals do not decay by themselves, intercepting groundwater flow by the use of barriers could be another way of managing heavy metal pollution, keeping the contaminant in one place over an indefinite period of time (according to Dr Dongreyl Ryu, in the lecture Hydrological Processes 2, May 26 2010, The University of Melbourne).

2.1.1. *Sustainable Remediation*

Today, sustainable soil remediation is quite a large research field and even though much of this research has been promising, commercial appliance is still rare. The techniques mentioned above are sometimes referred to as sustainable and sometimes not. A technique that has been recommended for use in Dar es Salaam is the remediation of soils using plants, so called phytoremediation (Mwegoha, 2008).

2.1.2. *Phytoremediation*

Using plants for remediation must be seen in a medium to long term perspective in comparison to traditional site remediation. However, considering the competitive cost of this method, starting at US$ 0.05 / m^3 (USDA, 2000), and its savings of around 200,000 euros / ha (Zodrow, 1999), this is a method that is expected to grow in popularity.

Whereas natural dilution processes can take hundreds of years to remediate a contaminated site and could have negative effects on human health, the cultivating and harvesting of plants that, to a very high degree accumulate heavy metals (so called hyperaccumulators) could reduce the amounts of harmful heavy metals in the soil below recommended limits in as little as less than 10 years (USDA, 2000).

Plants have five different properties which can be used to treat soils and which can be more or less tailored in order to fit the specific soil, contamination and local circumstances. These five properties which give rise to processes of phytoremediation are; phytoextraction, phytotransformation, phytostabilization, phytostimulated bioremediation and rhizofiltration, with the two most practised processes being phytoextraction and phytostabilization.

Phytoextraction

Phytoextraction is the best documented of the processes, and it is also the easiest to conceptualize. The technique means that the soil contaminants are absorbed into the plant by the roots and transported up to the above ground part of the plant, which can be harvested and transported away along with the contaminants in question. In order for a plant to be used for phytoremediation it has to:

- Be able to grow in the contaminated soil
- Be able to absorb a high concentration of the contaminants in the root zone and translocate them to the above ground part of the plant
- Grow fast enough
- Become big enough

The final destiny of the contaminants and the harvested plants remains an open question. Different suggestions have included commercial extraction of the contaminants and bio energy production.

Phytostabilization

With phytostabilization the contaminants are not removed from the site, but instead they are immobilized to prevent them from spreading and contaminating further. By choosing plants that can survive the contaminated conditions and with active and well-adjusted irrigation and fertilizers, plants may grow where they previously could not due to the contaminants and hence they can stop the spread of contaminants via the ground water (Salt et al., 1995).

2.2. Dar es Salaam

Dar es Salaam is situated on the ocean front in the middle of Tanzania (Fig 1) and is a city of great expansion, both physically and in respect to its population. The population of Dar es Salaam has increased ten fold over the last half century, from less than 300,000 in 1967 (Sawio, 1998) to over 3 million in 2007 (Kironde, 2006).

The city is predominated by dwellings, small scale businesses such as food shops, clothing shops, fruit stands, hairdressers, bars, restaurants and internet cafés and small scale industries ranging from textile production, woodcrafts, tile production, car washers and garages to tourism. According to Jacobi et al, (2000) about 30 % of the dwellings are attached to a sewerage system, which means that most of the people use on-site sanitation facilities.

2.2.1. *Industrial History*

Dar es Salaams industrial history is made up of three different eras. The first was under the colonial rule that ended in the 1960's, the second was one of nationalization which lasted until the 1990's and the third was one of privatization in the 1990's and early 2000's (Mbuligwe & Kaseva, 2006). Today the industrial sector in Dar es Salaam just like in Tanzania in general is largely privatised (BBC, 2011).

2.2.2. *Land Use in Dar es Salaam*

The total area of land used for agriculture within Dar es Salaam has been estimated in two different studies. Sawio (2008) claims that 110 850 ha are used for crop production, whereas Dongus (2001) claim that 650 ha are used for cultivation. The crops which are cultivated are coconuts, cashew, pineapples, vegetables, mangoes, cassava, rice, maize, bananas and sweet potatoes. About 350 000 tonnes of food are produced in urban Dar es Salaam every year according to Sawio (2008). The keeping of livestock, especially in the peri-urban areas, accounts for about one third of the consumption in the city (Sawio, 2008).

According to Kironde (2006), The National Human Settlements Development Policy considers urban agriculture to have a negative impact upon the city, in terms of its health, the pollution of water and the creation of safety hazards. Therefore it is not valued by city officials.

However, urban agriculture is nowadays officially recognised as a way of decreasing poverty and increasing food supply among the poor in Dar es Salaam (Sawio, 2008).

2.2.3. *Discharge Practice & Policy*

Mbuligwe & Kaseva (2006) state that in respect of industrial solid waste, 95 % is currently being disposed of as landfill, with more than 90 % of that, or almost 40,000 tonnes a year, coming from food and beverage production. As most of this could be recycled, the biggest problem reported is that hazardous waste is not separated from recyclable waste. If this was done, recycling could be increased, and solid waste treatment could be carried out in a more efficient and cost effective way. Mbuligwe & Kaseva also state that there is something of a trend among local industries to start reusing waste water.

Sawio (2008) claims that more than 3000 tonnes of solid waste is produced each day in Dar es Salaam, out of which only 40-45 % is processed. He compares this to the situation in 1992 when only 2-3 % was being processed. Air pollution, due to heavy traffic, is also apparently a major problem in Dar es Salaam (Sawio, 2008).

Mbuligwe & Kaseva (2006) suggest that very little is done in order to manage industrial waste and that since the large scale privatisation of industry in the 1990's the possibility for the authorities to control emissions and outlets has more or less vanished.

It was noted that there seemed to be no official procedure for the collection of used plastic objects, like plastic bottles and plastic bags. Yet, recycling seemed to exist since private companies are paying money for returned plastic bottles, resulting in bottles that are disposed of in public being regularly collected by plastic gatherers.

2.2.4. *Dumping Sites*

Two major dumping sites have received the bulk of Dar es Salaam's industrial waste; Vingunguti and Mbagala, and neither of them treat hazardous components before they are used as landfill. The Vingunguti dumping site is now closed and one of the reasons for this is that it is polluting the urban environment and the Msimbazi River. The dumping sites are neither lined nor covered, which makes it possible for effluents to leach into the groundwater downwards into the catchment (Mbuligwe & Kaseva, 2006). However, Mbuligwe & Kaseva do not specifically mention heavy metals, and measurements in respect of these in soils close to the dumping sites have not been made.

2.2.5. *Heavy Metal Pollution in Dar es Salaam*

In Soil

Measurements of heavy metal contamination in the soils of Dar es Salaam have been made, and some are specifically carried out with urban agriculture and the levels of heavy metals in crops in mind.

In tests carried out in 1986, the levels of heavy metals in the sediments of the Msimbazi River were not considered to be elevated (Ak'habuhaya & Lodenius, 1988). In 1992, heavy metal levels in the bay area of Dar es Salaam were considered to be elevated (Machiwa, 1992).

In more recent studies, sediments on the downstream side and adjacent to a textile dyeing mill had high levels of Al, Zn, Fe, Pb, Cd, Cu, Cr, Sn and Ni (Kruitwagen et al., 2008), with some levels more than 100 times the WHO and FAO limits (Bahemuka & Mubofu, 1999). However, further downstream the levels were, in general, assessed as being far from dangerous (Kruitwagen et al., 2008).

It is suspected that the increasingly heavy traffic in Dar es Salaam is also spreading heavy metals throughout the city (Mbuligwe & Kassenga, 1997) though it is uncertain as to whether this will have any significant effect on the soil quality.

In the northeast, Tanzania borders Uganda, where samples were taken from soils nearby roads with heavy traffic in order to see if the airborne pollution from traffic was affecting the amount of heavy metals in the soil. The result was that a high level of lead was discovered in the soil and that the level decreased with the distance from the road, until it had no measurable effect 30 meters from the road (Nabulo et al., 2006).

In a study on heavy metal levels in vegetables irrigated with wastewater in Harare, Zimbabwe, it was concluded that the levels exceeded EU and UK limits for agricultural soils (Muchuweti et al., 2006).

In Plants

Bahemuka and Mubofu (1999) discovered that cowpea leaves and African spinach, and to some extent Chinese cabbage and lettuce, irrigated along the Msimbazi and Sinza river banks in Dar es Salaam contained levels of lead and cadmium higher than FAO and WHO permissible limits. They went on to recommend that consumption of these is kept low and that continued research on other crops, soils and sediments is undertaken.

In the study in Uganda of heavy metals in crops growing close to roads, in Kampala City the highest concentration of heavy metals were measured in the leaves and the lowest in the fruits (Nabulo et al., 2006).

Studies in India on heavy metals in crops irrigated with wastewater showed high levels of heavy metals in spinach (Arora et al., 2008).

2.2.6. *Remediation in Dar es Salaam*

No soil remediation has been performed in Dar es Salaam, but some research has been undertaken on the topic.

Phytoremediation

Mwegoha (2008) considered phytoremediation to be a remediation technique that is likely to be efficient in Dar es Salaam, especially due to its low cost, and recommended further studies on the subject. Mwegoha recommended focusing on pesticides, heavy metals and the rehabilitation of dumping sites and the identification of locally available plants and the final disposal of biomass containing heavy metals.

The benefits of using locally occurring plants are amongst others:

- That the introduction of alien species might cause a conflict in the local eco-system and is often regulated by legislation
- That local species are adapted to the local soils and to the climate
- Their availability

2.3. Study Area

Soil and plant samples were gathered in Dar es Salaam and were analysed at the Ardhi University. The aim was to see the correlation of heavy metal content between the soil and the plant in order to get an idea as to whether the plants, wild or farmed, had potential for application in phytoremediation.

Three sampling sites where chosen with respect to:

- Likeliness of contamination
- No known research having been carried out in the area before
- Urban agriculture being practised on the site or in its proximity

The places were (Fig 3):

- Tabata / Kigogo, along the river
- Vingunguti, next to the dumping site on the Msimbazi River
- Mabibo; agricultural field

A larger format of the map (Fig 3) is enclosed in Appendix II

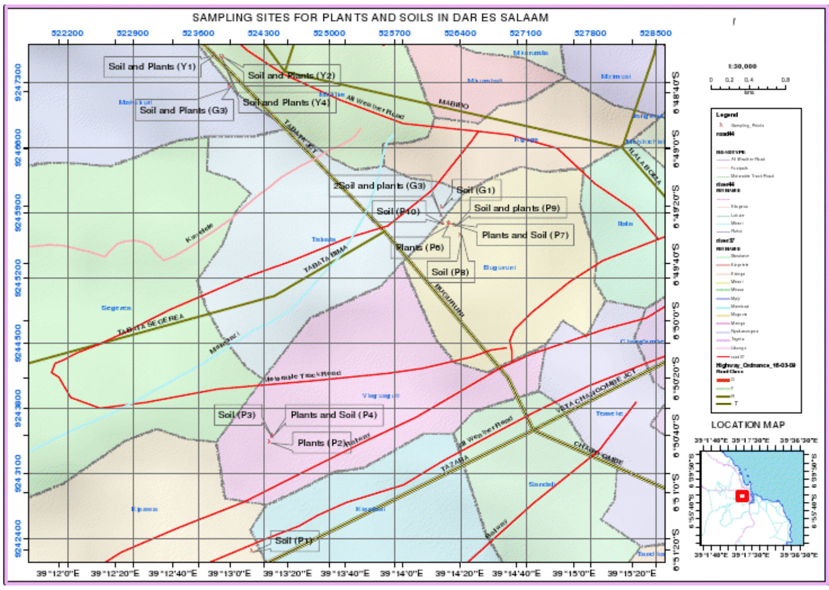

Figure 3: Map illustrating samplings sites.

Vingunguti

The Vingunguti dumping site stretches along the Msimbazi River in the Vingunguti area. It has a road passing by it and across the river just next to the site. When we went there to collect samples, the river crossing was being furnished with a bridge, which meant that the original soil and sediments of the site were all mixed up and partially replaced by alien soils brought in for the construction. Also, on our first visit to the site, the road was closed about 200 m away from it and it was deemed too risky to leave the car behind unattended.

Tabata

The Tabata sample series is from the area around an unnamed river running through Tabata not far from Kigogo. The samples were taken all along this river bank and in its close proximity where agriculture was practised. The area was expected to be polluted from a former dumping site and from the garages that make up the Tabata area today. At the time of taking the samples the river was nearly dry and could in most places easily be walked across without getting ones shoes wet. A man with a bucket continuously fetched water from the river for irrigation. Hence, there was no doubt as to where the water for irrigating the fields came from. At the tip of the sampling series, the unnamed river flowed into and merged with the Msimbazi River.

Mabibo

The Mabibo sample series is from a field where African spinach (*Amaranthus blitum* Linn) is commercially cultivated, adjacent to the Nelson Mandela Road, a BP gas station and a river. The name of the river was not possible to find out. The plants are irrigated with water from the river, to a large extent by pumping water from it. However, some parts are irrigated with hand carried buckets. During the sample collection, the field was solely used for growing African spinach.

3. Materials & Methods

The two main parts of this thesis were undertaken individually and this chapter explains how they were performed.

3.1. Evaluation of Remediation Techniques

Textbooks and previous studies on remediation techniques were studied and information was extracted and categorized in order to make a scheme whereby the different techniques could be compared in a numerical way

The remediation techniques were evaluated according to three main properties:

- Cost
- Efficiency
- Feasibility

The techniques were graded in respect of each of the properties mentioned above, with a grade from 1 to 5. For example, 5 were awarded to the techniques which were very efficient, to the techniques which were very feasible and to the techniques with a very low cost.

As the grades given to each remediation technique in respect of each property were not of the same reliability, the reliability of each given grade was itself graded, with a grade from 1 to 5. For example, 1 was awarded where the given grade had to be based mostly on assumptions about the property and 5 points were awarded where the given grade was based upon detailed information about the property.

Hence, for every remediation technique three properties were evaluated and were given two digits each. These two digits were multiplied one with another to give one product for each property, and these three products were added up to give one total sum for every remediation technique.

After all the remediation techniques had received their final total points they were compared with each other and listed according to those points. The reason behind this was to see if any other remediation techniques apart from phytoremediation seemed appropriate in Dar es Salaam.

Using this method of evaluation enables a focus to be placed on the techniques that gather a high number of points, but it says little or nothing at all about the techniques that receive a low score. Perhaps these low scoring techniques could turn out later to be the most promising ones. However, from what could be gathered at this point in time, the methods with the highest points appeared to be the most promising (See Appendix I for a detailed description of the assessment method and the detailed assessments made of the remediation techniques).

3.2. Methods & Tools

For each sample set taken (soil and / or plant) the following information was collected:

- GPS position
- Information regarding if plant or soil
- Short description of the sampling site

Please see Appendix II for the detailed list.

Figure 4: Pre-drying of soil and plant samples.

3.2.1. *Soil Samples*

The soil samples were collected from the top 10 cm of the soil layers using wooden spades, and then placed in aluminium foil wrapping and put into separate plastic bags. The tools were cleaned thoroughly between the collection of every sample. The samples were left to pre-dry in open air for between 48 hours and up to one week *(Fig 4)*. The samples that dried into lumps were separated into granular like particles before all samples were dried completely using a hot air oven of the brand Toshniwal at 70 °C. The oven did not have a thermostat, which made it difficult to know if the temperature remained at exactly 70 °C and therefore the temperature was regularly checked by inserting an external thermometer through an opening on the top of the oven. After the drying procedure the samples were grounded and sieved through a 2 mm nylon sieve and placed in plastic containers.

The analysed properties were:

- Heavy metal content of:
  - Zinc
  - Copper
  - Lead
- pH
- Salinity (electric conductivity)
- Organic matter (OM)
- Particle size distribution

Mean values and standard deviations were calculated for these properties using the functions in Microsoft Excel.

Heavy Metal Content

For determination of the heavy metal content, 0.5 grams of the dried soil sample, with an error margin +- 1 % was put into a graded test tube and mixed with 2 ml of HNO3:HCl (1:3, V/V). The samples were then put onto a hotplate at 95°C for one hour. Sample weights were measured with a Boeco weighing scale and digestion was done with a Hach 200 DRB hotplate.

After cooling the samples were diluted with 10 ml of distilled-deionised water, shaken, filtered and put into plastic containers with lids and stored in a fridge until analysed. Heavy metal analysis was done using an atomic absorption spectrometer (AAS) (Perkin Elmer AAnalyst 100 with HGA 850 Graphite Furnace).

Salinity and pH

Electric conductivity and pH in soil samples were measured using HACH equipment. Salinity was estimated from the electric conductivity. Selected samples were duplicated to assess the accuracy of the analysis.

Organic Matter

Organic matter (OM) content was measured by weighing an amount of dry soil, between 30 and 60 grams, in a crucible, burning the sample in a furnace at 440°C overnight and weighing again. The weight difference, minus the weight of the crucible for both weights, was calculated to be the OM.

Particle Size Distribution

Particle size distribution was measured using a sieve stalk and a mechanical sieve. This was preceded by breaking the lumps in the oven dried sample by hand.

3.2.2. *Plant Sampling*

Plant samples were taken from the same spots as the soil samples, so that a plant sample corresponded to a specific soil sample. The entire plant, or as much of the plant as possible, was collected. The plant samples were put into plastic bags and brought back to the laboratory where they were cleaned with tap water to remove soil remnants and other alien particles. The plants were then rinsed with deionised water and left to pre-dry in open air for one week. The plants were then cut and separated into the following parts:

- Above Ground
- Roots
- Edible part (for vegetables)

Once separated, the samples were put into ceramic crucibles and left over night in a hot air oven (Toshniwal brand) at 80 °C. They were then grounded to a powder using mortar and pestle and sieved using a 2 mm plastic mesh. The samples were then put into test tubes. If 1 g or more was available, 1.00 g was put into the tube. Where there was less than 1 g left, the entire remaining sample was weighed and put into a tube. 5 ml of Aqua Regia:$HClO_4$ (5:1 V/V) was added to each test tube, and the tubes were put into a hot air oven (Toshniwal) at 120 °C until complete digestion had taken place. After drying in the oven, the samples were left to cool and thereafter diluted with 10 ml of deionised water. When the samples had completely dissolved in the water they were filtered and put into plastic containers with lids, the test tubes were then rinsed with deionised water which was filtered again and added to the sample. The plastic containers containing the dissolved samples were stored in a fridge ready for final analysis using AAS (Perkin Elmer AAnalyst 100 with HGA 850 Graphite Furnace). The reaction between the plant sample and the acids would in some cases appear to be out of control, which makes it doubtful that the test results could be relied on entirely. Instead, the results should be interpreted as indicative.

3.2.3. *Bioconcentration Factor*

In order to determine the contaminant uptake and translocation factor of the plant, the bioconcentration factors (BCF) were determined for the plant samples.

4. RESULTS

The results of the thesis are presented without comments under the following two headings.

4.1. Remediation Evaluation

In the assessment of remediation techniques two methods received significantly higher scores than the others. Most points were received by reactive zone remediation (34 points), closely followed by phytoremediation (33 points). Vacuum enhanced recovery and reactive walls were next in line (both at 26 points) (Fig 5).

Both reactive zone remediation and phytoremediation received most of their points from the fact that they appeared low cost. Please see Appendix I for in detail assessments and accounting in respect of point distribution.

4.1.1. *Reactive Zone Remediation*

Reactive zone remediation is the use of a reactive agent that is mixed into the saturated soil in order to stabilise, immobilise or transform the contaminants so that they become harmless (Suthersan, 1997).

4.2. Sampling & Analysis

For detailed description of the sampling sites, please see the appendix.

4.2.1. *Soil*

<u>*Vingunguti Dump Site*</u>

The concentration in soil of Cu, Pb and Zn in the Vingunguti (Fig 6, 7 and 8), Mabibo (Fig 9, 10 and 11) and Tabata / Kigogo (Fig 12, 13 and 14) areas are shown along with the Swedish and Tanzanian limits for the respective metal.

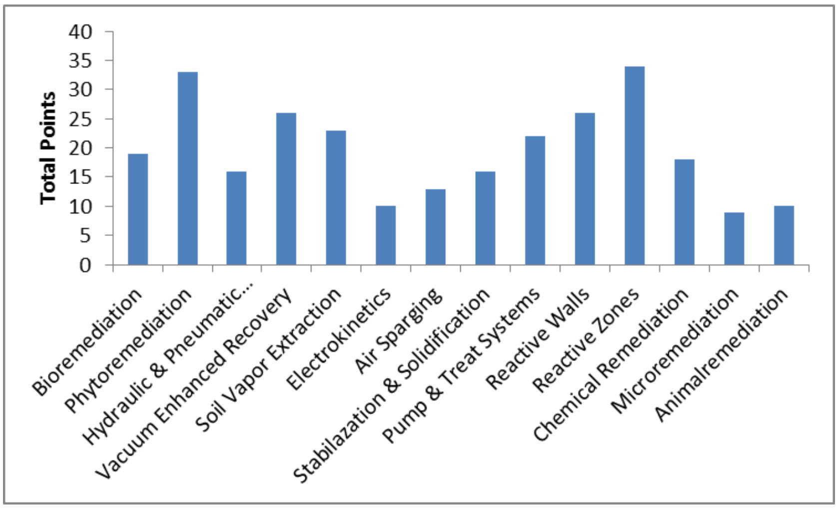

Figure 5: Evaluation of remediation techniques.

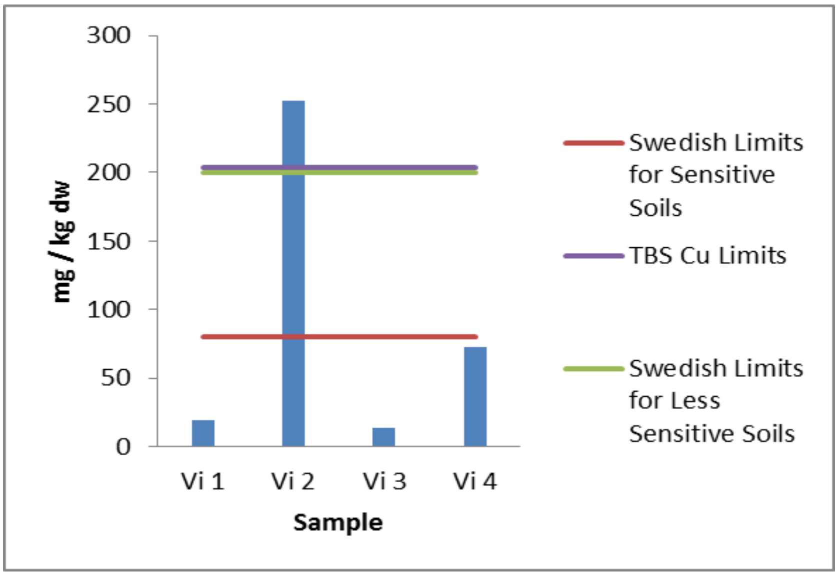

Figure 6: Cu content in soil, Vingunguti area.

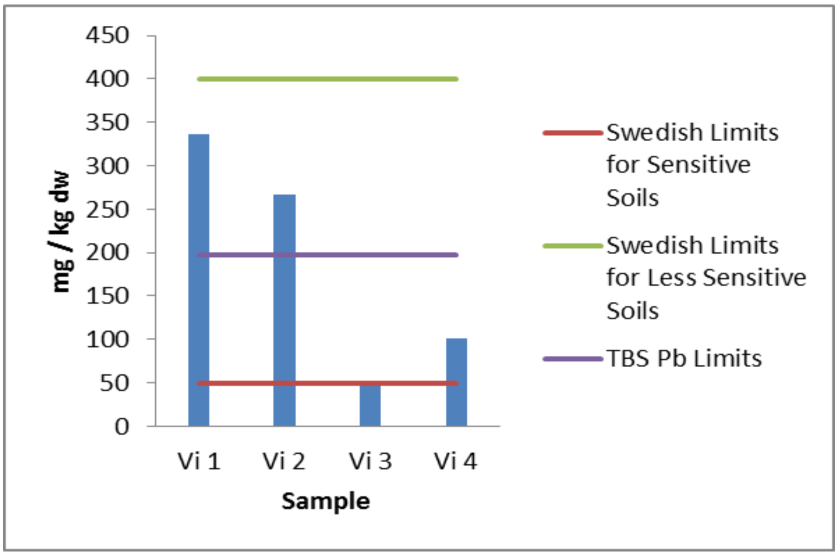

Figure 7: Pb content in soil, Vingunguti area.

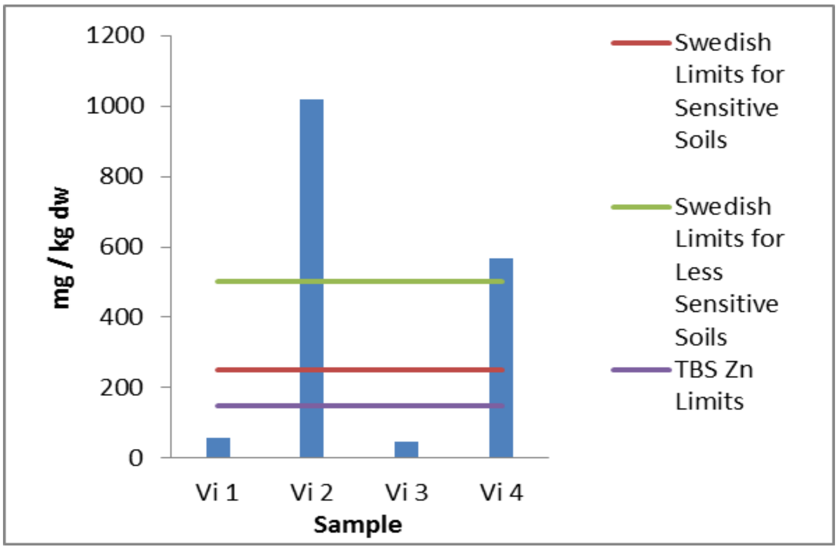

Figure 8: Zn content in soil, Vingunguti area.

Mean Values & Standard Variations

The mean values and standard deviations of Cu, Pb and Zn content for the respective samples were calculated and compared to the Tanzanian limits (Fig. 15).

Salinity and pH

The highest level of salinity of the soil samples was about 10 times as high as the lowest (Fig. 16) and the pH varied between 6 and 11 (Fig. 17).

Organic Matter

All the samples had an organic matter content below 20 %, with the highest around 18 % and the lowest below 1 % (Fig. 18).

Particle Size Distribution

There was a predominance of clay and silt in the soil samples. (Fig. 19).

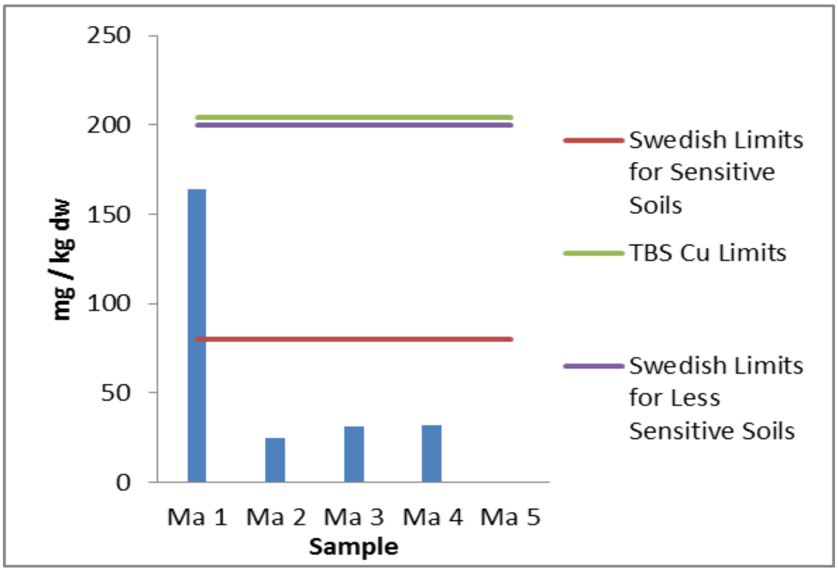

Figure 9: Cu content in soil, Mabibo area.

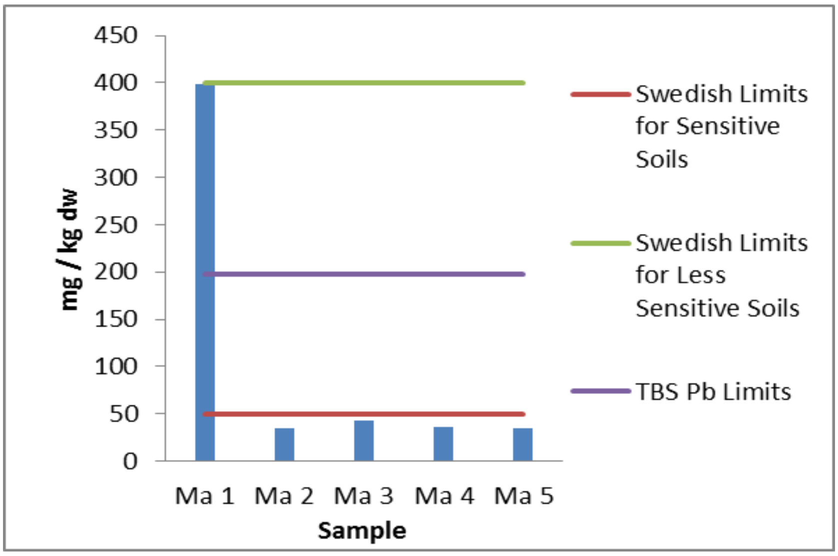

Figure 10: Pb content in soil, Mabibo area.

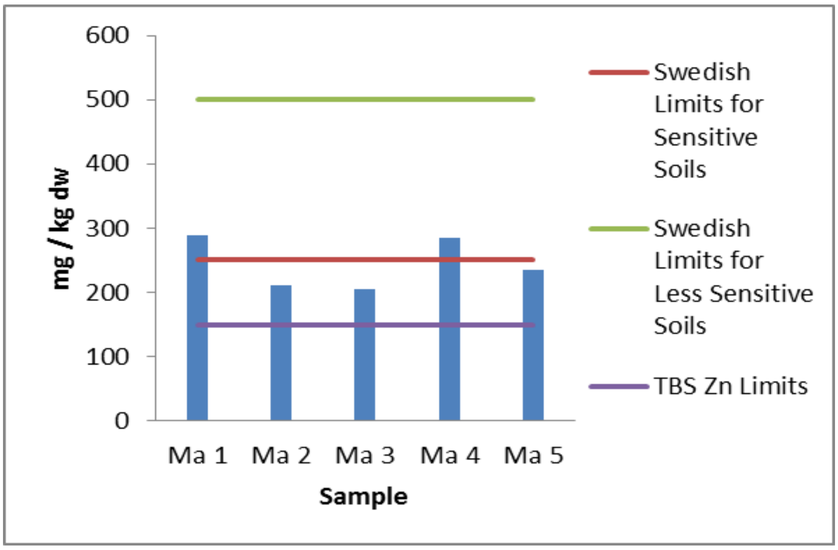

Figure 11: Zn content in soil, Mabibo area.

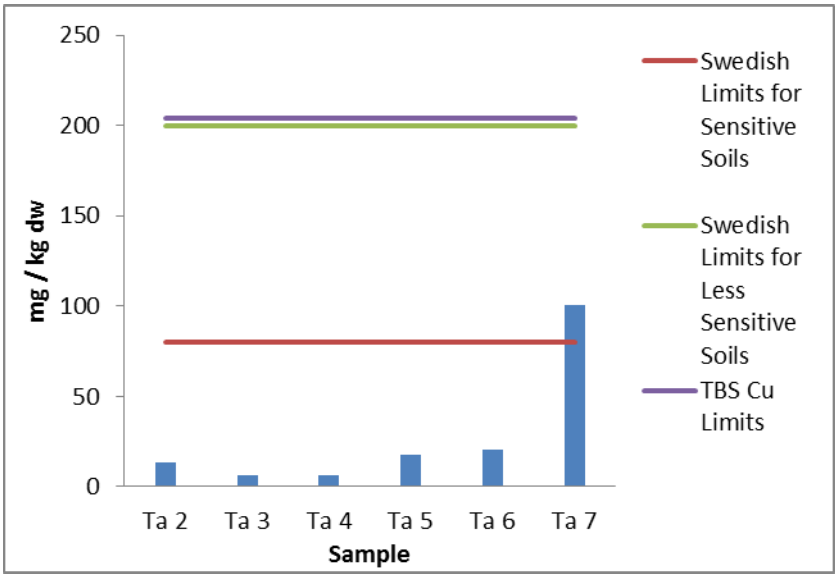

Figure 12: Cu content in soil, Tabata area.

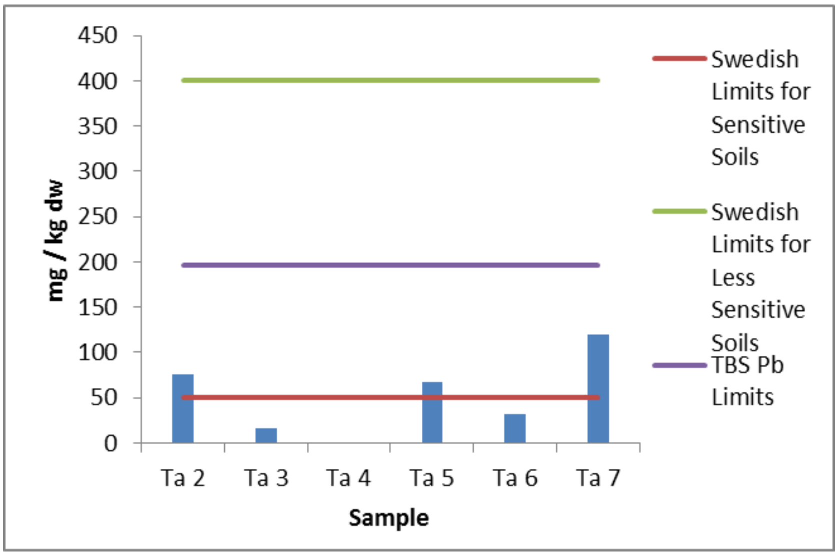

Figure 13: Pb content in soil, Tabata area.

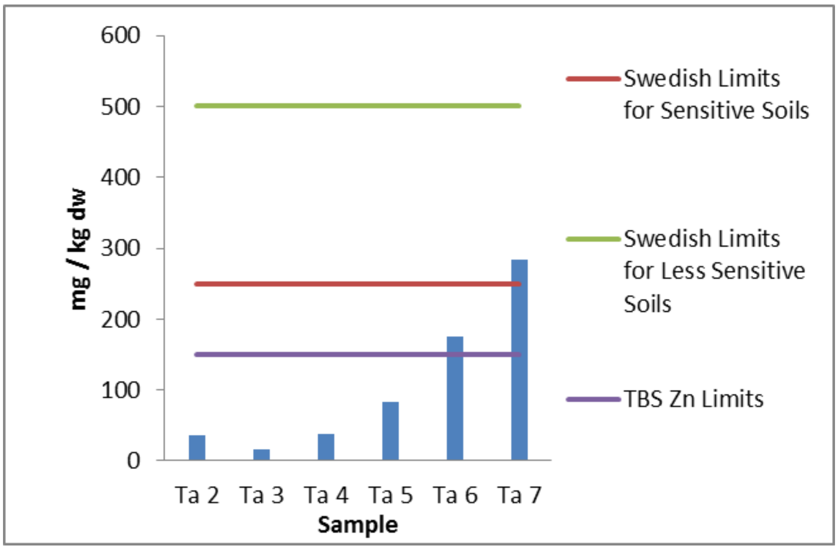

Figure 14: Zn content in soil, Tabata area.

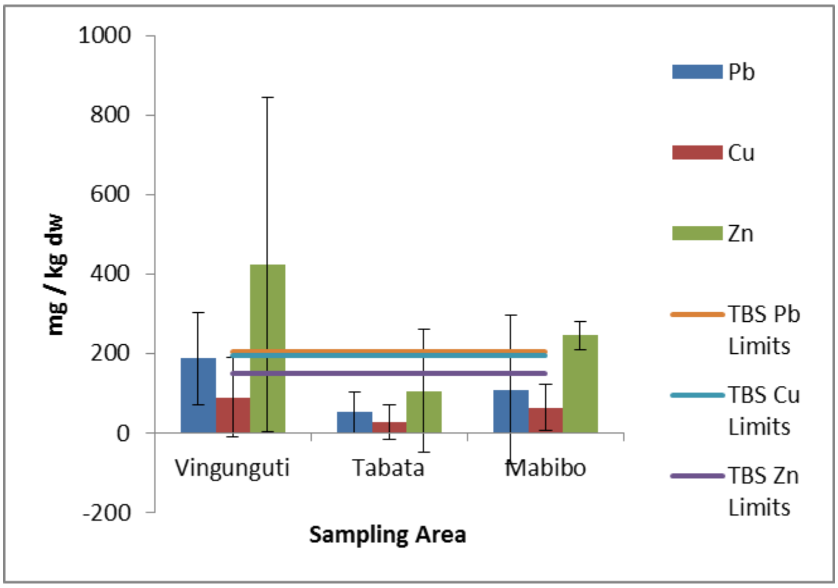

Figure 15: Showing the mean concentration of Cu, Pb and Zn for the soil samples over the areas where they were collected, along with the standard deviations.

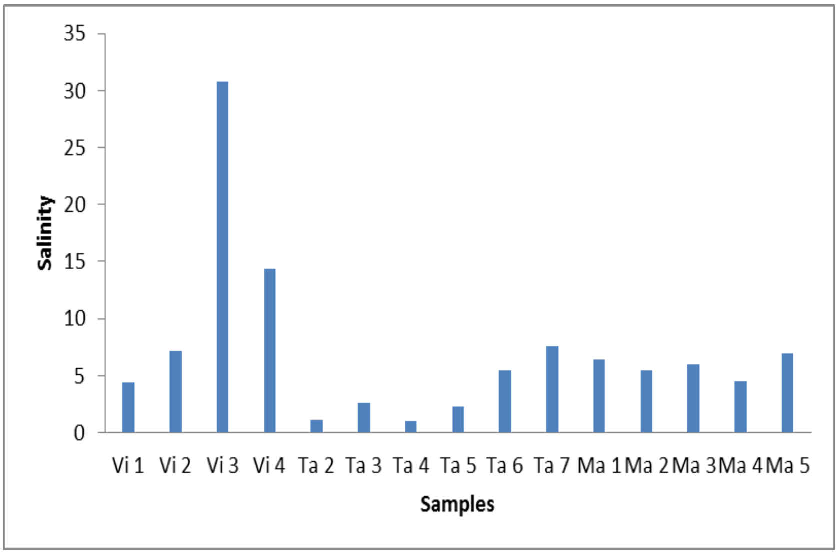

Figure 16: Salinity in Soil Samples.

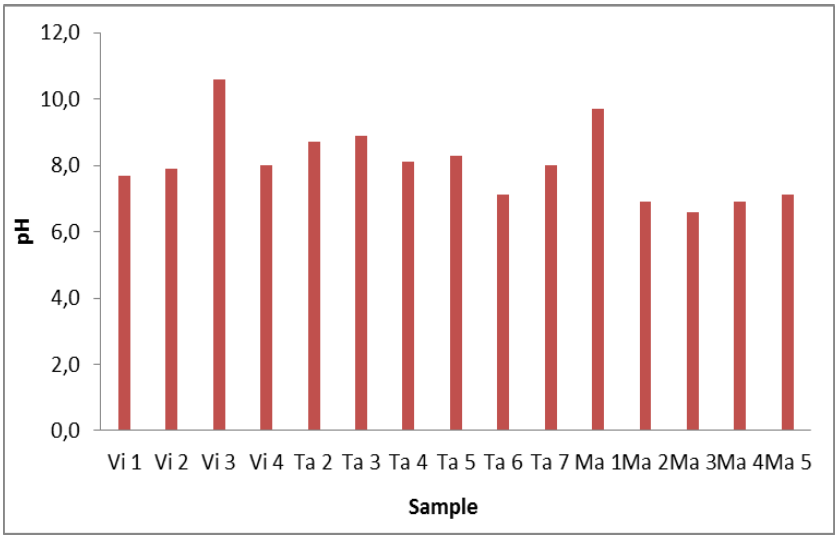

Figure 17: pH in Soil Samples.

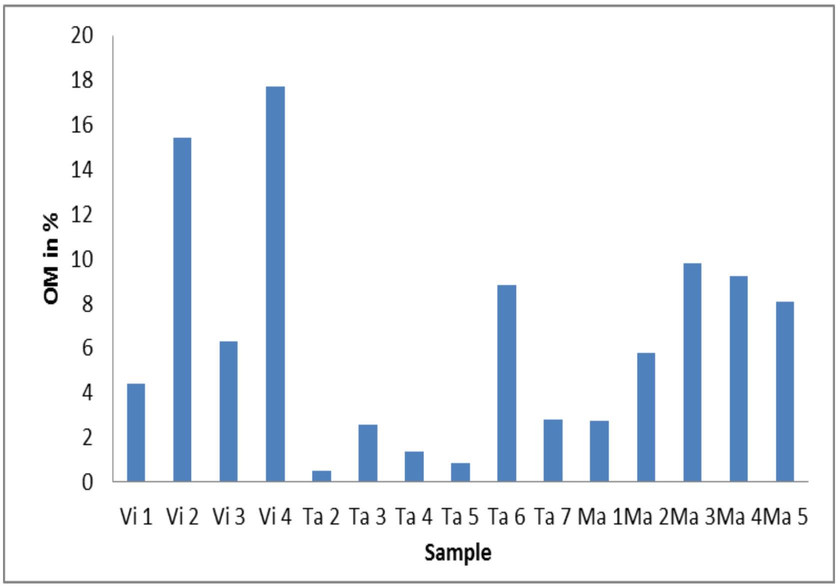

Figure 18: Organic matter in soil samples.

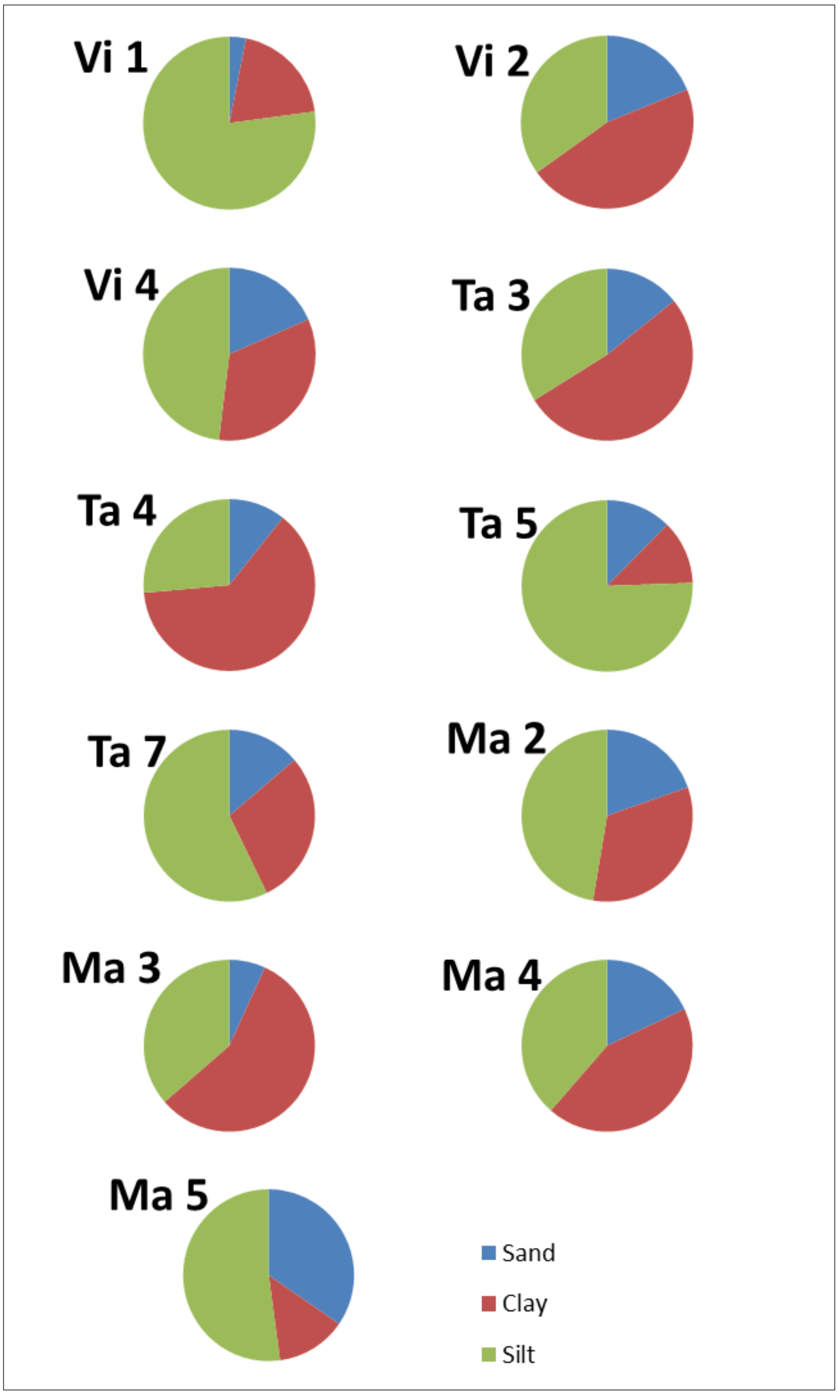

Figure 19: Soil Particle Distribution.

4.2.2. *Plants*

The Zn, Pb and Cu concentrations of the plant samples are shown together with the WHO and FAO recommended limits for consumable vegetables (Fig. 20, 21 and 22).

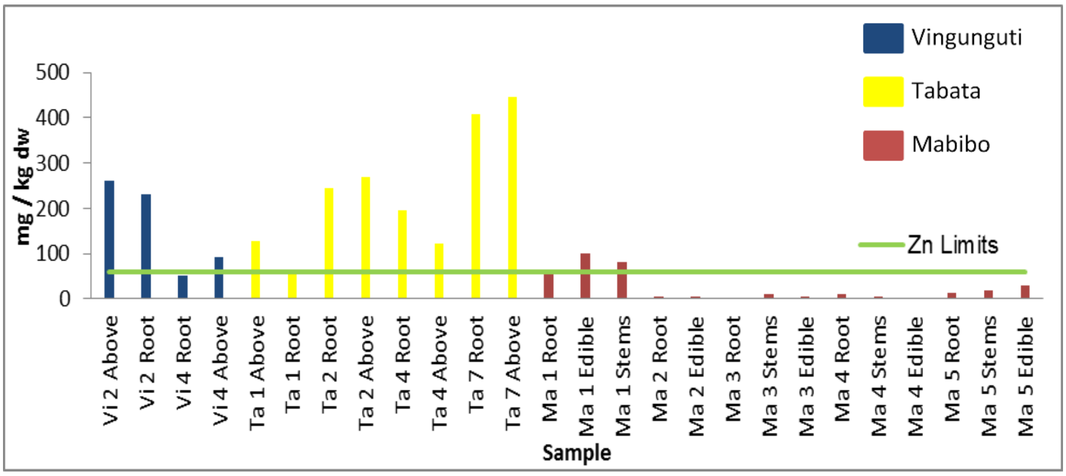

Figure 20: Zn content in plant samples, mg / kg dw.

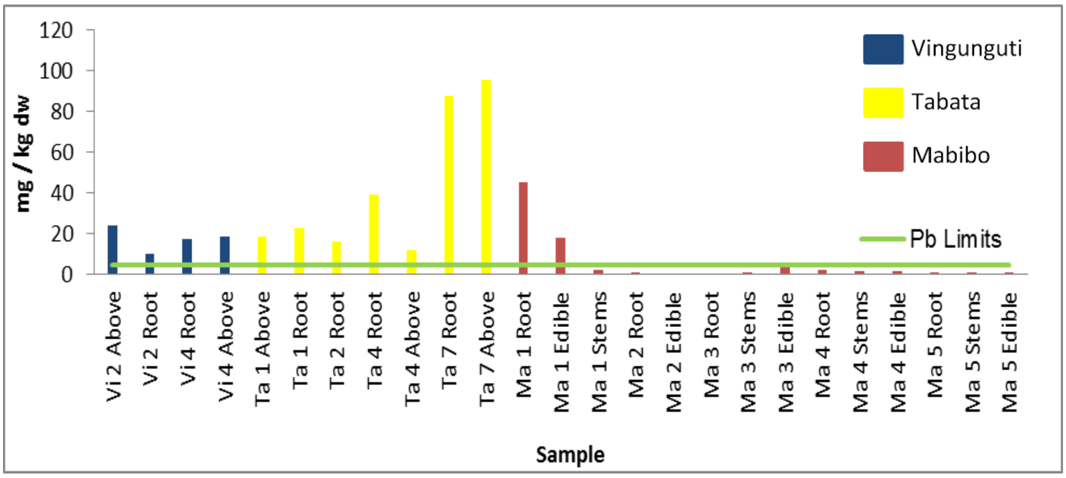

Figure 21: Pb content in plant samples, mg / kg dw.

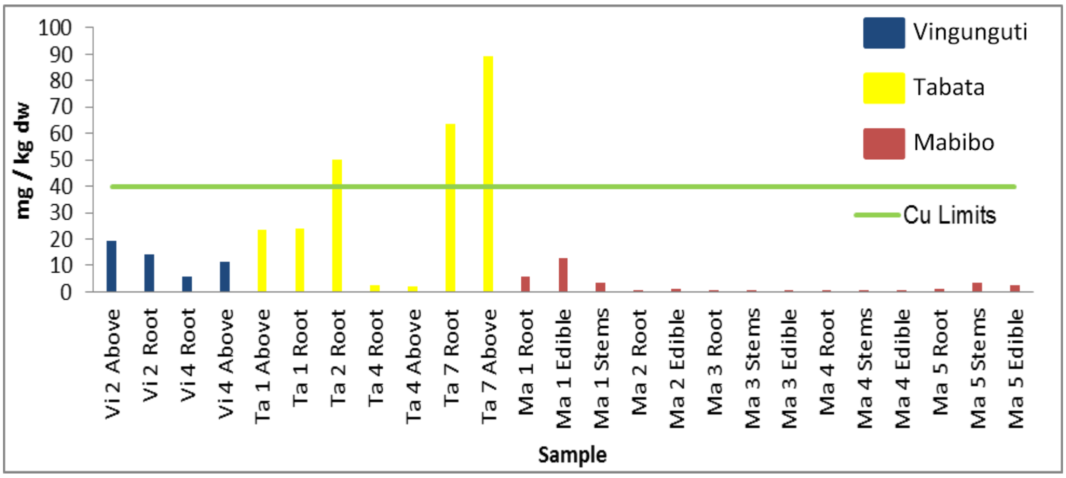

Figure 22: Cu content in plant samples, mg / kg dw.

4.2.3. *BCF*

The bioconcentration factors for Cu, Pb and Zn are shown in figures 23, 24 and 25.

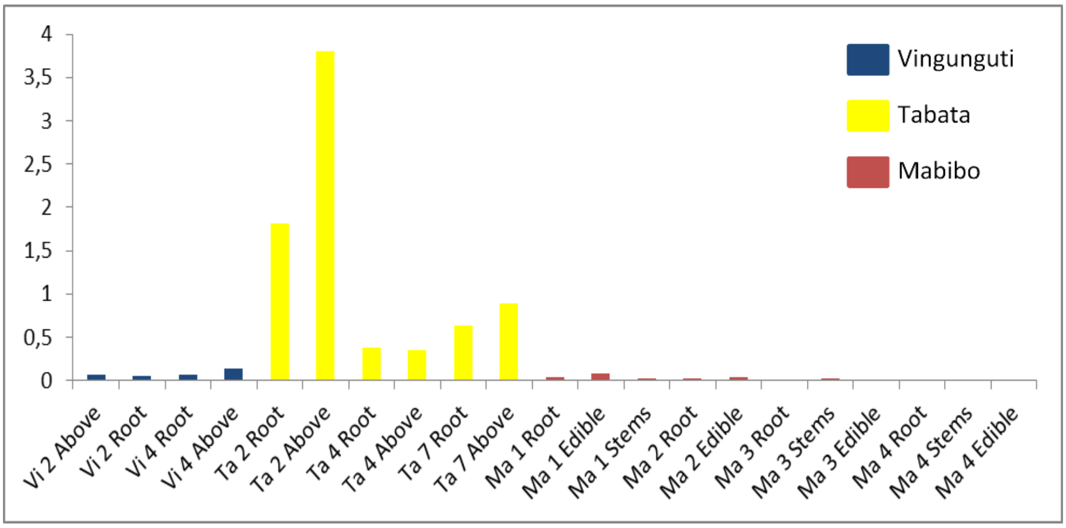

Figure 23: BCF Cu.

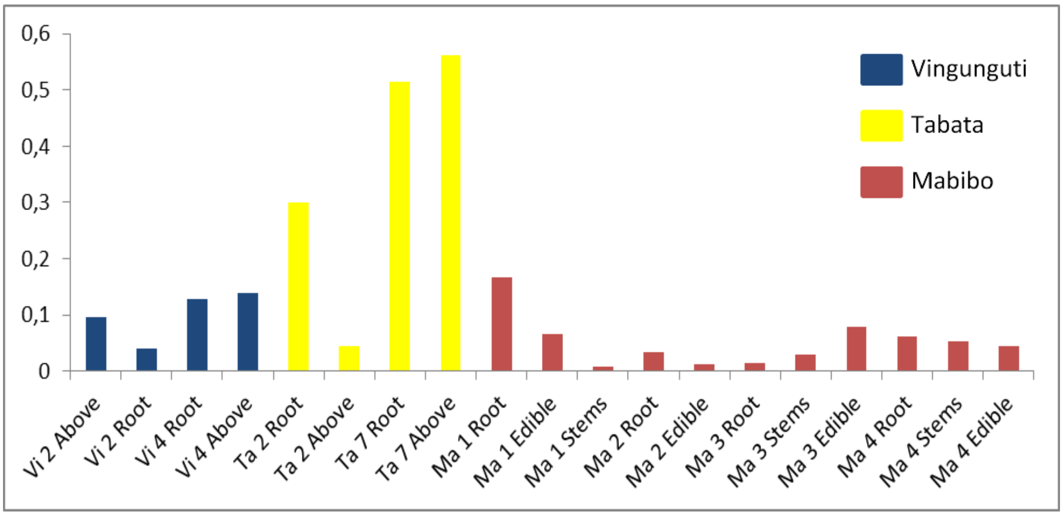

Figure 24: BCF Pb.

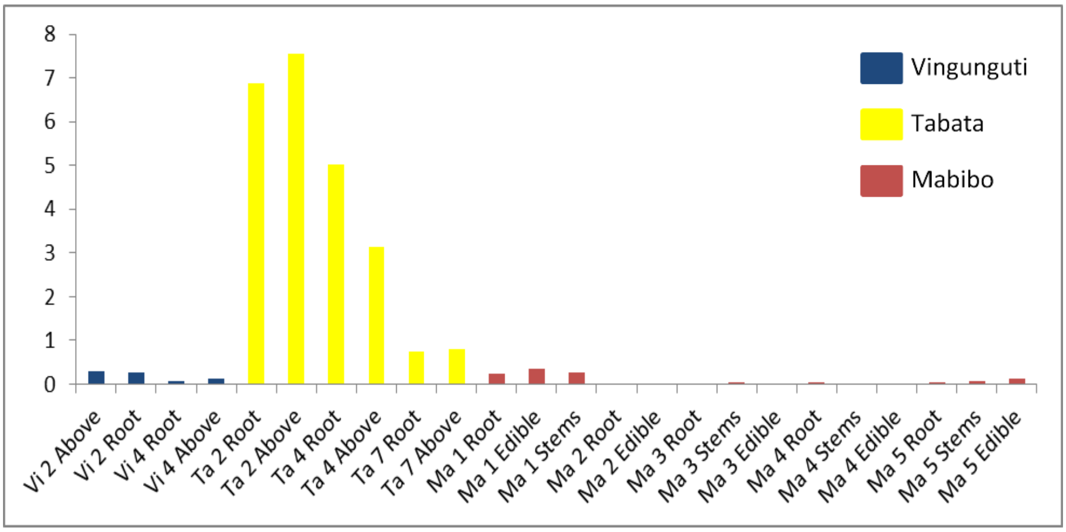

Figure 25: BCF Zn.

5. DISCUSSION

In this chapter the results in the previous chapter are commented upon and discussed.

5.1. Remediation Evaluation

Two methods of remediation that stand out clearly as more feasible than others are reactive zone remediation (RZR) and phytoremediation.

Reactive zone remediation appears to have both benefits and drawbacks compared to phytoremediation. Its biggest benefit is probably that it appears to be a less complicated procedure to use whilst its biggest drawback is that continuous control of the chemical reactions is needed (Suthersan, 1997).

In the material which was studied concerning remediation techniques, reactive zone remediation was said to be at an experimental stage, which enables much interesting research to be carried out in respect of it.

As hypothesised, phytoremediation seems to be feasible in Dar es Salaam. Reactive zone remediation and phytoremediation received almost exactly the same number of points in the evaluation, and in each case most of these came from the likelihood of the techniques being economically viable.

5.2. Study Area / Sampling & Analysis Discussion

Not all of the results from the sampling analysis appear entirely reliable. Some of the duplicate samples analysed showed differing results. Most likely, the main reason for this is that upon preparing some of the samples of the first sample batch, there was a heavy chemical reaction which, it is suspected, disturbed the properties of the sample.

However, even when the results from the analysing procedure were diverse, they would still be inclined towards the same direction. Therefore it is considered that the quality of the results is good enough to enable a conclusion to be drawn in respect of this study.

5.2.1. *Soil*

There was a great variation of heavy metal concentration in the analysed soils.

In most samples the levels were around the limits set by the Swedish Environmental Protection Agency (2009) and the Tanzania Bureau of Standards in the National Environmental Standards Compendium. Not surprisingly, the highest contents of heavy metals were in the samples from the soils and sediments adjacent to the Vingunguti dumping site. In the sediment of a leachate rivulet running straight from the dumping site into the Msimbazi River, the highest pH of just above 10 was measured. This sample also had the highest salinity content. The sample showed no particularities in any other respect, except for its dark colour, bordering on black. Notably, the OM was not elevated as compared to other samples.

Some, but not extensive, agricultural activity was seen in this area. However, further investigation would be needed in order to estimate the full extent of agricultural activities here.

About 100 m downstream from the dumping site, two people were seen fetching water from a self-made well in the dry river sediment, presumably for the irrigation of plants.

In general, the heavy metal concentrations of the soil samples were very spread out, ranging from far below the Swedish limits for sensitive soil, to the highest, being more than double the recommended limits for less sensitive soils.

The most homogenous contents were occurs in the Mabibo area, which is likely to be due to the fact that the samples were all taken from places in the same homogenous area. One sample here though, sample Ma 1, is above the recommended levels for sensitive soil on all three metals measured. One can only speculate that the reason for this difference is that it was taken from a place closer to the Nelson Mandela Road (which carries very heavy traffic) or that this specific piece of land was irrigated with a hose using a pump whilst the other pieces were irrigated with buckets of water carried from the river.

5.2.2. *Plants*

For some of the plants a higher metal concentration was noted in respect of a specific metal, whilst only one plant sample, Ta 7 (*Alternanthera sissilis L*) (*Fig 26*) from the Tabata river basin, had levels of all metals analysed exceeding the WHO and FAO limits of 40 mg / kg dw, 5 mg / kg dw and 60 mg / kg dw for Cu, Pb and Zn respectively.

The root of the figili plant (*Brassica carinata* A.)(Sample Ta 4) which is cultivated in order to be sold as food, had levels of zinc and lead about three times as high as the WHO and FAO limits for consumable vegetables. In Mabibo, where all the plant samples were African spinach (*Amaranthus blitum* Linn) which is very popular in the Tanzanian cuisine, the plant with the highest metal contents corresponded to the soil with the highest metal contents, with zinc surpassing the WHO and FAO limits in the entire plant and lead surpassing these limits in the root and in the edible leaves but not in the stems.

5.2.3. *BCF*

Most of the plants analysed had a BCF considerably lower than 1, meaning that the concentration was higher in the soil than in the plant. However, two plant samples, Ta 2 (*Alternanthera sissilis L*) and Ta 4 (*Brassica carinata* A.) from the Tabata sample location, showed bioconcentration factors of between 2 and 6 for zinc, and one of these, Ta 2 (Fig 27), had concentration of Cu about 4 times as high in the above ground part of the plant as compared to the soil it grew in. These concentrations make these two plants interesting from a phytoremediation point of view. That said, it should be noted that the zinc and copper contents in the soils where these plants grew were not very high and hence the soils would probably not be subject to remediation.

Figure 26: Photo of sample Ta 7 (Alternanthera sissilis L.).

Figure 27: Photo of plant sample Ta 2 (Alternanthera sissilis L.).

5.2.4. *Additional Perceptions*

At the Ardhi University in Dar es Salaam there is a vast resource of data, stored analogically in the university library, difficult to access. It is noted that it would be of interest to make the material electronically accessible to the wider research community. It is also noted that it would have been of interest to have viewed the reports and theses at the Ardhi University and to have seen the data stored there in an effort to get as much information as possible on the sampling and analysis that has already been undertaken.

5.2.5. *Final Discussion*

Alternanthera sissilis L. was collected in two different samples, Ta 2 and Ta 7. Above, the samples have been discussed individually. However it should be noted that they are of the same species and that both samples stand out for their heavy metal accumulation, even though in one case, this resulted in a high metal concentration and in the other case in a high BCF ratio.

It seems as if *Alternanthera sissilis* L can grow in soil with a high content of Cu, Pb and Zn. When this was the case it accumulated a high concentration of these metals. In addition to this, if it grows in a soil with a lower metal concentration, it will take up the metals to an even greater extent, even though the level in the plant will not reach the same concentration as was the case when the plant grew in a highly contaminated soil.

6. Conclusions & Recommendations

It is concluded that, at present, two remediation techniques appear more feasible in Dar es Salaam than others, namely phytoremediation and reactive zone remediation.

No locally occurring plants have been identified that carry the necessary properties for phytoremediation. However, one plant, *Alternanthera sissilis L.* has some properties that make it interesting to examine further in this respect.

Even though some of the results indicate otherwise, the overall impact of consuming crops cultivated within Dar es Salaam does not appear to be hazardous. However, attention should be paid to extensive consumption of products produced in areas identified as being more polluted.

The combination of leaf vegetables being very popular in Dar es Salaam and them being inclined to accumulate high levels of heavy metals, necessitates that greater attention is paid to them in comparison to other crops.

In order to determine the health impact of the consumption of urban agricultural products, the extent of urban food production needs to be determined. This is the case because the range of the results of the studies carried out to date, namely those by Dongus (2001) and Sawio (2008), are too wide to be meaningful.

6.1. Recommendations

- For future research on phytoremediation in Dar es Salaam the following is recommended:
  - To continue the inventory in respect of the translocation capabilities of local plants, especially *Alternanthera sissilis* L
  - To conduct field practise (with laboratory control) in respect of heavy metal content in order to ascertain its actual effect on the plant
  - To consider the final destiny of the harvested plants and the pollutants
    - Could the plants be used for bio energy production?
    - Could the metals be extracted?
    - The final disposal of resulting wastes?
- It is recommended that duplicates of samples are analysed in different institutions using different methods and equipment, in order to eliminate any unreliability experienced during this study
- It is recommended not to consume figili (*Brassica carinata* A.) that has been cultivated in an area suspected of having suffered heavy metal pollution
- It recommended to grow flowers rather than crops in ditches close to roads that carry heavy traffic and leaf vegetables preferably more than a minimum of 30 meters away from such roads
- It is recommended to repeat the study of Dongus (2001) to see if
  - His results seem reasonable and
  - If the situation is changing
- It is recommended that covering of the existing dumping sites in Dar es Salaam is considered. For new dumping sites, both covering and lining should be considered
- Remember, it is cheaper to stop polluting than it is to remediate pollution (USDA, 2000)

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APPENDIX I EVALUATION OF REMEDIATION TECHNIQUES

This evaluation of remediation techniques takes off from the book Remediation Engineering by Suthan S. Suthersan (1997). Suthersan's book is quite exhaustive, but since it dates back more than a decade, additional information about developing remediation techniques has been looked for in research articles.

This evaluation goes through the techniques listed by Suthersan one by one and assesses how attractive they appear from 19different perspectives, for instance cost and reliability (see list below for all properties evaluated)

As many of the statements as possible where assessed in this way, and they were graded from 1 to 5, where 1 is negative and 5 is positive.

The 19 different perspectives where then subcategorized under three more general properties; cost, efficiency and feasibility, and the grades originally given were transcribed to these.

In the process of transcribing the grades, it would appear that some of the grades given would be very well founded, they would be the mean of several subcategories grades, whereas for others, no statement at all about a specific property might have been made, wherefore, in order to be able to compare them, a more or less arbitrary grade would be assigned to the specific remediation technique and the property in question.

For instance, if nothing at all was written about the cost a technique, looking at the process of how it would function could give a feeling as of whether it would be cheap or not, whereas for other techniques entire paragraphs would describe the cost efficiency. Another dilemma would be that some of the techniques evaluated would still be in their experimental stage, and therefore it would be impossible to accurately estimate how feasible they would show out to be.

In order to account for this difference in the reliability of the given grades, the evaluation was again transcribed, this time to a scheme, where the remediation techniques were listed in rows in the left column, and the properties evaluated where listed in columns. The specific grade of a property would be multiplied with the reliability of the grade, again assesses from 1 to 5 where 5 was the most reliable. This would give a product for each of the remediation techniques three different properties, which could then be added up to give an individual total sum for each remediation technique, allowing them to be compared one to another.

The result of the assessment and the distribution of points can be seen in table 1 at the end of this appendix.

Numbers and Qualities (to analyse):

1) Reliability (has been used before, conventional vs. research project)
2) Cost
3) Specific efficiency (what metals and pollutants is the method having an effect with)
4) Transportability and logistics involved
5) Level of efficiency and efficiency over time
6) What operational skills are needed?
7) Is there any risk involved (environmental & human health)
8) Site specific criteria (how much does one need to know in advance about the soils to be remediated)
9) Will there be any hazardous or dangerous leftovers from the process
10) Additional aspects
11) Predictability
12) Feasibility? How difficult is the evaluation process
13) Aesthetic aspects
14) Heavy metal aspects
15a) additional positive aspects
15b) additional negative aspects
16) Integration with other techniques
17) Design process
18) Maintenance
19) Environmentally friendly

Remediation Techniques at Hand

Bioremediation

Bioremediation is "The application of biological treatment to the clean-up of hazardous chemicals present in the subsurface" (Suthersan, 1997, p. 123). This means that organic compounds are nourished in order to grow or multiply faster, and thereby also help to break down the harmful toxics. For instance, bioremediation might turn harmful organic compounds into harmless inorganic ones, at either aerobic or anaerobic conditions. Suthersan stresses the three most important factors to account for when dealing with bioremediation, the three factors being 1) the microbiological community 2) the environmental conditions and 3) physiochemical characteristics (of the soil?) (Suthersan, 1997).

Perspective	Statement	Property
1	Bioremediation has a great documentation as a remediation technique, both empirical, theoretical and laboratorial (Suthersan, 1997)	B - 5
1	Has been practiced since the 1970's. Suthersan talk about an "explosion" in the 1990's (Suthersan, 1997)	B - 5
11	Depending on the physiochemical factors, small differences in the prerequisites might have a big impact on the result (Suthersan, 1997)	B - 3
12	The parameters that need to be evaluated for a bioremediation project are: contaminants, mineralization potential, microbial substrate, P & N, hydro-geological characteristics, extent of contaminants, bio-geo-chemical parameters (Suthersan, 1997)	B - 3

Phytoremediation

"The use of plant to remediate contaminated soil or groundwater" (Suthersan, p. 255). Phytoremediation can work in two different ways; Phytostabilization and phytoextraction. Phytoextraction is when the plants are used to accumulate toxics, and then harvested and transported away. Phytostabilization is when toxics are accumulated by the plants (via the root system) and then fixed there, in this way stopped from spreading further. The accumulation of toxics by plants is referred to as bioaccumulation (Suthersan, 1997).

The mechanism is that the plant roots release protons that acidify the soil. This makes the heavy metal more bioavailable, and thus the metals can be removed by the plants (Wu, Kang, Zhang, Hongbo, Liye, & Chengjiang, 2010).

Perspective	Statement	Property
1	More need to be known about role of metabolites, enzymes and different plants (Suthersan, 1997)and more need to be known in general (Jankaitė & Vasarevičus, 2005)	B - 2
2	Costs can be kept low, but depending on many factors they might also be considerably more expensive (Suthersan, 1997)	C - 4
2	Trees are usually cheaper than other plants.(Suthersan, 1997)	C - 3
3	If low fertility and poor soil structure, trees tend to work better than other plants. (Suthersan, 1997)	A - 3

8	Phytoremediation works best with: Moderately hydrophobic contaminants (a whole list) and heavy metals (Suthersan, 1997)	B - 4
13	Phytoremediation might be aesthetically very fulfilling (Suthersan, 1997)	B - 4
10	If phytoextraction is the purpose; an additional benefit is probably that leaching is minimized. (Suthersan, 1997)	A - 4
10	Another additional benefit can in some cases be soil stabilization, which might prevent loose soils from eroding (Suthersan, 1997)	B - 4
14	Phytoremediation has been reported to have a good result remediation heavy metal polluted sites. (Suthersan, 1997)	A - 5
5	Pollution below the rooting system will not be affected nor treated (Suthersan, 1997)	A - 2
5	Phytoremediation, depending on the conditions, may take a very long time to have a substantial effect, and therefore require a long-term commitment (Suthersan, 1997)	A - 2
15a	Tree transpiration might be sufficient for preventing some spread of a plume (p. 461), (Suthersan, 1997) a.k.a phytovolatilazation (Jankaitė & Vasarevičus, 2005)	B - 4
16	The use of microbes to enhance uptake is a possible development of this technique, but still need to be looked into quite a bit (Wu, Kang, Zhang, Hongbo, Liye, & Chengjiang, 2010)	B - 4
17	Wildlife, animals as well as plants, should be separated from the remediation plants (Jankaitė & Vasarevičus, 2005)	B - 4
17	Works best with shallow soils (Jankaitė & Vasarevičus, 2005)	B - 3

Hydraulic and Pneumatic Fracturing

H & P fracturing is not a remediation technique by itself, but can be used jointly with other remediation techniques in order to speed up the groundwater flow and hence make the technique more efficient. It can be used in dense soils, and the idea is to increase the pressure in the soil to the point where, either additional fractures appear, or where the existing fractures increase in size. This can be done to a certain level without losing the created texture after lowering the pressure again, and if this level is passed, the additional fractures created will either "sink back" to its highest point, which would make the additional pressure a waist of energy and efforts, or worse, would make the texture collapse, which would take you back to where you started or even below that point. In this case, it's is not only expensive but even contra-productive to increase pressure (Suthersan, 1997).

Hydraulic fracturing is using liquids, often water. Pneumatic fracturing is using air, to extend the pressure and create the fracturing (Suthersan, 1997).

Perspective	*Statement*	*Property*
1	There is very little documentation available for how efficient hydraulic fracturing is. (Suthersan, 1997)	B - 1

2	HF might be an effective way of reducing costs for remediation by limiting the number of wells needed, since it helps making each well more efficient (Suthersan, 1997)	C - 4
3	Should be considered as an alternative to a larger number of wells (Suthersan, 1997)	A - 1
8	Good for: Clay, silt, sandstone, siltstone, limestone, shale (p. 238) (Suthersan, 1997)	-
11	Design with some flexibility in mind (Suthersan, 1997)	B - 3
15b	Can, with "slow o2 releases" create an aerobic subsurface environment (p. 252) (Suthersan, 1997)	-

Vacuum Enhanced Recovery (A.k.a dual phase extraction) (VEC)

(Opposite to H & P Fracturing = "sucking")

VEC does not work single handed, but is a way of enhancing remediation by pumping. By applying a negative pressure in the well, water is "sucked" towards the extraction point, for the purpose of allowing a higher extraction flow (Suthersan, 1997).

- Increase the gradient => capture zone => recovery => allows a smaller number of wells (Suthersan, 1997)
- (Sometimes the only option to excavation) (Suthersan, 1997)

Perspective	*Statement*	*Property*
2	Cost effective (Suthersan, 1997)	C - 5
17	Increase capture zone (Suthersan, 1997)	A - 5
17	Reduced number of recovery wells (Suthersan, 1997)	A - 5
20	Reduced time (Suthersan, 1997)	C - 4
8	Effective source removal at low permeability sites (Suthersan, 1997)	A - 5
16	Can open up for Vapour Extraction in fine grained sediments (Suthersan, 1997)	A - 4
3	Helps extracting LNAPL's (Suthersan, 1997)	A - 4
	· More products than would have appeared with only pumping will come with the liquid (Suthersan, 1997)	-
	· Will probably enhance biodegradation, by sucking in oxygen into the pores (Suthersan, 1997)	-
8	Good in areas with shallow saturation or limited saturated thickness (Suthersan, 1997)	B - 2
8	Good in low permeability soils and sediments (Suthersan, 1997)	-
8	Low transmissivity formations (Suthersan, 1997)	-
8	Low hydraulic conductivities (Suthersan, 1997)	-
8	Perched NAPL or groundwater layers (Suthersan, 1997)	-
8	Total fluid recovery in low permeability formatting (Suthersan, 1997)	-
8	Formation consisting of interbedded clay and sand (Suthersan, 1997)	-
8	Low permeability fractured systems (Suthersan, 1997)	-
2	High operation and maintenance cost => must be effective in order to be cost effective (Suthersan, 1997)	C - 1

8	Works in limited range of hydrogeological settings (Suthersan, 1997)	B - 2
9	Produces gases that will require treatment (Suthersan, 1997)	B - 2
7	High vapour concentration might be explosive which require an incorporated solution to handle the risks (Suthersan, 1997)	A - 2

Soil Vapour Extraction (SVE) (A.k.a Soil Venting or Vacuum Extraction)

SVE is a bit like pumping water, except it pumps only gases. The idea is to create an induced airflow in the non-saturated zone, pumping up "toxic" gases, which is treated above the ground (Suthersan, 1997).

"Works a lot like bioventing => "1/6 of remediation can be biodegradation" (Suthersan, 1997).

Perspective	*Statement*	*Property*
2	Cost effective (Suthersan, 1997)	C - 5
2	Can treat large volumes of soils relatively cheap (Suthersan, 1997)	C - 5
1	Accepted and recognized for removing volatile and semi volatile organic compounds (Suthersan, 1997)	B - 3
15	May enhance aerobically biodegradation (Suthersan, 1997)	A - 3
4	Easy to transport and install (Suthersan, 1997)	B - 5
16	integrates easily with other remediation techniques (Suthersan, 1997)	B - 3
8 + 17	Airflow characteristics and mass transfer consideration will influence SVE (Suthersan, 1997)	B - 3
8	Air permeability needs to be known, just like porosity and subsurface conditions (Suthersan, 1997)	B - 2
8	Porosity, air permeability, water content, organic matter content, heterogeneity and surface seals all have an impact on the movement on the surface seals (Suthersan, 1997)	B - 3
8	Contaminant characterizations needed in the evaluation process are: Type, age, composition, concentration, phase, distribution (Suthersan, 1997)	B - 2
8	Site geologic conditions that need to be knows are: soil moisture content, manmade site conditions, topography, depth to water table, horizontal and vertical extent of contamination spread (Suthersan, 1997)	B - 2
6 +8	You need to evaluate water table elevation fluctuations, barometric pressure changes, presence of NAPL's (LNAPLs') or (particles?) isolated in the matrix, groundwater concentrations (Suthersan, 1997)	B - 2
11 + 2	A pilot testing with "all" the equipment is needed in order to evaluate the suitability of the method (Suthersan, 1997)	C - 2
2 + 18	Continuous fine tuning makes way for expensive maintenance (Suthersan, 1997)	C - 2
2	The vapour treatment technology is the capital cost (Suthersan, 1997)	C - 3

2 + 11 + 17	It's presumptuous to apply one site's site specific criteria on any other site (Suthersan, 1997)	B - 2
2	Break even costs should be calculated (Suthersan, 1997)	C - 2
10 + 12 + 2	The availability of electricity and energy man have great influence on how attractive this method is as a remediation method (Suthersan, 1997)	B - 2

Electro Kinetics

The governing principle in Electro kinetics are the anodes and cathodes induced in or next to the contaminated soils, inducing a weak electric current that will attract the captions and anions to the respective electrodes. This will also induce a flow in the groundwater that can transport other contaminants than anions and captions. The contaminants can be interrupted and treated in the electrode surroundings (Jankaitė & Vasarevičus, 2005).

Perspective	*Statement*	*Property*
8	Works best in a saturated soil with low permeability (Jankaitė & Vasarevičus, 2005)	B - 2

Air Sparging

Works through pumping air (or other similar gases) into the saturated zone. It's three governing phenomenon are 1) stripping, 2) volatilization and 3) biodegradation (Suthersan, 1997).

Perspective	*Statement*	*Property*
16	Often works in conjunction with Vacuum Extraction systems (Suthersan, 1997)	B - 2
1	Not so reliable, much dependent on the experience and empirical knowledge of the engineer (Suthersan, 1997)	B - 1
6	An experienced engineer is vital (Suthersan, 1997)	B - 1
3	Aerobically biodegradable contaminants in the saturated zone, permanently (Suthersan, 1997)	A - 3
5	The biodegradation governed remediation works better in the long run than in the beginning (Suthersan, 1997)	A - 3
1	A pilot study is probably the necessary since not enough is known about the theoretic (Suthersan, 1997)	C - 2
2	A pilot well could well be used in the full scale application as well (Suthersan, 1997)	C - 4
14	Heavy metals does not seem to be treated in an efficient way (Suthersan, 1997)	A - 1
1	Quite a research field still, not so many case studies have been made (Suthersan, 1997)	B - 2
8	Not recommended for; Tight geologic conditions, Heterogeneous geologic conditions, Non-strippable and non-biodegradable contaminants, When integration with vapour extraction is impossible, If there are nearby constructions sensible for flooding (Suthersan, 1997)	B - 2
8	8) Silty soils have been reported to work well with Air Sparging (Suthersan, 1997)	B - 3

Stabilization and Solidification (S/S) (A.k.a Waste Fixation) (Conventional)

Stabilization is to "make less soluble, immobile and less toxic form without changing the physical nature" (Suthersan, 1997).

Solidification is to "Encapsule in a monolithic solid of high structural integrity", on an either macro or micro level (Suthersan, 1997).

Perspective	*Statement*	*Property*
14	Sorption: Inorganic heavy metals can be adsorbed onto clay, humic materials and fly ashes via ion exchange (Suthersan, 1997)	A - 4
14	There are two main difficulties with metals: 1)Completion 2) Variable oxidation states (Suthersan, 1997)	A - 2
14	S/S for heavy metals include: Control of excess acidity by neutralization, Destruction of metal complexes if needed, Conversion to soluble species (stabilization) if needed, Using solidification reagents to form a solid (Suthersan, 1997)	B - 2
2	Energy demanding (Suthersan, 1997)	B - 2
17	can be used both in- and ex-situ (Suthersan, 1997)	B - 3
2	In-situ appears to be cheaper than ex-situ, but still expensive (Suthersan, 1997)	C - 2
17	Fixation of heavy metals will differ some between fixation in soil and fixation in groundwater, which calls for a very thorough design process (Guo, Zhou, & Ma, 2006)	B - 2
8	Promising method for low heavy metal contamination (Guo, Zhou, & Ma, 2006)	B - 4

Pump and Treat Systems

The principle phenomenon behind pump and treat systems is to pump up contaminated water to the surface, treat it there, and then either extract it back to the source or onto a municipal waste water treatment facility. This can be done either to prevent contaminants from spreading (containment) or in order to remediate an already contaminated site (Suthersan, 1997).

However, the mere extracting of groundwater does not ensure the excavating of the contaminants in question (Suthersan, 1997).

There is a wide range of sub-categories to pump and treat (Suthersan, 1997).

Perspective	*Statement*	*Property*
1	Once pumped up to the surface, regular waste water cleaning techniques (Suthersan, 1997)	B - 2
2	Containment demands a smaller pumping rate and is therefore cheaper than restoration (Suthersan, 1997)	C - 3
16	Works well, apparently, with many other remediation techniques (Suthersan, 1997)	B - 4
2	See table 11.4 on page 271 in Suthersan (1997) for box with comprehensive costs	C - 3

17	*Water cleaning techniques are, amongst others:* * air stripping = aeration = degasification (Suthersan, 1997) * adsorption (organic molecules) (Suthersan, 1997) * chemical oxidation (Suthersan, 1997) * biodegradation (Suthersan, 1997) * membrane filtration (Suthersan, 1997) * ion exchange (Suthersan, 1997) * metal precipitation (Suthersan, 1997)	B - 2

Reactive Walls (or Funnel and Gate Systems or Treatment Walls) (emerging)

The technique is to dig out trench and fill it up with either impermeable material to funnel into a porous gate, where the remediation takes place, or to fill up the trench entirely with reactive material. The volume of reactive material must be decided after what ground water flow must be sustained (Suthersan, 1997).

The amount and size of reactive gates is a design parameter, where one way to increase the remediation quality is to make the gates thicker, hence increasing the treatment time (Suthersan, 1997).

In order to remediate faster, pumping down gradient from the source and treatment point can be done. Charging water up gradient might increase the flow still more (Suthersan, 1997).

Monitoring points should be installed in the contamination plume, in the reactive gate/trench and after the treatment point (Suthersan, 1997).

Perspective	*Statement*	*Property*
2	Monitoring points should be installed in the contamination plume, in the reactive gate/trench and after the treatment point (Suthersan, 1997)	C - 2
2	Low long term and maintenance cost, where almost all the cost is in the establishing of the remediation. (Suthersan, 1997)	C - 5
2	Synergy savings can be made in bigger projects (as an alternative to pump and treat) (Suthersan, 1997)	A - 4
	General) in general, in situ treatment methods provide longer cleaning times than ex-situ Methods (Suthersan, 1997)	B - 2
8	Feasibility is dependent on - site geology (Suthersan, 1997) - hydrogeological conditions and type (Suthersan, 1997) - concentrations (Suthersan, 1997) - vertical and lateral distribution (Suthersan, 1997)	B - 2
2	More gates generate higher cost, but also higher ground water flow (gates more expensive than cut off walls) (Suthersan, 1997)	C - 3
17	Iterative modelling seems to be the most accurate way to design reactive walls (Suthersan, 1997)	B - 2
17 + 12 10 + 3	Design is easier for reactive trench than for funnel and gate (Suthersan, 1997)	B - 3

17	Well-designed systems should be able to last for years without maintenance (Suthersan, 1997)	A - 4
2	In general these systems are expensive initially, and then more or less free (Suthersan, 1997)	C - 3
7	A large calculation margin is probably needed to be sure the results sought after are answered to (Suthersan, 1997)	B - 2

Reactive Zones (experimental), (mostly empirical)

"Subsurface zones where migrating contaminants are intercepted and immobilized or degraded" (Suthersan, 1997, p. 215).

One method is to mix the resident soils with an agent so it becomes a reactive slurry. The difference from reactive Walls is sometimes not so big; zones can be constructed litter walls for the same reason. The difference then is that in the reactive zone methods, no excavation has been made. Instead the reactive agent is mixed into or injected into the resident material (Suthersan, 1997).

Perspective	*Statement*	*Property*
18	Continuous control of the reactions will be needed (Suthersan, 1997)	B - 1
17	Can have either degradation or immobilization as governing phenomenon (Suthersan, 1997)	-
17	There are two main reactions that have to be designed (Suthersan, 1997) - the relation of the reagent and the contaminant (Suthersan, 1997) - the relation of the reagent and the resident soil (Suthersan, 1997)	B - 2
15A	(In situ vs. Ex situ) no need for infrastructure nor logistics once the site is up and running (suthersan, 1997)	C - 4, B - 4
2	Cheap to install and super cheap to run (Suthersan, 1997)	C - 5
15A + 8	Can be used for deep sites (Suthersan, 1997)	A - 4
15A + 13	Minimal obstruction once up and running (Suthersan, 1997)	A - 4
	Some of the reactions at hand: - denitrification (Suthersan, 1997) - abiotic reduction by dithionite (hydrosulphite) good for ferric ion and carbon tetrachloride (the half-life for dithionite is about 2-3 days) (Suthersan, 1997) - chemical oxidation (for organic compounds) (Suthersan, 1997) - microbial mats: usually with the naturally occurring microbes that have been added to a much larger extend than naturally (experimental) (Suthersan, 1997)	
15B + 9	Can give toxic wastes other than the ones treated, and leave these on the spot (Suthersan, 1997)	B - 2
17	One design option is to design as a grid pattern over the contaminated plume (Suthersan, 1997)	-
	A case study (p. 235) was revealed promising (Suthersan, 1997)	B - 4

Chemical Remediation

With the help of chelators, that create multilateral bonds to the metal particles, the metals change characteristic, and they are to a higher extent made available to plant roots (Wu, Kang, Zhang, Hongbo, Liye, & Chengjiang, 2010).

Perspective	Statement	Property
1	Is well established, but appears to have negative second hand effects on the soil quality (Wu, Kang, Zhang, Hongbo, Liye, & Chengjiang, 2010)	B - 4, A - 2
2	Appears to be almost sixty times more expensive than for phytoremediation, for the same result over a ten year period (Wu, Kang, Zhang, Hongbo, Liye, & Chengjiang, 2010)	C - 2
7	The chelators may have, in their turn, had a negative impact on the environment, and may leach out to the surroundings (Wu, Kang, Zhang, Hongbo, Liye, & Chengjiang, 2010)	A - 2
9	Possible hazardous leftovers, from the chelators used (Wu, Kang, Zhang, Hongbo, Liye, & Chengjiang, 2010)	A - 2
15B	Will destroy the natural texture of the soil (Wu, Kang, Zhang, Hongbo, Liye, & Chengjiang, 2010)	A - 2
16	Can integrate with phytoremediation, but negative effects has to be considered (Wu, Kang, Zhang, Hongbo, Liye, & Chengjiang, 2010)	B - 4

Micro remediation

Microbial Remediation or micro remediation is a rather complex chemical series where microbes play an essential role. The heavy metal contaminants remains in the soil, but are presumed to change the character of the contaminant so as to be less toxic (Wu, Kang, Zhang, Hongbo, Liye, & Chengjiang, 2010).

Animal Remediation

Wu et al (2010) recommend that what they call Animal Remedation is being looked into a bit further. This kind of remediation mainly including earthworms, may in some circumstances enhance bio-uptake of heavy metals. The process is similar to Microremediation.

Perspective	Statement	Property
16	Supposedly integrates well with phytoremediation (Wu, Kang, Zhang, Hongbo, Liye, & Chengjiang, 2010)	B - 4

Table 1: Point distribution in remediation evaluation.

Techniques	**Efficiency**	**Reliability**	**Product**	**Feasability**	**Reliability**	**Product**	**Cost**	**Reliability**	**Product**	**Sum Procucts**	**Rank**
Bioremediation	4	1	4	4	3	12	3	1	3	19	**7**
Phytoremediation	3	3	9	4	2	8	4	4	16	**33**	**2**
Hydraulic & Pneumatic Fracturing	3	1	3	1	1	1	4	3	12	16	**9**
Vacuum Enhanced Recovery	4	2	8	2	3	6	4	3	12	26	**3**
Soil Vapor Extraction	3	1	3	2	4	8	4	3	12	23	**5**
Electrokinetics	2	1	2	2	2	4	4	1	4	10	**12**
Air Sparging	2	3	6	2	2	4	3	1	3	13	**11**
Stabilazation & Solidification	3	2	6	3	2	6	2	2	4	16	**9**
Pump & Treat Systems	4	1	4	3	3	9	3	3	9	22	**6**
Reactive Walls	4	2	8	2	3	6	4	3	12	26	**3**
Reactive Zones	4	2	8	3	2	6	5	4	20	**34**	**1**
Chemical Remediation	2	3	6	4	2	8	2	2	4	18	**8**
Microremediation	3	1	3	3	1	3	3	1	3	9	**14**
Animalremediation	3	1	3	4	1	4	3	1	3	10	**12**

ADDITIONAL REFERENCES FOR APPENDIX I

Guo, G., Zhou, Q., & Ma, L. Q. (2006). Availability and Assessment of Fixing Additives for the In Situ Remediation of Heavy Metal Contaminated Soils: A Review. *Environmental Monitoring and Assessment*, 513 - 528.

Jankaitė, A., & Vasarevičus, S. (2005). Remediation Technologies for Soils Contaminated with Heavy Metals. *Journal of Environmental Engineering and Landscape Management*, 109a - 113a.

Wu, G., Kang, H., Zhang, X., Hongbo, S., Liye, C., & Chengjiang, R. (2010). A Critical Review on the Bio-Removal of Hazardous Heavy Metals from Contaminated Soils: Issues, Progress, Eco-Environmental Concerns and Opportunities. *Journal of Hazardous Materials*, 1 - 8.

APPENDIX II SAMPLING SITE INFORMATION

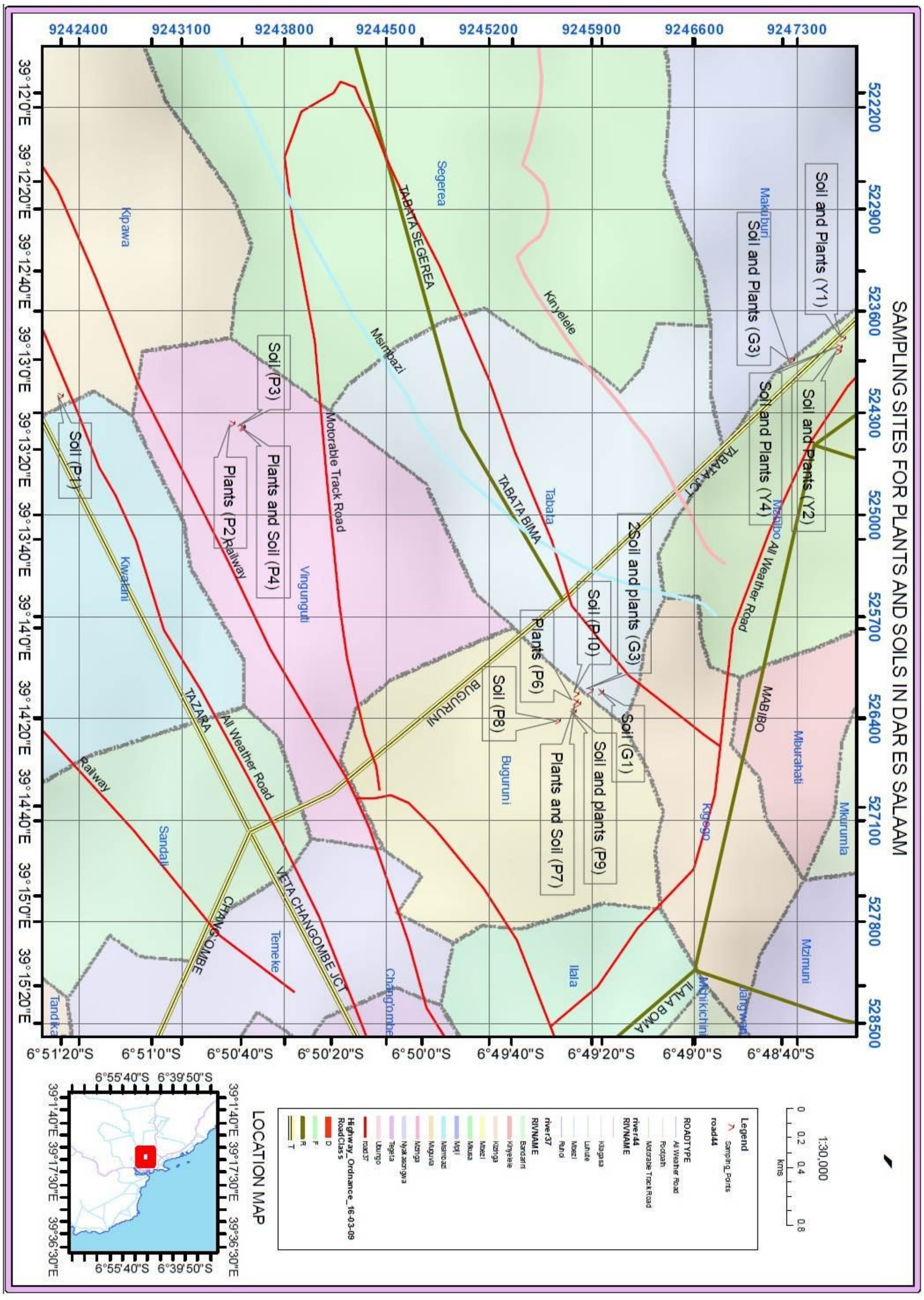

Figure 28: Map of Samplings Sites.

The samples were collected in Vingunguti, Mabibo and Tabata, with the individual sampling sites displayed in figure 28.

The information collected by each sample is displayed below and is the following:

- Name of Sample
- Working name of sample, the names shown on the map in figure 3 and 28
  - GPS position North
  - GPS position East
  - Elevation above sea levels (only displayed for some samples)
  - Description of the sample / samples and it / they site they was / were taken from

The samples site information is given below

Vingunguti Dump Site Area

- Vi 1
- Sample Pink 1
  - 0524190 N
  - 9242256 E
  - 28 m above sea-level
  - Sample from the river basin upstream from the dumpsite. Soil/sediment sample
- Vi 2
- Sample Pink 2
  - 0524378 N
  - 9243432 E
  - 30 m A.S.L
  - From the periphery of the actual dump site. Soil & plant samples.
- Vi 3
- Sample Pink 3
  - 0524399 N
  - 9243494 E
  - 28 m A.S.L
  - Sediment /soil sample of the leachate stream from the dump site
- Vi 4
- Sample Pink 4
  - 0524406 N
  - 9243500 E
  - 27 m A.S.L
  - Plant and Soil sample from the side of the dump site

Tabata River Basin Area

- Ta 1
- Sample Pink 6
  - 0526293 N
  - 9245768 E
  - Plant sample (*Pentodon pentandrus*) from the side of the river. The name of the river is still unknown, but approximately 100 meters downstream it is joining with the Msimbazi River. Too a sandy soil to be deemed relevant for sampling.
- Ta 2
- Sample Pink 7
  - 0526304 N

- 9245768 E
- Plant *(Alternanthera sessilis L)* and soil from the bottom of the river basin
- Ta 3
- Sample Pink 8
- 0526417 N
- 9245652 E
- Sediment sample from Msimbazi river (maybe 50 m upstream from the rivers meet)
- Ta 4
- Sample Pink 9
- 0526360 N
- 9245758 E
- Soil and plant (*Brassica carinata A.).* The plant is called Figili in Swahili, a bit like a milder piripiri, samples from irrigated garden between the two rivers
- Ta 5
- Sample Pink 10
- 0526234 N
- 9245778 E
- Sediment from the middle of the river basin, taken submerged (from the river with the unknown name again). The sampling point is somewhat linking the samples taken this day to the sample site of the samples taken the previous week.
- Ta 6
- Sample Green 1
- 0526218 north
- 9245946 east
- 1 soil sample and 1 vegetable sample (did we really take soil sample here? Additional note made on February 14, 2011)
- Ta 7
- Sample Green 2
- 0526212 north
- 9245866 east
- 2 soils (Green 2:1 and Green 2:2, of different textures) samples and 1 vegetable sample *(Alternanthera sessilis L).*

<u>*Mabibo Area*</u>

- Ma 1
- Sample Green 3
- 0523941 north
- 9247248 east
- 1 soil and 1 vegetable (*Amaranthus blitum* Linn, in Swahili called Mchicha, or African Spinach) sample
- Ma 2
- Sample Yellow 1
- 0523790
- 9247594
- 1 plant, 1 soil and 1 Seeds
- Ma 3
- Sample Yellow 2
- 0523881

  - 9247564
  - 1 plant, 1 soil
- Ma 4
- Sample Yellow 3
  - 0523902
  - 9247596
  - 1 plant, 1 soil
- Ma 5
- Sample Yellow 4
  - 0523854
  - 9247572
  - 1 plant, 1 soil (the soil I a mix of two spots separated by 20 cm)