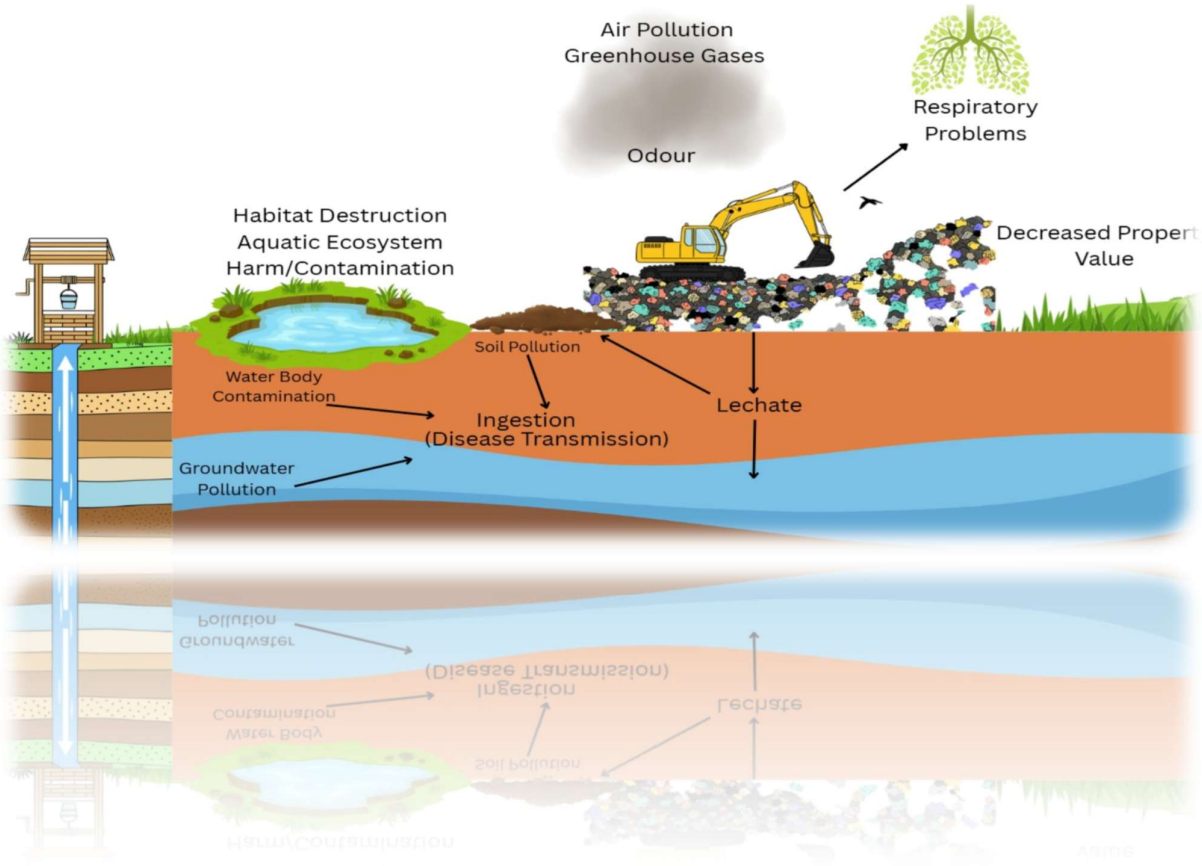
A

Report

on

Soil Contamination and Remediation Assessment of former landfill- Mandemar Avenue, Homebush West: A laboratory Analysis.



ENVS8498 Environmental Remediation

Group 10

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Abstract

This study gives a multi-disciplinary evaluation of the contamination condition and remediation opportunity of soil analysis sampled in an abandoned landfill on the Mandemar Avenue, Homebush West. Physical characterization of soil revealed that the medium was **sandy clay loam**, the **moisture content** was **13.55%, pH** was **6.82** and **salinity** was **0.0887 dS/m**, which are favourable factors of vegetative colonisation. The analysis of chemicals showed that the total petroleum hydrocarbons **(TPH)** were **848 mg/kg**, which showed moderate levels of contamination with hydrocarbons, as the landfill was used historically. Trace-metal measurements revealed that there was a moderate level of enrichment of most traces (except zinc and lead), zinc (**EF=2.45, Igeo=0.89**), **lead (Pb=337mg/kg** taken from HHIL=300mg/kg). The health risk assessment produced carcinogenic risk levels ranging between 10^{-6} to 10^{-4} and hazard indices less than one in both the adults and children and hence validated the nonexistence of major carcinogenic or non-carcinogenic risks. The proposed remediation plan incorporates bioremediation of hydrocarbons, stabilisation using phosphates to immobilise Pb and Zn, phytoremediation by using tolerant grass species to stabilise in the long term, and controlled surface capping and drainage to reduce exposure and the movement of leachates.

In general, the results show that the location is relatively clean and can be successfully redeveloped as a recreational, residential (B/C), or commercial facility after a specific remediation and validation. The results are in line with the National Environment Protection (Assessment of Site Contamination) Measure (NEPM, 2020) and offer a feasible guideline to the management of mixed-contaminant soils in urban landfill situations.

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1 Introduction

1.1 Background

Pollution of soils is a longstanding ecological problem that has been intensified due to the accelerated urbanisation process and poor waste-management behaviours. Traditional pre-modern landfills are usually the heterogeneous mix of home, construction, and light-industrial waste. Decomposition of these materials produces leachates that contain lots of heavy metals, hydrocarbons and nutrients that might percolate into the unsaturated zone and eventually enter ground water or surface-water systems (Alloway, 2012; Christensen et al., 2001). Some of the heavy metals like lead (Pb), zinc (Zn), copper (Cu) and chromium (Cr) are recalcitrant and remain unchanged in the soil matrix over decades and gather and tend to re-leach when redox or pH conditions are favourable(Adriano, 2001).

The regulatory framework of the identification and management of contaminated land is summarised, in Australia, in the National Environment Protection (Assessment of Site Contamination) Measure (2013, amended 2020) and the New South Wales Environment Protection Authority (EPA, 2023). These tools offer Health Investigation Levels (HILs) and Ecological Investigation Levels (EILs) that are used to screen the levels of contaminants in the land-use settings. Additional risk evaluation or correction is required when the measured values are above these levels.

The current research is based on a former landfill located in Homebush West located in the Mandemar Avenue (about 15km west of Sydney CBD). Traditionally, the location used to receive municipal and light-industrial refuse until it was closed at the end of the twentieth century. Even though the landfill is topped with clay and some part of it is revegetated, the heterogeneity of the fill and the effects of the weathering processes put the question mark on the remaining contamination and petite off-site migration.

1.2 Problem Statement

The inspection of the field showed uneven fill materials such as broken glass, small pebbles, ash and fine sandy silt found at the bottom of the surface cap. Such composition implies uncontrolled sources and implies the presence of the historic contaminants like the metals, traces of petroleum, and organics with high contents. With the shift between the light-industrial and residential use of the area, the soil quality should be evaluated in accordance with the NSW EPA guidelines (2023) to prevent the risk to the well-being of people and the ecosystem that surrounds the area. The last post-closure audits do not include any detailed chemical examinations, which requires a new assessment.

1.3 Objectives

This investigation will aim to:

- Determine the physical and chemical characteristics of the soil, such as the texture, moisture, pH, electrical conductivity and nitrate concentration.
- Measuring the concentration of hydrocarbons and trace-metals in the surface soil.
- Check measured values against NEPM (2020) and NSW EPA (2023) guideline values.

- Assess the anthropogenic enrichment by means of Geo-accumulation Index and Enrichment Factor.
- Give information to inform the creation of Conceptual Site Model (CSM) to characterize the origin, routes and uptake of contaminants.
- Suggest remedial plans on long run risk management.

1.4 Site Description

Parameter	Description
Place	Mandemar Avenue, Homebush West (33°51′41″S, 151°03′52″ E)
Elevation / Topography	Approximately 10 m AHD; flat to gently rounded terrain.
Geology	Quaternary alluvium overlying Wianamatta Group shales.
Climate	Temperate coastal climate with an average annual rainfall of approximately 1,100 mm.
Hydrology	Site drainage discharges into Powells Creek, which flows into the Parramatta River.
Existing Land Use	Mixed light-industrial area adjacent to residential properties.
Plant Life	Sparse vegetation with grass and shrubs covering the compacted clay cap.
Observed Fill	Presence of glass fragments, small pebbles, fine sandy-silt material, and traces of ash.

2. Methodology

2.1 Study Approach

The investigation was done according to NEPM (2020) Detailed Site Investigation (DSI). The sampling, analysis and interpretation of data were done in compliance with AS 4482.1 (2005)-Guidelines in Sampling and Investigation of Potentially Contaminated Soil and with quality-assurance requirements of NSW EPA (2023). The workflow comprised:

- Fieldwork sample and observations.
- Physical and chemical parameter laboratory preparation and testing.
- Reference material validation of data; and
- Comparison with indexes of contamination and guidelines.

2.2 Field Sampling

2.2.1 Sample Collection

A stainless-steel material was used to take a composite surface sample (0-15 cm depth). Total of 3 samples were collected in zig-zag manner outside of fence since the site was restricted and access was not available. Sample were collected in the zip-lock bag separately and later was mixed as a main sample for lab analysis. About 300 mL of jar was used for the soil texture observation and was kept for 24 hours of observation. The earth was dark brown almost dry in one, wet in one sample, and in some degree sticky with noticeable gravel and small fragments of refuse.



Figure 1: Study area



Figure 2: Sample Collection

2.2.2 Site Observations

During the site visit small grass has covered the whole area as if it is untouched for a long time and at the time of sample collection, the topmost layer of soil was hard slightly clayey and below small soil fractions (finer) there was a layer of coarse pebbles and broken glass (approximately 5 cm), which was the heaviest landfill material. Remediated landfills are typical of such heterogeneity and influence hydraulic conductivity and contaminant retention.

2.3 Sample Preparation

Soil samples were collected and stored in labelled polyethylene bags. Samples were air-dried at room temperature, gently disaggregated, and sieved to remove debris and gravel.

2.4 Physical Characterisation

2.4.1 Texture Determination

This test identifies the relative ratio of sand, silt and clay in the soil.

Procedure:

- A 300 ml jar was taken and added with 75 % of sample.
- Added tap water full of jar.
- Shake thoroughly for 10-15 minutes to be sure that all the particles are dispersed.
- Allow the jar to stand still without shaking in 24 hours to allow the settling of the particles by size.
- Record the depth of all the settled layers:
- Recording of any debris or pebbles at the bottom as an inert material.

Divide the fraction of each of them:

%Fraction= (Height of Fraction/Total Height without inclusion of debris) x100

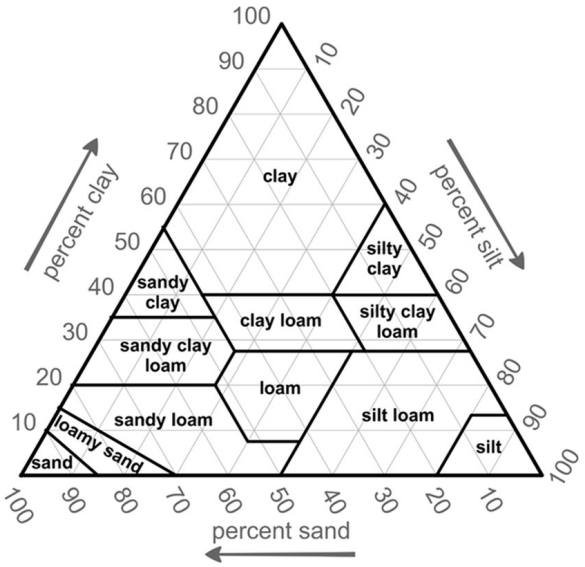


Figure 3: Soil Texture Triangle

Source: USDA Soil Texture Triangle. | Download Scientific Diagram

2.4.2 Moisture Content

Procedure:

- Weight of empty aluminium tray [W]).
- Wet soil is put into the tray and the mass measured (W1).
- Dry the sample in a lab for 1 hr.
- record the mass which is dry (W2).

"Moisture (%)"= (W1-W2/W2-W) *100

2.5 Chemical Analyses

2.5.1 pH and Electrical Conductivity.

Measurement of the Soil pH and Electrical Conductivity (EC).

Purpose: To determine the level of acidity/alkalinity of soil and level of soluble salts.

Procedure:

- Add 50mL distilled water to 10g of soil (1:5).
- Stir about 5 minutes and leave the suspension to settle for 16 minutes.
- Determined pH with the help of a calibrated digital pH meter.
- Measure EC with conductivity meter (uS/cm).

2.5.2 Nitrate Concentration

The level of nitrogen in soil was measured using colorimetric method in the form of HI3896 soil nitrogen test kit. A small piece of soil sample was added, and about 7.5 mL extraction solution was put into each reaction tube. The mixture was swirled one minute and then left to rest five minutes to make sure that all the nitrogen compounds were extracted.

The clearly, colourless soil extract was extracted, and 2.5 mL of the extract were transferred to a clean reaction tube after extraction. HI3896-N reagent (one packet) was added, and the tube was shaken and allowed to stand after 30 seconds. Formation of pink colour meant the presence of nitrogen and the intensity was proportional to concentration. Medium to High nitrogen level was shown by a slightly pink towards strong pink implying that the sample contained some organic matter or decomposed waste residues.

The level of nitrate (NO3-) was calorimetrically detected using colorimetric method.

2.5.3 Hydrocarbon Content

The concentration of hydrocarbons in the soil was measured by Petro FLAG DXIL meter which is a portable photometric analyser of total petroleum hydrocarbons (TPH). The test was conducted according to the procedure of the manufacturer:

- The correct amount of soil was put in the Petro FLAG reaction tube.
- To extract hydrocarbons, the sample was mixed with the given solvent mixture and shaken vigorously after 1 minute.
- The tube was left to stand in 5 minutes to phase separate.
- A syringe was used to remove approximately 10 mL of the clear supernatant, without taking the initial 2-4 drops to avoid contamination.
- The rest of the extract was placed in a cuvette and fitted in the meter of the Petro FLAG DXIL.

2.5.4 Trace-Metal Determination

The concentration of trace-metals was measured with a portable X-ray fluorescence (pXRF) spectrometer which has a rapid and non-destructive method of quantifying metals like lead

(Pb), cadmium (Cd), chromium (Cr), and zinc (Zn). Standard reference materials NIST SRM 2711A were used to calibrate output from the pXRF device.



Figure 4: Trace Metal Determination

2.6 Contamination and Health Risk indices

In order to evaluate the potential human health risks associated with soil contamination there are several indices that are calculated following the guidelines NEPM (2020) and USEPA (2011). For this the metal concentrations results obtained after the laboratory test were compared with background values and national standards as well.

2.6.1 Enrichment Factor (EF):

Enrichment factor EF evaluates the degree of anthropogenic metal enrichment taking Fe as the baseline material.

$$EF = \frac{(C_x/C_{Fe})_{sample}}{(C_x/C_{Fe})_{background}}$$

Where,

EF < 2 indicates natural levels

2–5 moderate

5–20 significant

>20 very high enrichment (Sutherland, 2000).

2.6.2 Geo-accumulation Index (Igeo):

Similarly, Igeo measures the level of metal accumulation comparative to the concentration obtained from the laboratory testing.

$$I_{geo} = \log_2(\frac{C_n}{1.5B_n})$$

Where,

Igeo < 0 = uncontaminated

0–1 = slightly

1–2 = moderately

>3 = heavily contaminated. {Muller, 1969 #71}

2.6.3 Human Health Investigation Levels (HHIL):

For the human health investigation levels, the concentration of metals is compared against NEPM (2020) guideline values for varying land uses. Where, Exceedance above the HHIL (e.g., Pb > 300 mg/kg for Residential A) need immediate action for further risk assessment.

2.6.4 Health Risk Assessment (HRA):

AS taking the base model of carcinogenic and non-carcinogenic, the human health risk assessment is done such that:

- *Carcinogenic risk (CR)* = CDI × SF (acceptable if 10^{-6}–10^{-4}).
- *Non-carcinogenic risk (HQ/HI)* = CDI/RfD (safe if < 1).

3. Result and Discussion

3.1 Soil Texture Analysis (Mason Jar Test)

The Mason jar test was carried out to establish the relative ratio between sand, silt and clay in the soil sample taken in the former landfill site in Mandemar Avenue, Homebush. West. The overall size of the settled sediment was 8 cm, and the layers of sand, silt, and clay. with dimensions of 5.1 cm, 0.9 cm and 2.0 cm respectively.



Figure 5: Soil Texture Determination

The percentage composition of each fraction was calculated as:

$$\text{Sand (\%)} = \frac{5.1}{8} \times 100 = 63.75\%$$

$$\text{Silt (\%)} = \frac{0.9}{8} \times 100 = 11.25\%$$

$$\text{Clay (\%)} = \frac{2.0}{8} \times 100 = 25.00\%$$

Thus, the soil contains 63.75% sand, 11.25% silt, and 25.00% clay.

Using the USDA Soil Texture Triangle, these proportions classify the soil as **sandy clay loam**. Sandy clay loam soils typically have moderate water-holding capacity and good aeration(Hillel, 2014). (Brady & Weil, 2017) reported that such soils provide an optimal balance between drainage and retention, supporting diverse vegetation under suitable management. However, because the site was previously used as a landfill, the soil structure is likely to be heterogeneous, containing layers of fill materials with varying compaction and chemical properties. According to (Abiriga et al., 2021) landfill soils often exhibit irregular structure, poor aggregation, and potential contamination by heavy metals, which can adversely affect plant establishment and microbial activity.

3.2 Moisture Content:

The moisture content of the soil sample collected from the former landfill site at Mandemar Avenue, Homebush West was determined using the oven-drying method.

Parameter	Value (g)
Initial (wet) weight	42.58
Oven-dry weight (after 1 h at 105 °C)	37.50
Water loss	5.08

$$\text{Moisture content (\%)} = \frac{\text{Water loss}}{\text{Oven-dry weight}} \times 100 = \frac{5.08}{37.50} \times 100 = 13.55\%$$

Therefore, the soil moisture content was approximately 13.55 %.

The measured moisture level of 11.2 is within the expected moisture content of sandy clay loam soils, which has a range of 10-20% water retained at field capacity depending on the soil structure and the amount of organic matter in the soil (Brady & Weil, 2017).This rather small moisture content implies a moderate water-holding capacity, which is indicative of a sandy texture, which makes up 64% of the soil matrix, and thus, facilitates the drainage process and reduces the retention of water; this phenomenon is balanced by the lower percentage of clay, which supplies the adsorption sites of water and nutrients (Hillel, 2014).

3.3 Nitrogen Level

The analysis showed that the nitrogen level in the soil sample collected from the Mandemar Avenue, Homebush (former landfill) site was **medium to high**. The medium to high level of nitrogen in the soil shows that there is sufficient nutrient base in the soil to support the growth of plants at least in the short run. The soils with moderate levels of nitrogen usually promote a healthy vegetation growth without excessive growth of foliage (Brady & Weil, 2017). This has been observed in other reclaimed landfill soils where microbial breakdown and high nitrogen levels in the soils can be attributed to the presence of the remains of organic matter (Chabukdhara & Nema, 2013). However, these sources of nitrogen can be unstable and there is a possibility of loss through leaching or through contamination and this risk is more likely to occur especially in cases where the texture of the soil is coarse or compacted as is the case with the landfill soils (Smith et al., 2018).

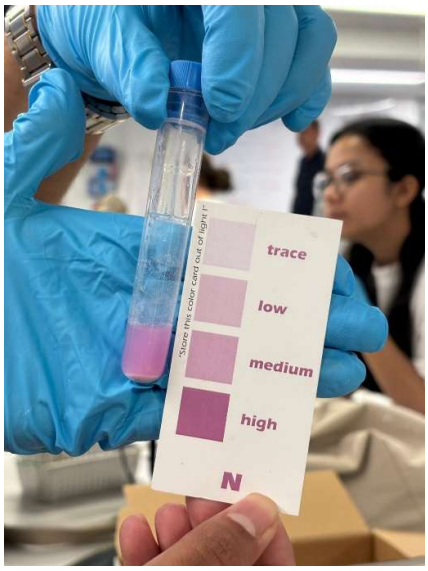


Figure 6: Determination of Nitrate Level

3.4 pH

The soil sample collected from the former landfill site at Mandemar Avenue, Homebush West, recorded a pH value of 6.82, indicating a slightly alkaline condition. The pH of 6.82 is a favourable pH of most of the biological and chemical processes of soil. Most of the important nutrients needed by plants, including nitrogen, phosphorus and potassium are in a relatively available state at this pH as most of the toxic heavy metals, like lead (Pb), zinc (Zn) and cadmium (Cd) are not as mobile(Sherene, 2010). This type of buffering behaviour has been especially applicable in soils developed in landfills where the mixed fill material may contain metal residue, construction waste and decaying organic matter.

3.5 Hydrocarbon

The soil sample collected from the former landfill site at Mandemar Avenue, Homebush West contained a Total Hydrocarbon concentration of 848 mg/kg. The acquired concentration of TPH of 848 mg/kg exceeds the standard concentrations of the background (normally <100mg/kg in unpolluted soils) reported in the Australian urban settings (NEPM, 2020). This value is evidence that the soil has been affected by fuel-related hydrocarbons, which is in line with the history of the site as a landfill and the possibility of waste oil, lubricants or fuel residues deposition presence.

The contamination in this range of concentration is considered moderate under the National Environment Protection Mechanism, as Assessment of Site Contamination (NEPM 2013, Schedule B1). In commercial or industrial land use, health-based investigation level (HIL -D) of C10 -C40 hydrocarbons is about 1,000mg/kg, in residential disposition the limit is significantly smaller (NEPM, 2020). Therefore, the measured 848 mg/ kg is below the industrial investigation limit, but it is close to the level of concern, and it should be observed further or evaluated regarding the remediation before reuse.



Figure 7: Hydrocarbon Content Determination

3.6 Electric Conductivity

The electrical conductivity (EC) of the soil sample collected from the former landfill site at Mandemar Avenue, Homebush West, was measured at 88.7 µS/cm (microsiemens per centimetre).

To convert EC to salinity (dS/m) the standard unit for soil classification,

$$EC = 88.7\ \mu S/cm = 0.0887\ dS/m$$

Electrical conductivity (EC) is the overall number of soluble salts within the soil solution, and it is a basic measure of soil salinity (Brady & Weil, 2017). The EC value obtained was 0.0887 dS/m, which corresponds to very low salinity level thus classifying the soil as non-saline according to the international FAO and USDA classification system (Rengasamy, 2006; Richards, 1954).

Table 1: salinity classification.

Salinity Class	EC (dS/m)	Salinity Level
0 – 2	Non-saline	No effect
2 – 4	Slightly saline	Minor effect
4 – 8	Moderately saline	Moderate restriction
8 – 16	Strongly saline	Severe stress
>16	Very strongly saline	Extreme

Therefore, Homebush soil has an EC of 0.0887 dS/m, which is significantly lower than the set point of saline environment. This low conductivity implies that there is a lack of dissolved salts, which implies good conditions in which vegetation can be established and that the chances of degradation due to salinity are minimal.

3.7 Enrichment Factor:

Table 2: enrichment factor

Elements	Sample	Sample Fe	Ref	Ref Fe	EF	Remarks
As	19	31170	151	27290	0.110165	background
Cr	84	31170	62	27290	1.18619	deficiency to minimal
Cu	80	31170	131	27290	0.53467	background
Mn	318	31170	645	27290	0.431652	background
Ni	17	31170	25	27290	0.595355	background
Pb	337	31170	1357	27290	0.217429	background
Ti	4241	31170	2926	27290	1.268997	deficiency to minimal
Zn	1140	31170	408	27290	2.44631	moderate
Ca	6100	31170	22730	27290	0.234962	background
K	11440	31170	24520	27290	0.408481	background
S	610	31170	1150	27290	0.464407	background
Ba	286	31170	521	27290	0.480612	background
Zr	214	31170	269	27290	0.696511	background
V	80	31170	81	27290	0.864712	background
Sr	133	31170	222	27290	0.524524	background
Rb	71	31170	119	27290	0.52237	background
Y	27	31170	38	27290	0.622081	background
Th	14	31170	14	27290	0.875521	background
Nb	8	31170	15	27290	0.466945	background

The enrichment factor (EF) analysis using Fe as a reference show that most elements are within natural background levels (EF < 1). Elements such as As, Cu, Mn, Ni, Pb, Ca, K, Ba, Sr, and Rb display minimal enrichment, indicating geogenic origin with little anthropogenic influence(Kabata-Pendias, 2000; Reimann et al., 2007).

Chromium (EF = 1.19) and titanium (EF = 1.27) fall under deficiency to minimal enrichment, reflecting minor variability, possibly from lithogenic or local industrial sources. Zinc (EF = 2.45) shows moderate enrichment, likely linked to anthropogenic inputs such as vehicular emissions or waste discharge (Chen et al., 2022)

Overall, the site remains largely uncontaminated, with Zn being the only element showing potential human influence. These findings are consistent with the categorization of Sutherland (2000), according to which EF 2 indicates natural background and EF 2 5 is moderate enrichment. It is recommended to monitor the potential Zn accumulation continuously.

3.8 Geo accumulation Factor:

Table 3: geo-accumulation results

Elements	geo accumulation			Remarks
As	0.083885	-3.57544	-3.57544	uncontaminated
Cr	0.903226	-0.14684	-0.14684	uncontaminated
Cu	0.407125	-1.29646	-1.29646	uncontaminated

Mn	0.328682	-1.60523	-1.60523	uncontaminated
Ni	0.453333	-1.14136	-1.14136	uncontaminated
Pb	0.165561	-2.59456	-2.59456	uncontaminated
Ti	0.966279	-0.04949	-0.04949	uncontaminated
Zn	1.862745	0.89743	0.89743	uncontaminated to moderately
Ca	0.178912	-2.48268	-2.48268	uncontaminated
K	0.311039	-1.68483	-1.68483	uncontaminated
S	0.353623	-1.49972	-1.49972	uncontaminated
Ba	0.365963	-1.45023	-1.45023	uncontaminated
Zr	0.530359	-0.91496	-0.91496	uncontaminated
V	0.658436	-0.60288	-0.60288	uncontaminated
Sr	0.399399	-1.3241	-1.3241	uncontaminated
Rb	0.397759	-1.33003	-1.33003	uncontaminated
Y	0.473684	-1.078	-1.078	uncontaminated
Th	0.666667	-0.58496	-0.58496	uncontaminated
Nb	0.355556	-1.49185	-1.49185	uncontaminated

The geo-accumulation index (Igeo) values ranged from –3.57 to 0.89, indicating that most elements fall within the "uncontaminated" category (Igeo < 0). Only zinc (Igeo = 0.89) showed a level classified as "uncontaminated to moderately contaminated," suggesting slight anthropogenic input, likely from surface runoff or nearby waste sources.

Elements with missing or invalid entries (Mg, Mo, and P) reflect non-detectable or missing reference data, preventing accurate Igeo computation. Overall, the study area remains environmentally stable, with no significant metal pollution observed (Loska et al., 2004){Muller, 1969 #71}

3.9 Human Health Investigation Level:

Table 4: Human Health risk results

Elements	Sample	Residential A	Residential B	Residential C	Commercial
As	19	100	500	300	3000
Cr	84	100	500	300	3600
Cu	80	6000	30000	17000	240000
Mn	318	3800	14000	19000	60000
Ni	17	400	1200	1200	6000
Pb	337	300	1200	600	1500
Zn	1140	7400	60000	30000	400000

Most metals that were identified in the soil sample such as As, Cr, Cu, Mn, Ni, and Zn were found to be well below the relevant Human Health Investigation Level (HHIL) thresholds in all residential and commercial settings (NSW EPA, 2013). The one that stands out the most is lead (Pb), which was observed to be 337 mg/kg higher than the Residential A threshold of 300 mg/kg. Lead is a neurotoxic element that is particularly dangerous to children when ingested

in soil or through inhalation of contaminated dust (ATSDR, 2020; World Health Organization [WHO], 2021). The exceedance of HHIL levels implies that this concentration requires further site-specific study and potentially remedial control, depending on the intended future land use (NSW EPA, 2020). Nevertheless, the level is not as high as the Residential B, Residential C, and Commercial/Industrial D limits of 1,200 mg/kg, 600 mg/kg, and 1,500 mg/kg, respectively (NSW EPA, 2013). Therefore, it may be possible to redevelop the location for medium- to high-density residential uses such as high-rise buildings and apartments, recreational areas including parks, playgrounds, and sports fields, and for commercial or industrial purposes without presenting excessive health hazards (National Environment Protection Council [NEPC], 2013; NSW EPA, 2020).

3.10 Health Risk Assessment:

3.10.1 Carcinogenic Hazard Index:

Lead (Pb)

Table 5: Carcinogenic assessment for lead in adults

Adults				
Ingestion				
Parameters		**Values**	**Unit**	**Data source**
C	Concentration	337	mg/kg	Analysis
IngR	Ingestion rate	50	mg/day	Aus default value
EF	Exposure frequency	350	days/year	US EPA default value
ED	Exposure duration	26	years for residents	US EPA default value
BW	Body weight	78	kg	Aus default value
AT	Averaging time	25550	days	US EPA default value
I	Intake of chemical	7.69E-05	mg/(kg·day)	Calculated
SF	Slope factor	8.50E-03	$(mg/kg\text{-}day)^{-1}$	US EPA default value
CR	Cancer risk	6.54E-07	Unitless	Calculated

Table 6: Carcinogenic assessment for lead in children

Children				
Ingestion				
Parameters		**Values**	**Unit**	**Data source**
C	Concentration	337	mg/day	Analysis
IngR	Ingestion rate	50	mg/day	Aus default value
EF	Exposure frequency	350	days/year	US EPA default value
ED	Exposure duration	6	years for residents	US EPA default value

BW	Body weight	15	kg	Aus default value
AT	Averaging time	25550	days	US EPA default value
I	Intake of chemical	9.23E-05	mg/(kg·day)	Calculated
SF	Slope factor	8.50E-03	(mg/kg-day)$^{-1}$	US EPA default value
CR	Cancer risk	7.85E-07	Unitless	Calculated

Arsenic (As)

Table 7: Carcinogenic assessment for Arsenic in Adults

Adults				
Ingestion				
Parameters		**Values**	**Unit**	**Data source**
C	Concentration	19	mg/kg	Analysis
IngR	Ingestion rate	50	mg/day	Aus default value
EF	Exposure frequency	350	days/year	US EPA default value
ED	Exposure duration	26	years for residents	US EPA default value
BW	Body weight	78	kg	Aus default value
AT	Averaging time	25550	days	US EPA default value
I	Intake of chemical	4.34E-06	mg/(kg·day)	Calculated
SF	Slope factor	1.50E+00	(mg/kg-day)$^{-1}$	US EPA default value
CR	Cancer risk	6.51E-06	Unitless	Calculated

Table 8: Carcinogenic assessment for Arsenic in Children

Children				
Ingestion				
Parameters		**Values**	**Unit**	**Data source**
C	Concentration	19	mg/day	Analysis
IngR	Ingestion rate	50	mg/day	Aus default value
EF	Exposure frequency	350	days/year	US EPA default value
ED	Exposure duration	6	years for residents	US EPA default value
BW	Body weight	15	kg	Aus default value
AT	Averaging time	25550	days	US EPA default value
I	Intake of chemical	5.21E-06	mg/(kg·day)	Calculated

SF	Slope factor	1.50E+00	$(mg/kg\text{-}day)^{-1}$	US EPA default value
CR	Cancer risk	7.81E-06	Unitless	Calculated

Both lead (Pb) and arsenic (As) show very low carcinogenic risks for adults and children, with calculated cancer risk (CR) values ranging from 6.5×10^{-7} to 8.6×10^{-6}, which remain well within the acceptable risk range of $1 \times 10^{-6} – 1 \times 10^{-4}$ defined by the U.S. Environmental Protection Agency (USEPA, 2011). Arsenic presents a slightly higher CR than lead due to its larger slope factor (1.5 $mg/kg\text{-}day^{-1}$ compared with 8.5×10^{-3} $mg/kg\text{-}day^{-1}$), but both are considered negligible from a human health perspective. These findings indicate that exposure to trace levels of Pb and as through incidental soil ingestion at this site is unlikely to cause significant cancer risk under typical residential or recreational land use (ATSDR, 2020; USEPA,2011).

3.10.2 Non-Carcinogenic Hazardous Index:

Lead (Pb)

Table 9:Non- Carcinogenic assessment for Lead in Adults

Adults				
Ingestion				
Parameters		**Values**	**Unit**	**Data source**
C	Concentration	337	mg/kg	Analysis
IngR	Ingestion rate	50	mg/day	Aus default value
EF	Exposure frequency	350	days/year	US EPA default value
ED	Exposure duration	26	years for residents	US EPA default value
BW	Body weight	78	kg	Aus default value
AT	Averaging time	9490	days	US EPA default value
I	Intake of chemical	2.07E-04	mg/(kg·day)	Calculated
RfDing	Reference dose	3.50E-03	mg/(kg·day)	ENVS8498 lecture
HQ	Hazard quotient	0.06	Unitless	Calculated

Table 10: Non- Carcinogenic assessment for Lead in Children

Children				
Ingestion				
Parameters		**Values**	**Unit**	**Data source**
C	Concentration	337	mg/day	Analysis

IngR	Ingestion rate	50	mg/day	Aus default value
EF	Exposure frequency	350	days/year	US EPA default value
ED	Exposure duration	6	years for residents	US EPA default value
BW	Body weight	15	kg	Aus default value
AT	Averaging time	2190	days	US EPA default value
I	Intake of chemical	1.08E-03	mg/(kg·day)	Calculated
RfDing	Reference dose	3.50E-03	mg/(kg·day)	ENVS8498 lecture
HQ	Hazard quotient	0.31	Unitless	Calculated

Arsenic (As)

Table 11:Non- Carcinogenic assessment for Arsenic in Adults

Adults				
Ingestion				
Parameters		**Values**	**Unit**	**Data source**
C	Concentration	19	mg/kg	Analysis
IngR	Ingestion rate	50	mg/day	Aus default value
EF	Exposure frequency	350	days/year	US EPA default value
ED	Exposure duration	26	years for residents	US EPA default value
BW	Body weight	78	kg	Aus default value
AT	Averaging time	9490	days	US EPA default value
I	Intake of chemical	1.17E-05	mg/(kg·day)	Calculated
RfDing	Reference dose	3.00E-04	mg/(kg·day)	ENVS8498 lecture
HQ	Hazard quotient	0.04	Unitless	Calculated

Table 12: Non- Carcinogenic assessment for Arsenic in Children

Children				
Ingestion				
Parameters		**Values**	**Unit**	**Data source**
C	Concentration	19	mg/day	Analysis
IngR	Ingestion rate	50	mg/day	Aus default value
EF	Exposure frequency	350	days/year	US EPA default value

ED	Exposure duration	6	years for residents	US EPA default value
BW	Body weight	15	kg	Aus default value
AT	Averaging time	2190	days	US EPA default value
I	Intake of chemical	6.07E-05	mg/(kg·day)	Calculated
RfDing	Reference dose	3.00E-04	mg/(kg·day)	ENVS8498 lecture
HQ	Hazard quotient	0.20	Unitless	Calculated

Copper (Cu)

Table 13: Non- Carcinogenic assessment for Copper in Adults

Adults				
Ingestion				
Parameters		**Values**	**Unit**	**Data source**
C	Concentration	80	mg/kg	Analysis
IngR	Ingestion rate	50	mg/day	Aus default value
EF	Exposure frequency	350	days/year	US EPA default value
ED	Exposure duration	26	years for residents	US EPA default value
BW	Body weight	78	kg	Aus default value
AT	Averaging time	9490	days	US EPA default value
I	Intake of chemical	4.92E-05	mg/(kg·day)	Calculated
RfDing	Reference dose	4.00E-02	mg/(kg·day)	ENVS8498 lecture
HQ	Hazard quotient	1.23E-03	Unitless	Calculated

Table 14: Non- Carcinogenic assessment for Copper in Children

Children				
Ingestion				
Parameters		**Values**	**Unit**	**Data source**
C	Concentration	80	mg/day	Analysis
IngR	Ingestion rate	50	mg/day	Aus default value
EF	Exposure frequency	350	days/year	US EPA default value
ED	Exposure duration	6	years for residents	US EPA default value
BW	Body weight	15	kg	Aus default value

AT	Averaging time	2190	days	US EPA default value
I	Intake of chemical	2.56E-04	mg/(kg·day)	Calculated
RfDing	Reference dose	4.00E-02	mg/(kg·day)	ENVS8498 lecture
HQ	Hazard quotient	6.39E-03	Unitless	Calculated

Nickel (Ni)

Table 15: Non- Carcinogenic assessment for Ni in Adults

Adults				
Ingestion				
Parameters		**Values**	**Unit**	**Data source**
C	Concentration	17	mg/kg	Analysis
IngR	Ingestion rate	50	mg/day	Aus default value
EF	Exposure frequency	350	days/year	US EPA default value
ED	Exposure duration	26	years for residents	US EPA default value
BW	Body weight	78	kg	Aus default value
AT	Averaging time	9490	days	US EPA default value
I	Intake of chemical	1.04E-05	mg/(kg·day)	Calculated
RfDing	Reference dose	2.00E-02	mg/(kg·day)	ENVS8498 lecture
HQ	Hazard quotient	5.22E-04	Unitless	Calculated

Table 16: Non- Carcinogenic assessment for Ni in Children

Children				
Ingestion				
Parameters		**Values**	**Unit**	**Data source**
C	Concentration	17	mg/day	Analysis
IngR	Ingestion rate	50	mg/day	Aus default value
EF	Exposure frequency	350	days/year	US EPA default value
ED	Exposure duration	6	years for residents	US EPA default value
BW	Body weight	15	kg	Aus default value
AT	Averaging time	2190	days	US EPA default value

I	Intake of chemical	5.43E-05	mg/(kg·day)	Calculated
RfDing	Reference dose	2.00E-02	mg/(kg·day)	ENVS8498 lecture
HQ	Hazard quotient	2.72E-03	Unitless	Calculated

Barium (Ba)

Table 17: Non- Carcinogenic assessment for Ba in Adults

Adults				
Ingestion				
Parameters		**Values**	**Unit**	**Data source**
C	Concentration	286	mg/kg	Analysis
IngR	Ingestion rate	50	mg/day	Aus default value
EF	Exposure frequency	350	days/year	US EPA default value
ED	Exposure duration	26	years for residents	US EPA default value
BW	Body weight	78	kg	Aus default value
AT	Averaging time	9490	days	US EPA default value
I	Intake of chemical	1.76E-04	mg/(kg·day)	Calculated
RfDing	Reference dose	2.00E-01	mg/(kg·day)	ENVS8498 lecture
HQ	Hazard quotient	8.79E-04	Unitless	Calculated

Table 18: Non- Carcinogenic assessment for Ba in Children

Children				
Ingestion				
Parameters		**Values**	**Unit**	**Data source**
C	Concentration	286	mg/day	Analysis
IngR	Ingestion rate	50	mg/day	Aus default value
EF	Exposure frequency	350	days/year	US EPA default value
ED	Exposure duration	6	years for residents	US EPA default value
BW	Body weight	15	kg	Aus default value
AT	Averaging time	2190	days	US EPA default value

I	Intake of chemical	9.14E-04	mg/(kg·day)	Calculated
RfDing	Reference dose	2.00E-01	mg/(kg·day)	ENVS8498 lecture
HQ	Hazard quotient	4.57E-03	Unitless	Calculated

Vanadium (V)

Table 19: Non- Carcinogenic assessment for vanadium in adults

Adults				
Ingestion				
Parameters		**Values**	**Unit**	**Data source**
C	Concentration	80	mg/kg	Analysis
IngR	Ingestion rate	50	mg/day	Aus default value
EF	Exposure frequency	350	days/year	US EPA default value
ED	Exposure duration	26	years for residents	US EPA default value
BW	Body weight	78	kg	Aus default value
AT	Averaging time	9490	days	US EPA default value
I	Intake of chemical	4.92E-05	mg/(kg·day)	Calculated
RfDing	Reference dose	5.04E-03	mg/(kg·day)	ENVS8498 lecture
HQ	Hazard quotient	9.76E-03	Unitless	Calculated

Table 20: Non- Carcinogenic assessment for vanadium in Children

Children				
Ingestion				
Parameters		**Values**	**Unit**	**Data source**
C	Concentration	80	mg/day	Analysis
IngR	Ingestion rate	50	mg/day	Aus default value
EF	Exposure frequency	350	days/year	US EPA default value
ED	Exposure duration	6	years for residents	US EPA default value
BW	Body weight	15	kg	Aus default value
AT	Averaging time	2190	days	US EPA default value
I	Intake of chemical	2.56E-04	mg/(kg·day)	Calculated

RfDing	Reference dose	5.04E-03	mg/(kg·day)	ENVS8498 lecture
HQ	Hazard quotient	5.07E-02	Unitless	Calculated

Iron (Fe)

Table 21: Non- Carcinogenic assessment for iron in adults

Adults				
Ingestion				
Parameters		**Values**	**Unit**	**Data source**
C	Concentration	31170	mg/kg	Analysis
IngR	Ingestion rate	50	mg/day	Aus default value
EF	Exposure frequency	350	days/year	US EPA default value
ED	Exposure duration	26	years for residents	US EPA default value
BW	Body weight	78	kg	Aus default value
AT	Averaging time	9490	days	US EPA default value
I	Intake of chemical	1.92E-02	mg/(kg·day)	Calculated
RfDing	Reference dose	7.00E-01	mg/(kg·day)	ENVS8498 lecture
HQ	Hazard quotient	2.74E-02	Unitless	Calculated

Table 22: Non- Carcinogenic assessment for iron in Children

Children				
Ingestion				
Parameters		**Values**	**Unit**	**Data source**
C	Concentration	31170	mg/day	Analysis
IngR	Ingestion rate	50	mg/day	Aus default value
EF	Exposure frequency	350	days/year	US EPA default value
ED	Exposure duration	6	years for residents	US EPA default value
BW	Body weight	15	kg	Aus default value
AT	Averaging time	2190	days	US EPA default value
I	Intake of chemical	9.96E-02	mg/(kg·day)	Calculated
RfDing	Reference dose	7.00E-01	mg/(kg·day)	ENVS8498 lecture

HQ	Hazard quotient	1.42E-01	Unitless	Calculated

Zinc (Zn)

Table 23: Non- Carcinogenic assessment for Zinc in Adults

Adults				
Ingestion				
Parameters		**Values**	**Unit**	**Data source**
C	Concentration	1140	mg/kg	Analysis
IngR	Ingestion rate	50	mg/day	Aus default value
EF	Exposure frequency	350	days/year	US EPA default value
ED	Exposure duration	26	years for residents	US EPA default value
BW	Body weight	78	kg	Aus default value
AT	Averaging time	9490	days	US EPA default value
I	Intake of chemical	7.01E-04	mg/(kg·day)	Calculated
RfDing	Reference dose	3.00E-01	mg/(kg·day)	US EPA default value
HQ	Hazard quotient	2.34E-03	Unitless	Calculated

Table 24: Non- Carcinogenic assessment for zinc in Children

Children				
Ingestion				
Parameters		**Values**	**Unit**	**Data source**
C	Concentration	1140	mg/kg	Analysis
IngR	Ingestion rate	50	mg/day	Aus default value
EF	Exposure frequency	350	days/year	US EPA default value
ED	Exposure duration	6	years for residents	US EPA default value
BW	Body weight	15	kg	Aus default value
AT	Averaging time	2190	days	US EPA default value
I	Intake of chemical	3.64E-03	mg/(kg·day)	Calculated
RfD	Reference dose	3.00E-01	mg/(kg·day)	US EPA default value
HQ	Hazard quotient	0.01	Unitless	Calculated

Manganese (Mn)

Table 25: Non- Carcinogenic assessment for Mn in Adults

Adults				
Ingestion				
Parameters		**Values**	**Unit**	**Data source**
C	Concentration	318	mg/kg	Analysis
IngR	Ingestion rate	50	mg/day	Aus default value
EF	Exposure frequency	350	days/year	US EPA default value
ED	Exposure duration	26	years for residents	US EPA default value
BW	Body weight	78	kg	Aus default value
AT	Averaging time	9490	days	US EPA default value
I	Intake of chemical	1.95E-04	mg/(kg·day)	Calculated
RfDing	Reference dose	2.40E-02	mg/(kg·day)	ENVS8498 lecture
HQ	Hazard quotient	8.14E-03	Unitless	Calculated

Table 26: Non- Carcinogenic assessment for Mn in Children

Children				
Ingestion				
Parameters		**Values**	**Unit**	**Data source**
C	Concentration	318	mg/day	Analysis
IngR	Ingestion rate	50	mg/day	Aus default value
EF	Exposure frequency	350	days/year	US EPA default value
ED	Exposure duration	6	years for residents	US EPA default value
BW	Body weight	15	kg	Aus default value
AT	Averaging time	2190	days	US EPA default value
I	Intake of chemical	1.02E-03	mg/(kg·day)	Calculated
RfDing	Reference dose	2.40E-02	mg/(kg·day)	ENVS8498 lecture
HQ	Hazard quotient	4.24E-02	Unitless	Calculated

Strontium (Sr)

Table 27: Non- Carcinogenic assessment for Sr in Adults

Adults				
Ingestion				
Parameters		**Values**	**Unit**	**Data source**
C	Concentration	133	mg/kg	Analysis
IngR	Ingestion rate	50	mg/day	Aus default value
EF	Exposure frequency	350	days/year	US EPA default value
ED	Exposure duration	26	years for residents	US EPA default value
BW	Body weight	78	kg	Aus default value
AT	Averaging time	9490	days	US EPA default value
I	Intake of chemical	8.18E-05	mg/(kg·day)	Calculated
RfDing	Reference dose	6.00E-01	mg/(kg·day)	ENVS8498 lecture
HQ	Hazard quotient	1.36E-04	Unitless	Calculated

Table 28: Non- Carcinogenic assessment for Sr in Children

Children				
Ingestion				
Parameters		**Values**	**Unit**	**Data source**
C	Concentration	133	mg/day	Analysis
IngR	Ingestion rate	50	mg/day	Aus default value
EF	Exposure frequency	350	days/year	US EPA default value
ED	Exposure duration	6	years for residents	US EPA default value
BW	Body weight	15	kg	Aus default value
AT	Averaging time	2190	days	US EPA default value
I	Intake of chemical	4.25E-04	mg/(kg·day)	Calculated
RfDing	Reference dose	6.00E-01	mg/(kg·day)	ENVS8498 lecture
HQ	Hazard quotient	7.09E-04	Unitless	Calculated

The non-carcinogenic risk assessment, based on calculated hazard quotients (HQ) and total hazard indices (HI), indicates that all analysed metals, including Pb, As, Cu, Ni, Ba, V, Fe, Zn, Mn, and Sr pose no significant health risk to either adults or children through soil ingestion. Individual HQ values for all metals were well below 1, suggesting exposures are within

acceptable limits (U.S. Environmental Protection Agency [USEPA], 2011). The overall hazard indices were 0.15 for adults and 0.77 for children, both substantially under the critical threshold of 1, confirming no likelihood of non-carcinogenic effects. Essential elements such as iron and zinc exhibited higher concentrations but remained toxicologically insignificant at environmental levels (Agency for Toxic Substances and Disease Registry [ATSDR], 2020). Hence, the cumulative results demonstrate that exposure to trace metals in this soil does not present a health concern, although continued monitoring is advisable due to the site's landfill history.

4. Remediation Technologies:

The remediation strategy for the contaminated site integrates biological, chemical, and physical approaches to address hydrocarbons, lead (Pb), and zinc (Zn). The selected technologies emphasize sustainable soil recovery, compliance with Australian guidelines, and long-term stability.

4.1 Hydrocarbon Remediation

Bioremediation is a useful and practical method of treating soils infected with hydrocarbons (Vidali, 2001). The process involves digging up of the contaminated soil and then laying it in aerated bio piles or landfarming structures. Nutrients are also adjusted to a C:N:P ratio of about 100:10:1 and moisture content is kept at 5060 percent field capacity to optimize the microbial activity. Compost or manure are often used as organic amendments to enhance biodegradation effectiveness and increase aeration. The process of hydrocarbon degradation by maintaining a pH scale of 6.5 to 7.5 and temperatures of over 15 degree C is effective and may produce up to more than 80% of complete reductions in total petroleum hydrocarbons (TPH) in 8-16 weeks(Das & Chandran, 2011). In more difficult or less permeable formations, in-situ bioventing, which is management of low-rate air injection, is also used to encourage aerobic degradation (USEPA, 2011).

4.2 Stabilization of Lead (Pb) and Zinc (Zn).

Stabilization and immobilisation are the ideal remediation methods to use in the case of heavy metals because they are cost-efficient and can minimize mobility (Adriano, 2001). Phosphate-based additions are used to create a stable pyromorphite mineral including triple superphosphate, rock phosphate or apatite (1-3% w/w) which enormously reduce the solubility of Pb (Ma et al., 1993). Biochar or compost (25 percent) is added to improve cation-exchange capacity and provide neutral pH conditions (6.5–7.5). There is also enhancing of Zn adsorption and decreasing leachability with these amendments(Beesley et al., 2011). Agricultural lime can be used in acidic soils (pH of less than 6.5) to enhance the efficiency of stabilization. To confirm a reduction in metal bioavailability, post-treatment validation is performed by examination of bio accessibility (e.g., IVBA or DTPA extraction) (Anzecc, 2000b) (ANZECC, 2000a).

4.3 Hydrocarbon-Metal Co-Contamination

A sequential approach to treatment is advantageous to the soils that contain not only hydrocarbons but also metals, such as those found on landfills. The aerobic bioremediation is performed first to lower organic contaminant and then stabilization of metals to immobilise Pb and Zn is performed. This order does not allow the amendments of phosphate to suppress the degradation by microbes (USEPA, 2011). Revegetation with tolerant species of plants is useful in the restoration of soil structure, improvement in infiltration, and inhibition of the release of dust after treatment.

4.4 Phytoremediation/Site Stabilization.

Phytoremediation is a supportive means of stabilisation of the remediation soils in the long term. Vetiveria zizanioides, Lolium perenne, and Cynodon dactylon grasses perform well about tolerating trace metals and hydrocarbons in addition to stabilising the surface layer (Ali et al., 2013) They reduce the erosion, increase the evapotranspiration and aesthetics of the sites due to their wide root systems. Depending on their frequency, mowing and reseeding maintain soil cover and enhance nutrient cycling.

4.5 Capping and Controlling Exposure.

Capping is used to reduce the direct exposure and generation of dust. Cover to the residential sites is 0.3-0.4m of clean soil over geotextile barrier as compared to recreational and commercial sites which have 0.15-0.25m of clean cover or hard surfacing like pavement or asphalt (Anzecc, 2000b). Appropriate drainage and vegetation cover is ensured to avoid infiltration and soil erosion.

4.6 Leachate and Run-off Control.

To restrict the movement of contaminants, regarding the site is done to channel the runoff to controlled sections and sediment traps. The perimeter drains ensure that no external water enters and the leachate in the capped areas are periodically sampled against compliance before discharge (USEPA, 2011).

4.7 Validation and Long-Term Follow-Up.

Post-remediation verification checks made to conform to the regulatory limit-Pb under 300mg/kg of the land to be used by the residents and less than 1500mg/kg of the land to be used by the businesses (ANZECC, 2000). The concentration of hydrocarbons is contrasted with site specific TPH limits. Two years of annual monitoring determines the pH, EC, metal levels and TPH. Cover and the vegetation on the surface are checked every time there is the wet season. Long-term management involves the need to have the vegetative cover, limit deep excavations and store validation data to be reviewed by the regulation authorities. The reuse of the site as parkland, solar or warehouses must be in line with the contamination restrictions.

5. Conceptual Site Model (CSM)

The conceptual site model provides the outlines of the possible relationships among the contamination sources, the transport routes and the receptors in the former landfill site, which is at 22 Mandemar Avenue, Homebush West. It provides a conceptual guideline on observing the behaviour of contaminants and guides the decision-making process in the remediation.

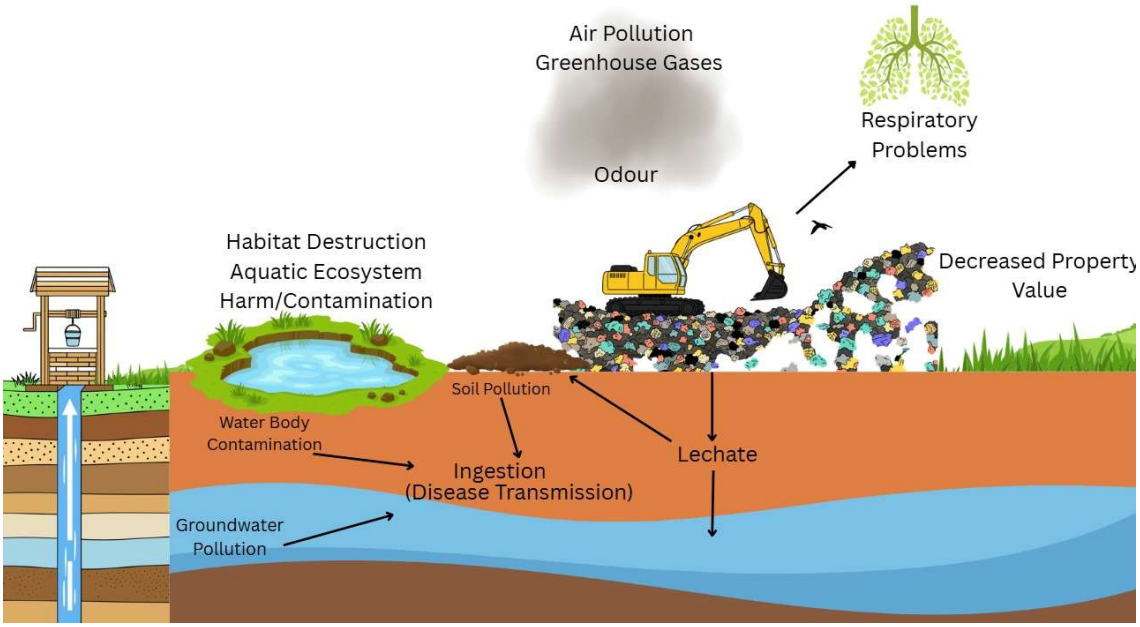


Figure 8: Conceptual Site model

5.1 Source

The history of landfill operations was the disposition process of mixed municipal and industrial wastes which included oils, paints, metals and plastics. The number of residual hydrocarbons in the waste material in the form of the fuel or lubricant spill was measured at a common concentration of total petroleum hydrocarbon (TPH) of 848 mg/kg. High levels of heavy metals were reported with lead (Pb) at 337mg/kg and zinc (Zn) at 1140mg/kg which are of battery, metal scrap and industrial residue origin. Breaking down organic residues produced leachate that consists of soluble ions and possibly volatile species.

5.2 Pathway

Soil contact is a form of direct human contact (dermal, ingestion or inhalation of dust) in an excavation or constructions. The process of leaching takes place when dissolved metals and hydrocarbons find their way down through the unsaturated zone to ground water. During rainfalls, surface runoff causes the transportation of contaminated sediments to the stormwater drains, thereby discharging into the Parramatta River. Although this is a minor concern, vapor intrusion can also be concerned with the horizontal movement of the subsurface hydrocarbon vapours to enclosed spaces. The incorporation of the food chain is minimal yet there is a possibility of incorporating the food chain by vegetation planting in case the contaminated soils are not remedied.

5.3 Receptor

This list of human receptors would be made up of site workers (construction and maintenance staff), future residents or recreational users and near-by commercial workers or visitors. Environmental receptors include soil biota (microbes, invertebrates and vegetation), surface water (local drains and the Parramatta River), ground water under the landfill at depths of 3-5m and terrestrial fauna that may be found at times in the vegetated or open land.

6. Recommendations

6.1 Targeted Lead Remediation

As lead (Pb) slightly exceeds the Residential A standard (300 mg/kg), the concerned soil ought to be subjected to phosphate-based stabilisation using triple superphosphate or rock phosphate (1 3 percent w/w), along with biochar/compost supplements to fix Pb and restrict bioavailability (Beesley et al., 2011; Ma et al., 1993). Before redevelopment, bio accessibility (IVBA/DTPA) testing should be carried out on the treated areas.

6.2 The Reduction of Hydrocarbons using Bioremediation.

The average TPH pollution (848 848 mg/kg -1) needs to be bioremediated aerobically via bio piles or landfarming. The balance of nutrients (C:N:P=100:10:1), a moist environment (5060% moisture) and constant pH (near neutral) will stimulate the rate of microbial degradation and attain than 80% reduction in 8-16 weeks (Das & Chandran, 2011; Vidali, 2001). In-situ bioventing can be used in deeper zones.

6.3 Zinc Management

The intermediate level of Zn enrichment (EF = 2.45; Igeo = 0.89) can be handled by means of pH and organic matter addition to increase the sorption capacity and decrease the mobility of the metal (Adriano, 2001).

6.4 Surface Capping and Exposure Control.

Areas that are to be occupied later either of residential or leisure purpose should be covered by 0.3 0.4m thick of clean topsoil on top of a geotextile barrier. On the commercial land, the 0.15-0.25m soil or hard-surface cap (paving/asphalt) is suggested, thus avoiding direct contacts and production of dust (Anzecc, 2000b).

6.5 Vegetative Rehabilitation

Plant tolerant grasses (long-term stabilisation, erosion control) e.g. Vetiveria zizanioides, Lolium perenne and Cynodon dactylon. The vegetative cover should be maintained through annual re-seeding and mowing that facilitates the cycling of nutrients(Ali et al., 2013).

6.6 Management of Leachate and Drainage.

The area must be graded to channel the runoff of the surface to the perimeter drains and sediment basins. Capped zones must periodically test the hydrocarbons and metals in the leachate before discharge (USEPA, 2011).

6.7 Monitoring and Regulatory Compliance

Conduct post-treatment validation sampling to confirm that:

Pb $\leq$ 300 mg kg^{-1} (Residential A) or $\leq$ 1500 mg kg^{-1} (Commercial).

TPH levels < site-specific investigation limits.

Perform annual monitoring for two years to measure pH, EC, TPH, and metal concentrations. Maintain inspection logs of surface covers and vegetation after each wet season (NEPC, 2020; NSW EPA, 2013).

6.8 Future Land-Use Planning

The site can be safely redeveloped for medium- to high-density residential, recreational, or commercial use, provided remedial actions and monitoring continue. Adaptive reuse such as parklands, solar installations, or warehouse construction is recommended under controlled excavation policies.

7. Conclusion:

The environmental study confirms that the soil at Homebush West is highly uncontaminated, except that localized heavy enrichment of Pb and Zn is present and moderate levels of hydrocarbons, which are related to the past landfill operations. Physicochemical status of soil is favourable to biological recovery, and anthropogenic levels of health risks are very low in comparison with the levels of concern. The adoption of a hybrid remediation solution, which is aerobic bioremediation, metal stabilisation, phytoremediation, and protective capping, is going to be an effective solution to curb the remaining risks and stabilise the site. Validation of the treatment processes after its completion, control of the leachate, and frequent monitoring are necessary to be following NEPM (2020) and NSW EPA (2013) requirements. All in all, the site has a great potential to be safe rehabilitated and redeveloped sustainably after the recommended actions are done.

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