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Treatment of Akkulam Dredged Material with Lime

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Abstract. The Akkulam lake is one of the oldest tourist spots in Trivandrum which has become a disposal site for biomedical and industrial wastes. The study hence emphasized on a pollution free effective utilization of the dredged material, analyzing the environmental risks with its remediation and stabilization. It initially involved determination of the heavy metals in the dredged material by X-Ray Fluorescence spectrometry and was found that, its heavily polluted by Nickel and Lead and is moderately polluted by Zinc as per US Environmental Protection Act standards. Remediation of the soil is done by stabilizing it with varying percentage of lime from 6% to 12%. The efficiency of the treatment is determined primarily through unconfined compressive strength test and column leachate test. The concentrations of heavy metal in the leachate were observed to be decreasing with time. The maximum immobilization was achieved for lime content 10 and 12% with an efficiency of 82% for lead and 67% for nickel, respectively. Moreover, the UCS values surpassed the disposal standards as well as the CBR value improved by 81.9%, which suggested possibility of reuse as subgrade fill in road pavements. WiscLEACH software was used to predict the concentration con-tours of leached metals upon reusing lime stabilized material, which proved that the remediation technique adopted not only improved the soil strength but also reduced the environment risk associated with the contaminated soil by avoiding any further leaching out of metals into the ground water table and eco-system.

Keywords: Heavy metals, Leachability, Lime stabilization, Remediation

1 Introduction

Akkulam lake is one of the oldest tourist spots in Thiruvananthapuram, Kerala. Akkulam was once well known in the country for its rich biodiversity, scenic beauty and natural habitat with plenty of aquatic species and amphibians. In India, with rapid industrial development and urbanization over the past few decades, the waste generation has boomed significantly high in many urban and densely populated cities, contaminating the water and soil in and around these areas. One such clear scenario is the Akkulam lake, wherein, as a part of the rapid urbanization and inefficacious waste management system, the water canals which flowed into the lake were met for the purpose of disposal of wastes from nearby factories, industries and hospitals. These have stressed the lake into a heavy metal contaminated water body. If a soil is contaminated by heavy metals it gets retained in the site for a longer extent of time since they do not undergo any major chemical degradation or microbial decomposition as in the case of an organic pollutant. So, it has to be either removed or immobilized from entering into the ecosystem. In addition of being hazardous and causing public health problems, the heavy metal contamination of soils also causes considerable distress to structures due to the degradation of mechanical behaviour of soils.

The aim of the study is to determine the concentrations of minor, major and trace elements of the Akkulam dredged material, specializing in the types of heavy metal contamination and to remediate it using suitable immobilization agent, whose potential is studies w.r.t. leachability of contaminants and unconfined compressive strength. Also, the study emphasizes on the beneficial use of the stabilized optimized sample on to pavement subgrade and analyze its impact on the groundwater table as well.

1.1 Literature Review

Risk assessment studies of heavy metals in the Akkulam-Veli Lake system indicates that Cd is found to be the most hazardous metal contaminant of sediments in spite of its lowest content in AV Lake sediments. Apart from Cd, Pb exhibit the highest hazard indices and hence need to be closely monitored [1]. From previous studies, it has been seen that the Ni reached carcinogenically unsafe limits in the lake sediments, however the concentrations of other metals are currently at non-carcinogenic levels [2].

Amidst the numerous techniques of remediation researched, the immobilization technique achieved through solidification/stabilization (S/S) appears to be the one of the most effective method due to its ability to entrap the waste within a soil-binder matrix and its cost effectiveness. The high strength, low permeability and relative durability of lime S/S products make lime one of the most adaptable stabilizing agent easily available for the immobilization of heavy metals in soil [3]. There are numerous other advantages in using lime as binder material as the calcium oxide has minimal environmental impact, low solubility, and high alkalinity. Also, upon reaching a maximum pH of 10.5, it triggers immobilization due to pozzolanic reactions and also helps to neutralize acids and precipitate metals [4].

2 Methodology and Material Used

The methodology of the study includes a series of test to find out the leachability characteristics of different heavy metals present in the soil subjected to the study and also the chemical and geotechnical property analysis before and after the treating it with the suggestive stabilization agent, un-hydrated lime.

2.1 Dredged material

Initially, the dredged materials were collected from several points near the Akkulam Boat Club, Thiruvananthapuram, where dredging activity was being carried out by the government of Kerala. Indian standard tests were performed to determine the chemical, physical and engineering characteristics of the soil samples. The details of the physical, geotechnical and chemical properties of the dredged materials are given in Table 1.

Table 1. Properties of Dredged material

Properties	Value
Colour	Dark Reddish Brown
Water content	41%
Specific Gravity	2.35
Fine sand fraction (%)	25.48%
Silt fraction (%)	51.42%
Clay fraction (%)	14.84%
Max dry density (g/cc)	1.87
Optimum moisture content (%)	23.1%
Liquid Limit	51.5%
Plastic Limit	28%
Shrinkage Limit	21.13%
Plasticity Index	23.5
Soil Classification	MH
Loss on Ignition	5.83%
pH	3.55
Percentage Carbon Content	3.37%

The chemical properties include the pH of the soil tested as per IS: 2720 (Part XXVI) - 1987, using electrometric method (standard method), the chemical constituents in the soil, which is determined by X-Ray Fluorescence Spectrometry (XRF) in National Centre for Earth Science and Studies, Akkulam and is listed in the Table 2. Also, the heavy metals present in the soil, which is determined by Atomic Adsorption Spectrometry (AAS).

Table 2. Constituents of dredged material

Constituents	Akkulam (%)	Constituents	Akkulam (%)
SiO_2	48.80	TiO_2	0.82
Al_2O_3	24.40	MgO	0.7
Fe_2O_3	12.40	Na_2O	0.59
SO_3	4.54	CaO	0.27
K_2O	1.07	P_2O_5	0.24
MnO	0.03	Total	99.69

Almost half of the dredged material was found to silicon dioxide being the major constituent. One fourth of the sample was aluminium trioxide and it may be reason for the considerable plasticity of the soil. The 12.4% of ferric trioxide is the third major constituent, which is the reason for the predominant reddish colour of the Akkulam dredged soil.

The grain size distribution of the soils used are shown in fig. 1. According to the experimental results as per Indian standard soil classification, the Akkulam dredged material has been classified as highly compressible silt (MH).

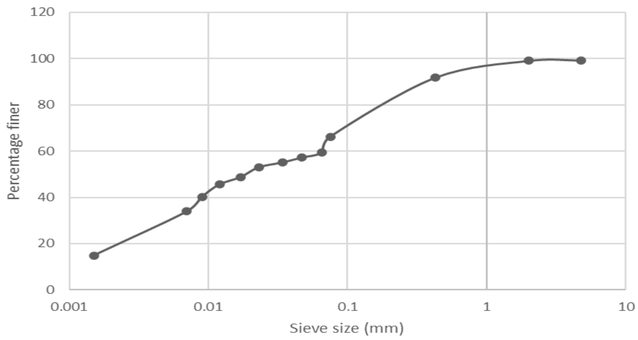

Fig. 1. Gradation curve of Akkulam dredged soil

2.2 Addition of lime

Based on the pH and the extend of metal contamination in the soil, suitable stabilizing agents were selected. In this study the stabilizing agent used was lime considering its immobilization properties and alkaline nature. Lime is initially added to the soil and the minimum lime content to be added was found as per Eades and Grim method (ASTM D6276). The optimum content of lime from lime varying by 6%, 8%, 10% and 12% of soil weight, was found out w.r.t. the unconfined cohesive strength and immobilization of heavy metal ions in the dredged material. The unconfined compressive (UCC) strength tests were performed on the samples after a day of curing as per IS: 2720 (Part X) - 1991. Five sets of specimens were prepared. One set was tested after half an hour of preparation directly. The other sets were tested after 1, 3 7 and 14 days of curing time. The method of curing was in an airtight container with a wet sponge placed upon it. The specimen was wrapped in plastic sheet and placed in an airtight container with a wet sponge for 1, 3, 7 and 14 days.

2.3 Preparation of column leachate test

The extend of immobilization of heavy metal ions in the dredged material was found out by column leachate test method as per USEPA method 1314 and the concentration of different heavy metal ions leached out was determined by atomic adsorption spectrometry. Column tests were done for both treated and untreated samples made with their corresponding OMC and MDD. The column used for this experiment was designed and built in college following the ASTM D 4874. The column body is constructed of PVC pipe and acrylic sheet with a total length of 500mm, with an inside diameter of 100 mm. The cylinder wall is of sufficient thickness, approximately 3 mm. The end plates are constructed of stainless steel. They are attached by means of eight, 3mm threaded rods and adhesives which ensures a leak-proof seal. Leachate collections were done using polyethylene bottles continuously for 28 days maintaining a constant water head reservoir of water (pH 6.5) of 20 ± 1.0 cm. A select number of samples which includes the 1, 7, 14 and 28th day samples were prepared for analysis by Atomic adsorption spectrometry. Similarly, columns for treated dredged material with lime content 6%, 8%, 10% and 12% were also carried out.

2.4 Software simulation

The geotechnical properties of the optimum soil additive mix were determined and analysed with the raw dredged material. Further the soak CBR improvement were done to assess the reusability of stabilized materials as a subgrade infill. The environmental risk based on the heavy metal leaching into the ground water was analysed by predicting concentration contours of the metals leaching into the ground using a software called WiscLEACH, based on the basic Advection-Dispersion-Reaction Equation (ADRE) [5]. The input site parameters that was used throughout the software was a typical highway cross section from Goel et.al. 2017, listed in table 7. The input parameters defining the leachability characteristics of different metals were obtained from column leach test results.

Table 7. Input site parameters of conceptual model

Site parameters	Values
Point of Compliance	20m
Pavement width	3.75m
Shoulder width	2.5m
Depth of Groundwater	6m
Depth to top of Stabilized layer	0.38m
Depth to bottom of stabilized layer	0.68m
Annual precipitation rate	2.0 m/year
Maximum Simulation Time	60 years

Table 8. Properties of pavement layers

Layers	Thickness (m)	Hydraulic Conductivity (m/yr)	Porosity
Pavement	0.125	1	0.07
Base	0.205	3650	0.25
Stabilized layer	0.3	44.15	0.48
Subgrade	N/A	132	0.35

3 Results and Discussions

3.1 Heavy metal levels

For analysis of chemical properties, XRF test were done on the sample to determine the concentration of different heavy metals present in the dredged soil. It was seen that the procured dredged material is heavily contaminated with Lead and Nickel, while it was moderately polluted by Zinc as per the US-EPA guidelines and US-Sediment quality guidelines. The traces of other metals like chromium, cadmium and copper were below the detection level (BDL) of XRF test.

Table 3. Contaminants in Akkulam dredged material

Metals	Akkulam Soil (ppm)	Limits as per US-EPA (ppm)	Sediment Quality Guidelines -US
Chromium	BDL	25-75	43-76
Nickel	79	20-50	23-36
Copper	BDL	25-50	25-75
Zinc	133	90-200	90-200
Lead	89	40-60	40-70

3.2 Influence of lime with pH

The pH of prepared specimens for the untreated and treated soils with different percentages of lime were determined. The lowest percentage of lime in soil that gives a pH of 12.4 was taken as the approximate lime percentage for stabilizing the soil. There may be some soils in which the pH is greater than 12.4. If this occurs, the lowest percentage of lime where the higher pH value does not rise for at least two successive test samples at increasing lime percentages is selected (ASTM D 6276). Based on this, the value of initial lime consumption as determined from the Eades and Grim pH test for the said soil was 6% as shown in fig. 2. The pozzolanic reaction of lime happens only at a pH>10.5, so min lime requirement was found out as 6%.

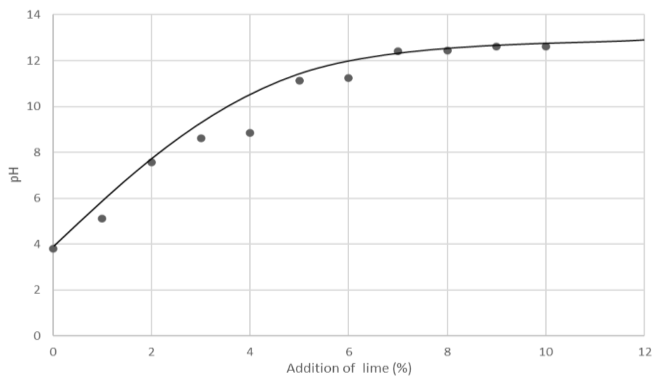

Fig. 2. Lime content vs pH for Akkulam Soil

3.3 Compaction and strength properties

All samples both untreated soils and treated soils with different percentages of lime were prepared to recognize the effect of compound admixture on the compaction properties. It should be noted that the MDD values of the dredged material are much higher than those obtained for the lime-treated silt clay.

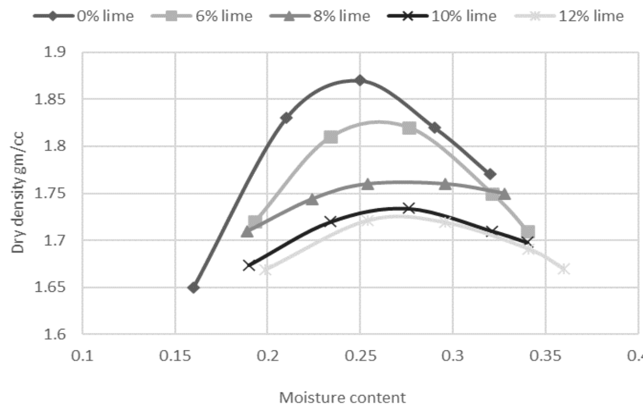

Fig. 3. Dry density vs moisture content plot

All MDD values can be seen to fall in the range of 1.87 to 1.72 g/cm3, while the OMC values range from 23.1 to 27.2%. As the lime content increases, the compaction curve tends to shift downward and towards the right. This indicates that as the lime content was increased, the MDD value tends to decrease and the OMC value were found to be increased. This behaviour can be attributed to the tendency of lime to absorb water in order to complete its hydration, thereby increasing the OMC. Moreover, the immediate reactions represented by flocculation and agglomeration tend to increase the OMC and decrease the MDD values, respectively [5]

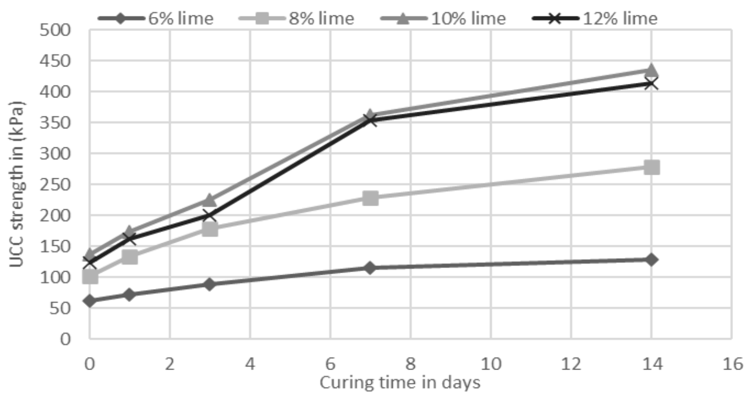

Fig. 4. Variation of UCC strength with curing period on lime stabilized soil

The effect of early strength of stabilized soil was studied by conducting UCC tests on soil stabilized using lime cured over a period of 1 day, 3 days, 7 days and 14 days shown in Fig. 4. For 6% lime there is a decrease in strength but the value increases from 8 to 10 and further drops down. So, the optimum lime content w.r.t the UCS values could be inferred as 10%.

3.4 HM concentration in collected effluent

The concentration of heavy metals in the leachate effluent collected from the column test were analysed using AAS. Ni and Pb were found to be above the standard limits set by different environmental and safety control authorities like FAO, WHO and US-EPA, considering the 1st day leachate of the column test.

Table 4. Initial concentration of metals on collected leachate of raw dredged material

Metals	Concentration of metals in day 1 effluent	Irrigation water standard as per FAO	Reusable Waste water standards as per WHO	Drinking water standards as per WHO	Effluent Standard as per US-EPA
Nickel	5.92 ppm	0.2 ppm	0.5 ppm	0.02 ppm	1 ppm
Lead	4.45 ppm	5.0 ppm	1 ppm	0.01 ppm	1 ppm

The lead and nickel concentration in leachate collected at 1, 7, 14 and 28 days are tabulated in Table 5 and 6. Concentration of both were found to reduce with increase in leaching duration. On checking it with the drinking water standards, it was unfit but the sample meets the standards of irrigation water and reusable waste water.

Table 5. Lead concentration (in mg/l) in leachate.

Addition of lime	Concentration of Pb (mg/l) in the leachate collected on			
	1 day	7 days	14 days	28 days
0% lime	4.45	1.94	1.46	1.18
6% lime	2.82	1.17	0.91	0.61
8% lime	2.15	1.26	0.62	0.29
10% lime	1.8	0.78	0.45	0.21
12% lime	1.85	0.85	0.51	0.23

Table 6. Nickel concentration (in mg/l) in leachate

Addition of lime	Concentration of Ni (mg/l) in the leachate collected on			
	1 day	7 days	14 days	28 days
0% lime	5.92	3.45	2.82	2.42
6% lime	4.12	2.91	2.36	1.45
8% lime	3.05	2.33	1.67	1.22

10% lime	2.65	1.74	1.34	0.93
12% lime	2.45	1.65	1.2	0.85

3.5 Immobilization efficiency

The immobilization efficiency I of the optimum binder dosage for each heavy metal can be evaluated using the equation:

$$E\ (\%) = [(C_o - C_i)/\ C_o] \times 100$$

where C_o is the concentration of heavy metal in untreated samples and C_i is the heavy metal concentration in the leachate from treated samples [6].

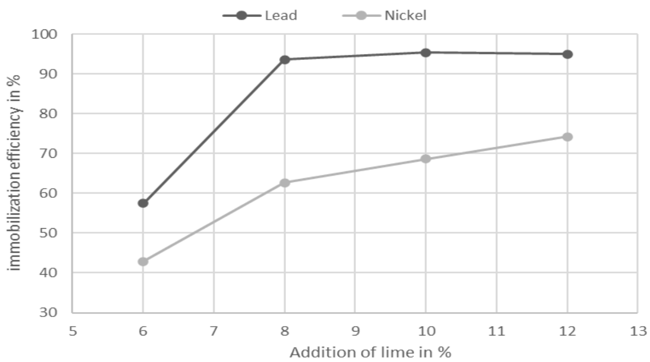

Fig. 5. Immobilization efficiencies achieved by S/S remediation

In Lead contaminated soils, use of lime resulted in 82% improvement over untreated treated sample for a lime content of 10% and on further increase to 12%, the immobilization efficiency decreased. In the case of Nickel, addition of lime did not bring high increase in the immobilization efficiency as in case of Pb, but the immobilization was seen to increase steeply with the increase of lime. The max. immobilization was achieved as 64.87% for a lime content of 12%.

4 Beneficial Use in Pavement

4.1 CBR values

For using the stabilized soil in road pavement, as a top layer of the subgrade it is significant to determine the CBR of the dredged material. Soaked CBR was carried out for this purpose and was tested to be 3.38. On addition of 10% lime, the CBR value increased to 6.15, i.e. an 80% improvement in the CBR value. As per IRC standards CBR should be > 5% for subgrade of roads, which is met by the improved CBR value, suggesting its reusability as a subgrade fill in road pavements.

4.2 Concentration contours

WiscLEACH is software, which was used to analyse the groundwater impact of utilising the stabilized dredged material with 10% lime by predicting the metal concentrations in contour graphs at different years and checking whether it is within the limits of drinking water standards set by WHO and IS:10500-2012 given in table 4.
The input parameter relating to the leaching behaviour of the three metals, lead, nickel and zinc were given from the trace metals concentrations in the column leach tests (CLT) effluents which are summarized in the tables 5 and 6. The thickness and properties of surrounding soil and pavement layer [7] where assumed as shown in Table 8. The porosity and hydraulic conductivity of the stabilized layer with 10% lime were determined in the laboratory as IS standards.

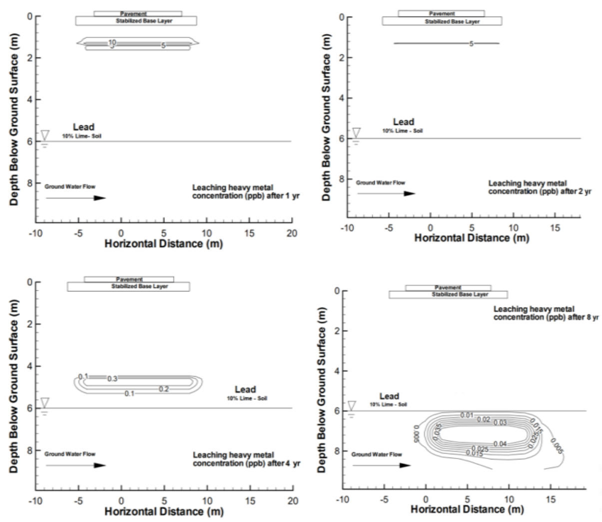

Fig. 6. Predicted Contour of Lead

Fig. 6 and 7 show the contour plots of the predicted concentrations of Pb and Ni in the partially saturated zone as well as the groundwater, respectively. The contour plots provide the predictions of the metal concentrations after 1, 2, 4 and 8 years of construction. From the figures, the metal concentrations in the unsaturated zone decrease significantly with time, which was expected. The metal concentrations decrease with distance from the lime stabilized layer surface and groundwater surface which is most probably due to the dispersion of the metals in the soil. High annual precipitation rate may also have caused an increase in the leaching rate of the metals from lime stabilized base layer and absorbing the metals before reaching to the groundwater. The maximum concentrations of the metals as per the predicted contour when it reaches the groundwater at 6m depth is 0.2ppb for Ni and 0.04ppb for Pb. All of these values are below the drinking water standards set by WHO and also the standards as per IS: 10500-2012 (Table 4).

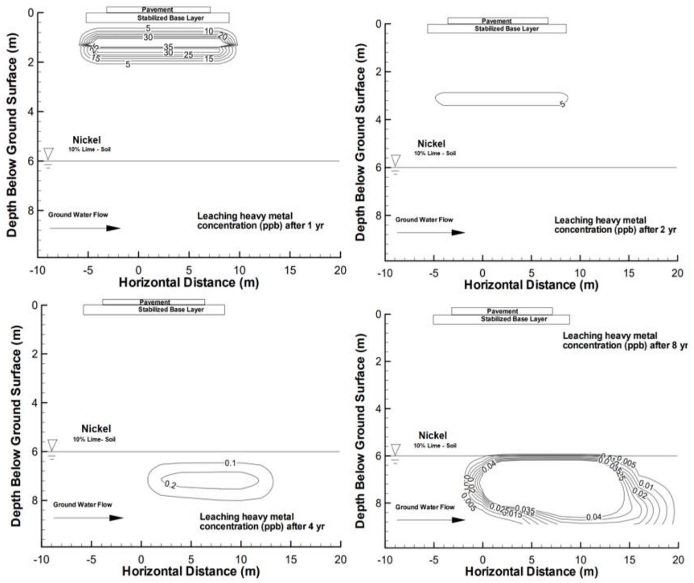

Fig. 7. Predicted Contour of Nickel

5 Conclusion

Akkulam dredged material is contaminated with heavy metals and is categorized as heavily polluted soil in terms of Lead (89 ppm) and Nickel (79 ppm) contamination and is moderately contaminated with Zinc (133 ppm). This makes the utilization of soil or disposal difficult because of the environmental risk. The dredged soil was stabilized with varying percentage of lime, for which the optimum binder dosage was found to be around 10-12% lime depending the UCS values and the immobilization efficiency for different types of heavy metals present. For 10% lime at corresponding OMC, the soaked CBR value has improved from 3.39 to 6.13 after stabilisation, implying that the dredged material can be used as subgrade fill for road pavement as well as for forming play grounds, parking areas, etc.

Lime treatment showed immobilization efficiency of 82% for Pb and 67% for Ni in the Akkulam soil. For Pb the maximum immobilization efficiency was achieved at 10% lime, for Ni the efficiency increased on further increase of lime beyond 10%. Strength of dredged material improved with addition of 10% and 12% lime after a curing period of seven days were above 350 kN/m^2 surpassing the regulatory waste disposal limit and the UCS limit required for in-situ stabilization (USEPA, 2009).

The release of both metals from the soil mixtures in column leach tests exhibited a first-flush pattern followed by a decrease in concentrations. Most of the metals were leached out at the beginning of the tests, and eventually reached an equilibrium concentration over time. This suggests soil washing as a choice of remediating Akkulam dredged material. Numerical simulations on the lime stabilized material showed that the metal concentrations decrease over time and distance. Also, when GWT was at a depth of 6m, all the metals were sufficiently dispersed in the unsaturated zone before reaching the groundwater, such that it would at least take 4 years to reach the groundwater and upon reaching the GWT all the HMs were within the drinking water standards.

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