Results and discussion of objective 1

Characterization of landfill leachate, groundwater and soil collected from open landfill sites in the Brahmaputra valley.

4.1. Physicochemical attributes of ground water, leachate and soil

The physicochemical properties of groundwater, leachate, and soil at the disposal site present a complex picture of environmental contamination. The leachate is characterized by its dark color, extreme turbidity, and unpleasant odor, with an alkaline pH ranging from 8 to 8.5. In contrast, the groundwater exhibits a slightly acidic pH between 5 and 6.5 and an electrical conductivity (EC) ranging from 0.3 to 0.75 mS/cm. Notably, the pH values highlight the aggressive nature of the leachate, suggesting potential aerobic or anaerobic conditions at the disposal site. The soil at the municipal solid waste (MSW) dumping site is just barely alkaline, significantly influencing the mobility and concentration of metals due to the pH and organic matter content. While pH itself may not directly impact human health, it affects all biochemical reactions and the solubility of various metal complexes, particularly at high pH levels (above 6.30). The soil's EC at the MSW site is considerably higher, ranging from 0.2 to 1.7 mS/cm, indicative of elevated total dissolved solids in the leachate. According to WHO standards, the optimal EC limit for drinking water is 1.5 mmhos/cm, with higher EC levels linked to increased salt concentrations. This trend of rising EC at the dumping site underscores the environmental impact of leachate on soil quality, posing potential risks to groundwater and overall ecosystem health.

4.2. Metal content in MSW dumping site leachate and soil and ground water

An analysis of heavy metals in leachate samples from the disposal site revealed that the concentrations of Pb, Cd, Ni, Mn, Zn, Cu, and Cr were within the permissible limits for metals in public sewers, as established by the Central Pollution Control Board of India under the Environment (Protection) Rules, 1989. The examination of soil samples exposed to municipal solid waste (MSW) leachate showed mean concentrations of 7.26 mg/kg for Pb, 3.65 mg/kg for Cr, 1.71 mg/kg for Ni, 45.9 mg/kg for Mn, 12.65 mg/kg for Zn, 5.02 mg/kg for Cu, and 0.025 mg/kg for Cd. The hierarchy of metal concentrations in the soil followed the order: Fe > Mn > Zn > Pb > Cu > Cr > Ni > Cd. Groundwater at the site exhibited a different trend, with heavy metal concentrations descending in the order of Zn > Mn > Cu > Ni > Co > Pb. These findings highlight the variability in metal contamination between soil and groundwater, emphasizing the need for ongoing monitoring and management to mitigate potential environmental and health risks associated with heavy metal pollution at the disposal site.

Table 4.1: Mean concentration of heavy metals of three different samples and from different sites.

Samples	Sites	B	Cr	Mn	Co	Ni	Cu	Zn	Cd	Ba	Pb
Soil	S1	0.229±0.090	3.86±0.27	62.868±21.436	0.779±0.115	1.888±0.170	3.564±0.712	9.091±1.333	0.021±0.010	12.800±0.671	4.053±0.990
	S2	0.196±0.064	4.48±0.64	47.875±7.906	0.807±0.112	1.964±0.234	4.716±0.802	15.467±1.575	0.0260.008	16.6396.228	10.3384.065
	S3	0.720±0.031	2.96±0.35	35.215±4.124	0.402±0.049	1.426±0.163	9.881±1.147	21.994±1.459	0.0430.004	16.9801.719	12.6332.418
	S4	0.085±0.011	3.29±0.30	37.668±1.148	0.736±0.038	1.576±0.140	1.927±0.087	4.087±0.612	0.0110.003	7.8650.676	2.0450.165
Ground water	S1	5.918±0.680	0.36±0.03	40.015±65.643	0.177±0.045	0.260±0.026	0.230±0.026	4.318±4.217	0.0000.000	2.9270.888	0.0570.025
	S2	14.465±5.057	1.97±1.36	639.515±428.967	1.073±0.524	0.643±0.332	2.550±2.046	4.478±3.165	0.0070.006	6.2782.675	0.6330.586
	S3	17.308±1.902	1.18±0.74	369.177±450.915	0.667±0.273	0.427±0.228	2.497±0.479	2.074±0.226	0.0100.017	5.6451.867	0.3070.085
	S4	20.924±3.076	0.95±0.17	63.926±29.350	0.503±0.091	0.367±0.086	0.870±1.022	6.102±3.146	0.0070.006	4.1410.608	6.9135.796
Leachate	S1	256.086±49.14	20.89±3.77	125.930±11.402	5.788±1.278	3.387±0.933	9.051±6.206	6.769±1.528	0.0070.006	2.2770.483	1.7370.636
	S2	30.649±21.17	2.31±2.33	310.842±80.309	1.977±0.657	0.863±0.320	4.451±1.189	19.266±6.875	0.0400.010	7.1151.894	2.1371.151
	S3	38.546±1.438	7.47±2.08	294.893±42.322	0.577±0.117	0.450±0.113	4.774±1.679	14.632±2.613	0.0300.010	4.1710.691	11.9518.266
	S4	97.679±4.142	4.27±0.05	211.376±27.897	1.867±0.228	1.934±0.107	1.797±0.110	4.514±0.578	0.0030.006	1.0570.264	0.3670.112
Samples	F Value	161.161	80.055	5.477	69.484	58.994	11.489	29.020	17.636	72.373	8.033
	P Value	0.000	0.000	0.011	0.000	0.000	0.000	0.000	0.000	0.000	0.002
Sites	F Value	40.842	27.410	3.801	21.884	16.542	6.429	18.881	14.521	12.471	6.460
	P Value	0.000	0.000	0.023	0.000	0.000	0.002	0.000	0.000	0.000	0.002
Samples * Sites	F Value	47.239	33.550	2.034	26.426	16.837	4.660	10.147	4.279	2.121	5.882
	P Value	0.000	0.000	0.100	0.000	0.000	0.003	0.000	0.005	0.088	0.001

Each Value is the mean and SD of three replicates measurements. $P < 0.05$ is considered statistically significant among samples, sites and interactions.

4.3. Heavy metals risks assessment strategies for different environmental matrices

4.3.1. Enrichment factor (EF/EF %) in soil

To assess metal enrichment EF values with, metal distribution in soil of typical shale as background referenced values were used (Aiman et al., 2016). For TMs and HMs, EF values were distinguished between anthropogenic, natural, and a mixture of factors (Table.4.2). Compared with the other reported studies our results were found to be lower than the reported studies from China and Poland (Ji et al., 2008; Zhiyuan et al., 2011).

Table.4.2: Enrichment levels

Sites	B	Cr	Mn	Co	Ni	Cu	Zn	Cd	Ba	Pb
Site 1	0.257	4.816	8.651	4.495	3.036	8.755	10.607	7.737	2.464	23.123
Site 2	0.207	5.608	6.243	4.677	3.196	11.955	18.348	9.883	3.238	57.118
Site 3	0.958	4.259	5.401	2.735	2.747	28.888	30.417	19.190	3.845	84.035
Site 4	0.094	3.993	4.791	4.196	2.509	4.604	4.766	3.780	1.457	11.097

$EF \leq 1$ - No enrichment; $1 \leq EF \leq 2$ -Minimal enrichment; $2 \leq EF \leq 5$ - Moderate enrichment; $5 \leq EF \leq 20$ – Severe enrichment

4.3.2. Health risk assessment

A health risk assessment was conducted to quantify the probability of health hazards associated with toxic metal exposure in the exposed population (Bora et al., 2021). HQ trend for non-carcinogenic in both adults and children were found in order $HQ_{derm}>HQ_{inh}>HQ_{ing}$ for soil for all metals which followed $HQ_{ing}>HQ_{inh}>HQ_{derm}$. Whereas, HQ trend for carcinogenic in both adults was found in order $HQ_{inh} > HQ_{ing} >HQ_{derm}$ and for children $HQ_{inh}>HQ_{ing}>HQ_{dem}$ Ni, Zn, Pb, and Cu suggested an acceptable ($HRI >1$). non-carcinogenic risk from the soil for the people living in the research region. Pb and Cd in the study area demonstrated a significant non-carcinogenic risk to the human population in all land uses. For non-carcinogenic the HI for both adult and children was found in order $HI_{derm}>HI_{inh}>HI_{ing}$ and $HI_{ing}>HI_{derm}>HI_{inh}$ respectively (Table.4.3). For carcinogenic, the ILCR for both adult and children was found in order of $ILCR_{ing}>ILCR_{derm}>ILCR_{inh}$ and $ILCR_{derm}>ILCR_{ing}>ILCR_{inh}$ (Table.4.4).

Table.4.3: Health risks of non-carcinogenic effects of toxic metals in MSW dumping site soil

	HQ_{ing}		HQ_{inh}		HQ_{derm}		HI_{ing}		HI_{inh}		HI_{derm}	
Metals	Children	Adult	Children	Adult	Children	Adult	Children	Adult	Children	Adult	Children	Adult
Cr	4.9x10^-3	2.2x10^-3	3.4x10^-10	3.3x10^-5	1.1x10^-5	4.3x10^-4	3.23 x10^-2	1.72 x10^-2	1.56 x10^-1	4.41 x10^-1	2.94 x10^-4	6.90 x10^-4
Mn	1.7x10^-3	7.6x10^-3	5.6x10^-9	3.1x10^-1	4.0x10^-5	3.0x10^-5	3.04 x10^-2	1.33 x10^-2	1.12 x10^-1	3.17 x10^-1	2.46 x10^-4	6.18 x10^-4
Co	6.9x10^-6	3.1x10^-5	6.9x10^-11	3.4x10^-5	4.3x10^-7	3.3x10^-7	2.92 x10^-2	1.11 x10^-2	8.75 x10^-2	2.47 x10^-1	2.11 x10^-4	5.71 x10^-4
Ni	3.6x10^-5	1.6x10^-4	1.6x10^-10	2.3x10^-9	2.1x10^-5	1.6x10^-5	3.52 x10^-2	1.84 x10^-2	9.78 x10^-2	2.76 x10^-1	4.43 x10^-4	9.11 x10^-4
Cu	3.2x10^-5	1.5x10^-4	3.1x10^-10	2.2x10^-8	7.9x10^-7	6.0x10^-7	3.12 x10^-2	1.5 x10^-2	8.55 x10^-2	2.41 x10^-1	3.49 x10^-4	7.66 x10^-4
Zn	1.1x10^-5	5.1x10^-5	8.1x10^-10	7.6x10^-9	2.7x10^-7	2.0x10^-7	2.73 x10^-2	1.15 x10^-2	7.01 x10^-2	1.98 x10^-1	2.56 x10^-4	6.25 x10^-4
Cd	1.6x10^-5	3.6x10^-5	1.8x10^-12	5.3x10^-9	1.9x10^-5	1.4x10^-5	2.76 x10^-2	1.57 x10^-2	6.88 x10^-2	1.94 x10^-1	4.29 x10^-4	6.82 x10^-4
Pb	4.4x10^-4	1.9x10^-3	3.6x10^-10	2.9x10^-7	6.8x10^-5	5.2x10^-5	2.60 x10^-2	1.38 x10^-2	6.29 x10^-2	1.77 x10^-1	3.74 x10^-4	6.16 x10^-4

Table.4.4: Health risks of carcinogenic effects of toxic metals in MSW dumping site soil

	HQ_{ing}		HQ_{inh}		HQ_{derm}		$ILCR_{ing}$		$ILCR_{inh}$		$ILCR_{derm}$	
Metals	Children	Adult	Children	Adult	Children	Adult	Children	Adult	Children	Adult	Children	Adult
Cr	2.9x10^-6	2.1x10^-4	8.2x10^-12	4.0x10^-8	1.7x10^-8	1.3x10^-8	2.12 x10^-6	9.48 x10^-6	1.12 x10^-8	4.47 x10^-8	8.34 x10^-7	6.37 x10^-7
Ni	4.2x10^-7	3.5x10^-6	1.8x10^-10	4.2x10^-10	3.9x10^-10	3.0x10^-10	1.98 x10^-6	8.87 x10^-6	8.81 x10^-9	4.13 x10^-8	7.87 x10^-7	6.01 x10^-7
Cd	2.1x10^-8	5.7x10^-5	3.0x10^-13	3.3x10^-11	4.9x10^-10	3.8x10^-10	1.82 x10^-6	8.13 x10^-6	7.19 x10^-9	3.93 x10^-8	7.09 x10^-7	5.42 x10^-7
Pb	1.8x10^-4	8.5x10^-2	8.6x10^-9	4.2x10^-11	4.2x10^-6	3.2x10^-6	2.42 x10^-6	1.08 x10^-5	3.08 x10^-8	5.5 x10^-8	9.02 x10^-7	6.89 x10^-7

4.4. Leachate pollution index

The characteristics of the MSW leachate used in the experiment as well as the elements needed to calculate the LPI, such as the sub-index value and pollutant weight factor (w_i) (p_i) are presented in table.4

It was found that the MSW leachate had a high leachate pollution index (LPI) of 18.39. (Table.4.5) from which we can summarize that the waste dumped in the landfill has not yet attained stability (Kumar and Alappat., 2005) and thus the waste should be treated and there should be regular monitoring of the site.

Table.4.5: Leachate pollution index of landfill leachate from dumping site

Parameters	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11	Site 12	Site 13	Site 14	Site 15
pH	0.275	0.275	0.275	0.275	0.275	0.275	0.275	0.275	0.275	0.275	0.275	0.275	0.275	0.275	0.275
Total dissolved solids	1.5	3	2	0.75	0.75	0.75	0.5	0.5	0.5	0.5	0.5	0.5	0.35	0.35	0.35
COD	1.86	5.58	1.86	2.17	2.17	1.86	1.86	1.86	1.86	2.17	2.17	2.48	2.48	2.48	2.48
Copper	1.25	5	5	3	2.5	1	1	2	3.5	0.25	0.25	0.25	0.25	0.25	0.5
Nickel	0.52	2.6	1.04	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.52	0.26	0.26	0.26
Zinc	0.28	1.68	0.56	0.56	0.84	0.56	0.56	0.56	0.56	0.28	0.28	0.28	0.56	0.56	0.28
Lead	0.63	4.41	1.26	0.63	0.63	1.575	1.575	5.985	6.3	0.315	0.315	0.315	1.26	2.835	4.41
Total Chromium	6.272	50.176	6.4	1.92	0.32	0.64	3.2	2.88	4.48	1.92	1.28	1.92	0.32	0.64	0.64
Total	12.587	17.265	18.395	9.565	7.745	6.92	9.23	14.32	17.735	11.94	5.33	6.54	5.755	7.65	9.195

4.5. Heavy metal pollution index

HPI values that were derived using the equations 3.1 in chapter 3. are displayed in Table.4.6. The mean HPI values across all locations were determined to be high which may be due to the leaching of TMs and HMs from the landfill leachate [9].

4.5.1. Index of contamination

Using Eq. (3.3), CI values have been determined while accounting for the allowed limits specified in IS 10500:2012 as well as the mean annual heavy metal concentrations for each site.

30% of the sites were found to be "High" contaminated, compared to only 13% of the sites that were found to be "Mid" contaminated. The majority of the locations (57%) are still categorised as having "Low" contamination. The areas with the highest pollution levels are near to the landfill. Nonetheless, a sizable chunk of the vicinity of the landfill was found to be highly polluted. This indicates that ground water pollution, in terms of the heavy metals involved, is the landfill leachate (Table.4.6).

Table.4.6: Heavy metal pollution index (HPI) and Contamination index in Ground water near municipality dumping sites

Heavy metal pollution index	Site 1	Site 2	Site 3	Site 4	Site 6	Site 7	Site 8	Site 9	Site 10	Site 12	Site 13	Site 14	Site 15
Copper	0.03	0.02	0.02	0.5	0.4	0.38	0.27	0.29	0.04	0.03	0.02	0	0
Zinc	0.01	0.01	0.01	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Cadmium	94.24	94.24	219.88	94.24	94.24	94.24	848.13	219.88	219.88	94.24	1476.36	848.12	94.24
Nickel	18.85	23.33	21.54	71.8	60.13	25.13	24.23	24.23	29.62	43.98	18.85	21.54	16.15
Lead	94.24	188.47	4115.16	910.95	659.65	1162.25	1068.02	753.89	33593.69	16589	1162.25	251.29	345.53
Manganese	5.55	605.75	754.83	4687.61	4657.29	627.04	512.35	511.18	235.44	290.84	2547.73	2944.39	2626.71
Total	212.91	911.82	5111.44	5765.11	5471.72	1909.05	2453.01	1509.48	34078.67	17018.1	5205.22	4065.36	3082.65
Contamination index	Site 1	Site 2	Site 3	Site 4	Site 6	Site 7	Site 8	Site 9	Site 10	Site 12	Site 13	Site 14	Site 15
Copper	-0.83	-0.85	-0.87	1.35	0.89	0.8	0.3	0.37	-0.8	-0.81	-0.89	-0.97	-0.95
Zinc	-0.89	-0.39	-0.46	-0.8	-0.86	-0.85	-0.88	-0.84	-0.48	-0.39	-0.93	-0.97	-0.94
Cadmium	-1	-1	1	-1	-1	-1	5	1	1	-1	9	5	-1
Nickel	2.29	3	2.71	10.71	8.86	3.29	3.14	3.14	4	6.29	2.29	2.71	1.86
Lead	2	5	130.01	28	20	36	33	23	1068.46	527.11	36	7	10
Manganese	2.87	385.02	479.94	2983.96	2964.65	398.57	325.55	324.81	149.24	184.51	1621.48	1874.04	1671.77
Total	4.44	390.78	612.33	3022.22	2992.54	436.82	366.11	351.48	1221.42	715.71	1666.95	1886.82	1680.73

4.5.2. Human health risk assessment of ground water

The assessment of human health risk involves calculating the type and severity of negative health consequences resulting from exposure to harmful substances. In the current investigation, the US Environmental Protection Agency (USEPA 2004) approach was utilized to evaluate both non-carcinogenic and carcinogenic health hazards associated with water exposure through ingestion and skin contact. Key parameters in this assessment included the cancer slope factor (CSF), the upper tolerable intake level (UTIL), the oral and dermal reference doses (RfD), and the average chronic daily metal intake (CDI) from both ingestion and dermal exposure. These calculations were applied to waters collected from the Morabhorali dumping site region of Tezpur, India. This comprehensive approach ensured a detailed evaluation of potential health risks, guiding the implementation of appropriate mitigation and management strategies to protect the exposed population.

4.5.2.1. Non-carcinogenic health risk

The assessment of non-cancer health effects for adult persons exposed to water from the Morabhorali dumping site via ingestion and dermal contact utilized hazard quotient (HQ) and hazard index (HI) metrics [9]. The mean estimated HQ_{oral} values for Cr, Mn, Cu, Zn, Cd, and Pb were 4.69E-03, 2.28E-01, 2.08E-04, 7.74E-04, 1.22E-04, and 4.89E-03, respectively. All HQ_{oral} values were below 1.0, indicating no unacceptable level of non-carcinogenic health risk at any location. To further assess the cumulative non-carcinogenic health impacts of all investigated heavy metals, the HI_{oral} was calculated for each sample, with all groundwater samples showing HI_{oral} values below 1.0. This suggests an absence of non-carcinogenic health risks from these metals. Additionally, the total non-carcinogenic risk from ingestion (HI_{ing}) was found to be higher than from dermal exposure (HI_{derm}) in both adults and children, emphasizing ingestion as the primary route of concern.

4.5.2.2. Carcinogenic health risk

Pb, Cr, and Cd concentrations in water were found to have the ability to increase a person's chance of developing cancer if they were exposed. Furthermore, only these 3 metals—out of the 7 studied—possess the CSF values outlined by OEHHA (2019). So, we estimated the cancer risks that these hazardous metals might pose to the study area's inhabitants when ingested and exposed topically. The findings revealed that the computed mean ILCR values for Cr, Cd, and Pb for ingestion were 5.9E-06, 1.83E-06, and 1.45E-07, respectively, and for cutaneous exposure they were 2.8E-08, 8.7E-09, and 4.14E-10. According to Akoto et al. (2019), exposure to cadmium (Cd) can lead to serious health issues such as lung cancer, kidney damage, and bone fractures. Although the current health hazard indices indicate no immediate danger, the hazard quotient (HQ) values for ingestion, inhalation, and dermal exposure were notably higher for children compared to adults. This suggests that children are more vulnerable to the adverse effects of Cd exposure. Furthermore, the incremental lifetime cancer risk (ILCR) was found to be higher for ingestion ($ILCR_{ing}$) than for dermal exposure ($ILCR_{derm}$) in both adults and children. This trend underscores the greater risk posed by ingesting contaminated water, highlighting the need for targeted risk mitigation strategies to protect the more susceptible child population.

Table.4.7. Health risks of non-carcinogenic and carcinogenic effects of toxic metals in MSW site ground water.

Metals	HI_{ing}		HI_{derm}		$ILCR_{ing}$		$ILCR_{derm}$	
	Children	Adult	Children	Adult	Children	Adult	Children	Adult
Cr	12.426	0.239	11.388	0.024	0.0082	0.0067	8.4335E-05	2.80146E-05
Cd	43.008	2.363	73.662	0.222	5.4E-05	0.0021	5.57336E-07	8.70003E-06
Pb	18.931	0.292	24.707	0.033	0.00016	0.0002	1.74542E-07	6.90236E-08
Cu	118.992	0.233	27.016	0.023				
Zn	10.075	1.363	13.794	0.118				

4.6. Multivariate statistical analysis to identify probable sources:

4.6.1. Correlation analyses:

The Spearman rank correlation matrices, presented in the table, illustrate the strength of linear relationships among various parameters in the groundwater, leachate, and soil at the Tezpur dumping site. In the soil, metal pairs exhibited positive correlations, including Cr-Mn (r=0.47), Cr-Co (r=0.78), Cr-Ni (r=0.93), Mn-Co (r=0.55), Mn-Ni (r=0.71), and Co-Ni (r=0.84), with some correlations being significant at the 95% and 99% confidence levels. In groundwater, strong positive correlations were observed for Cr-Mn (r=0.92), Cr-Co (r=0.95), Cr-Ni (r=0.96), Mn-Co (r=0.92), and Mn-Ni (r=0.94), all significant at the 99% confidence level. This suggests a common pollution source or similar geochemical behavior for these metals. In leachate, positive correlations were identified among B-Cr (r=0.92), B-Mn (r=0.82), B-Co (r=0.93), B-Ni (r=0.96), Cr-Co (r=0.85), and Cr-Ni (r=0.80), significant at the 95% and 99% confidence levels. These positive correlations imply a shared origin or consistent geochemical properties for the metals. Conversely, negative and inverse correlations between certain metals suggest they originate from different sources or exhibit distinct geochemical behaviors, such as rock weathering is the main source of element geochemical cycle as indicated by their negative correlation coefficients (Fig. 3.2).

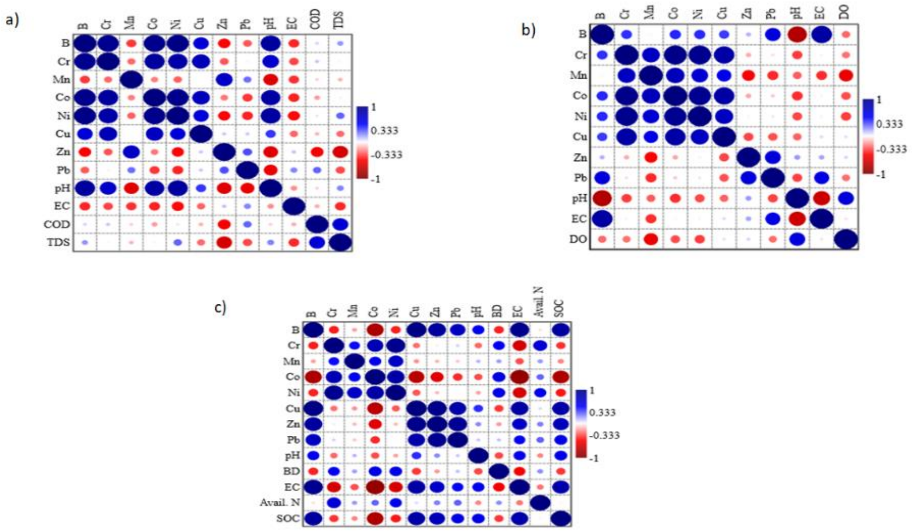

Fig.4.1. Correlation chart for different parameters of a) leachate, b) ground water and c) soil.

Table 4.8: Pearson Correlation matrix of various heavy metals of three different samples

Samples	Heavy metals	Pearson Correlation	B	Cr	Mn	Co	Ni	Cu	Zn	Cd	Ba
Soil	B	r	1								
	Cr	r	-0.442	1							
	Mn	r	-0.181	0.478	1						
	Co	r	-.820**	.789**	0.550	1					
	Ni	r	-0.434	.930**	.713**	.847**	1				
	Cu	r	.970**	-0.283	-0.208	-.759**	-0.331	1			
	Zn	r	.870**	-0.045	-0.142	-.607*	-0.135	.950**	1		
	Cd	r	.907**	-0.150	0.010	-.650*	-0.192	.939**	.924**	1	
	Ba	r	.591*	0.427	0.184	-0.144	0.319	.703*	.812**	.784**	1
	Pb	r	.735**	0.092	-0.113	-0.417	0.011	.822**	.916**	.783**	.796**
Ground water	B	r	1								
	Cr	r	0.415	1							
	Mn	r	0.207	.929**	1						
	Co	r	0.467	.958**	.920**	1					
	Ni	r	0.372	.962**	.945**	.957**	1				
	Cu	r	0.405	.842**	.811**	.859**	.763**	1			
	Zn	r	0.009	-0.318	-0.319	-0.257	-0.230	-.598*	1		
	Cd	r	0.194	0.015	-0.133	-0.030	-0.154	0.109	-0.112	1	
	Ba	r	0.399	.945**	.939**	.920**	.902**	.894**	-0.335	0.080	1
	Pb	r	.591*	-0.096	-0.293	-0.101	-0.052	-0.410	.598*	-0.007	-0.225
Leachate	B	r	1								
	Cr	r	.921**	1							
	Mn	r	-.826**	-.692*	1						
	Co	r	.936**	.853**	-.679*	1					
	Ni	r	.960**	.809**	-.786**	.932**	1				
	Cu	r	.590*	.740**	-0.276	.704*	0.573	1			
	Zn	r	-0.575	-0.387	.841**	-0.326	-.590*	0.092	1		
	Cd	r	-.617*	-0.445	0.571	-0.450	-.653*	-0.035	.695*	1	
	Ba	r	-0.520	-0.373	.760**	-0.237	-0.523	0.096	.971**	.736**	1
	Pb	r	-0.325	0.002	0.404	-0.404	-0.447	0.141	0.362	0.300	0.189

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

4.6.2. Cluster analysis:

An agglomeration schedule of cluster analysis (CA) was conducted on the data using nearest neighbor linkage and Euclidean distance to measure proximity between samples. The results, depicted in Figure 4.2, show the hierarchical cluster analysis of groundwater using Ward's method, which produced two distinct clusters with significant differences ($p<0.05$). The first cluster included B, Cr, Co, Ni, Cu, Zn, Pb, EC, and pH, indicating these elements likely have an anthropogenic origin. Mn and dissolved oxygen were classified in the second cluster, suggesting a mixed origin (both anthropogenic and lithogenic). Similarly, the hierarchical cluster analysis of leachate using Ward's method also produced two clusters. The first cluster comprised B, Mn, Co, Ni, Cu, Zn, Pb, EC, pH, and TDS, while the second cluster contained Cr and COD, highlighting distinct sources and behaviors of these parameters. The soil analysis, also using Ward's method, resulted in two clusters: the first included Cr, Co, Ni, Cu, Zn, Pb, EC, pH, bulk density, available nitrogen, and soil organic carbon, and the second contained B and Mn. These findings align with similar studies that attribute Pb to vehicular emissions and Zn to industrial activities and metal smelting processes. According to Fergusson and Kim (1991), Co, Mn, Cu, and Ni are associated with traffic-related sources such as the corrosion of metallic parts, concrete materials, re-entrained dust from roads, and wear and tear of tires and engine parts. (Fig.4.2).

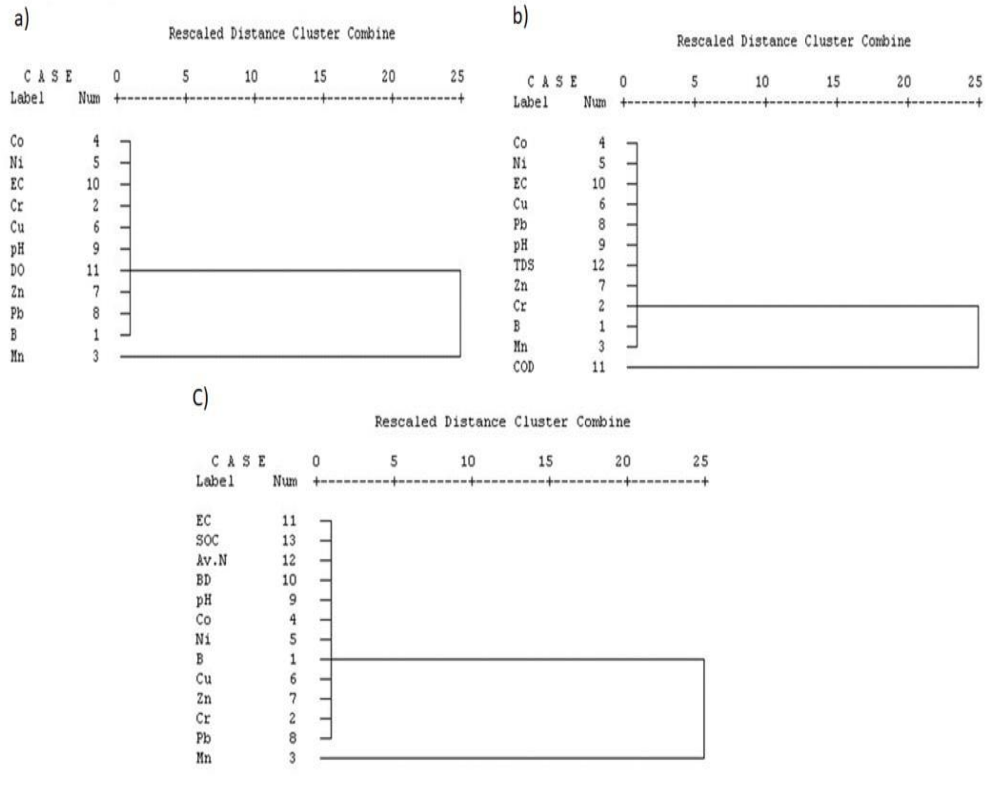

Fig.4.2. Dendrogram derived from hierarchical cluster analysis of heavy metals content in analysed a) ground water, b) leachate, c) soil parameters.

4.6.3. Principal component analysis (PCA)

Principal component analysis (PCA) was conducted to identify potential sources of toxic metals in the soil, leachate, and groundwater, as illustrated in Figure 4.3. Four principal components (PCs) were extracted, accounting for 96.86% of the variance in groundwater, 94.79% in leachate, and 86.69% in soil. In groundwater, the first principal component (PC1) explained 44.62% of the total variance, with the second (PC2) and third (PC3) components accounting for 28.77% and 12.24%, respectively. The fourth component (PC4) highlighted the prominence of Mn and Ni, contributing 11.21% to the variance. In leachate, Cr, Co, and pH dominated PC1, explaining 48.25% of the variance, while the second component (PC2) with high loadings of Cu, Zn, and Pb contributed 20.98%, indicating anthropogenic sources. The third component (PC3), accounting for 14.23% of the variance, also showed the dominance of anthropogenic metals like Cr, Cu, Co, and Zn, with the fourth component (PC4) contributing 11.32%. In soil, common sources of Cu and Zn, such as the deterioration of various alloys, electroplated goods, automotive parts, and building materials, were indicated by PC1, which accounted for 53.27% of the variance. The second component (PC2) accounted for 23.11%, while the third component (PC3), representing 10.4% of the variance, demonstrated the predominance of anthropogenic metals like Cr, Cu, Co, and Zn. Additionally, the high Zn concentration was linked to ash residues from tire burning. These findings underscore the significant influence of anthropogenic activities on the contamination levels in these environmental media.

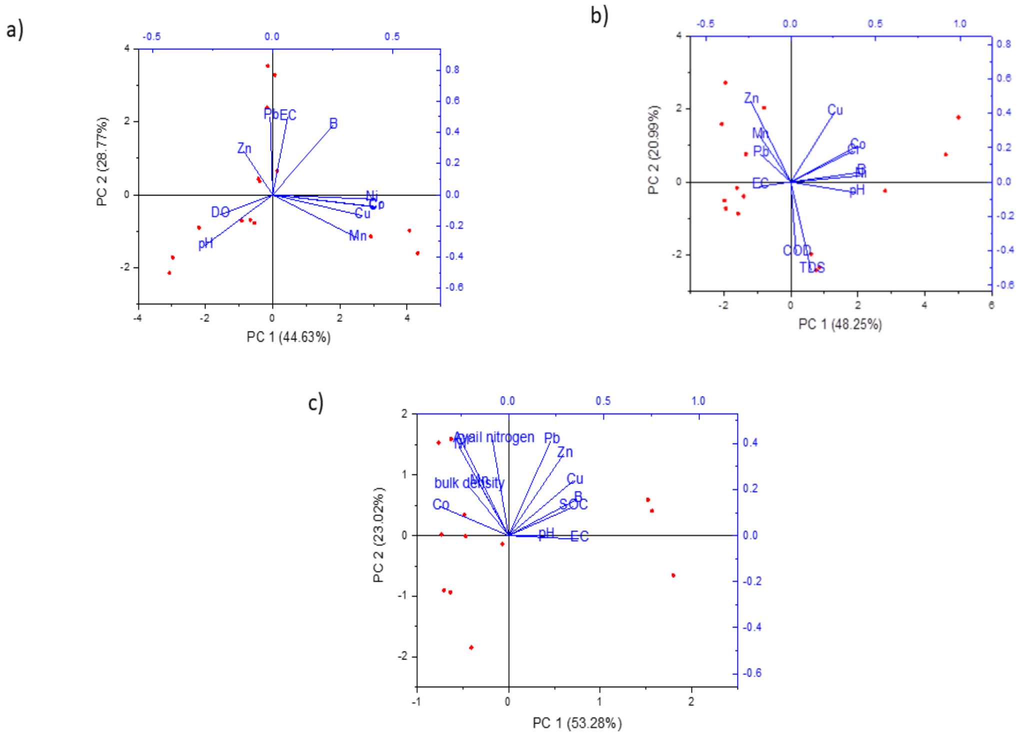

Table.4.3. Principal Component matrix of Ground water, leachate and soil parameters

Table.4.9. Principal Component matrix of Ground water, leachate and soil parameters.

Ground water	Component				Communalities	Leachate	Component				Communalities	Soil	Component			Communalities
	1	2	3	4			1	2	3	4			1	2	3	
B	0.554	0.787		-0.218	1.123	B	0.983				0.983	B	0.945	0.273	0.115	1.333
Cr	0.936	-0.138	0.257		1.055	Cr	0.873	0.282	0.118	0.327	1.6	Cr	-0.646	0.702	0.009	0.065
Mn	0.778	-0.49	-0.321	0.188	0.155	Mn	-0.447	0.429	0.682	-0.32	0.344	Mn	-0.418	0.402	0.694	0.678
Co	0.952	-0.136	0.195		1.011	Co	0.936	0.328			1.264	Co	-0.954	0.219	0.143	-0.592
Ni	0.903		0.276	0.27	1.449	Ni	0.978				0.978	Ni	0.688	0.67	0.24	1.598
Cu	0.822	-0.236	0.341	-0.373	0.554	Cu	0.617	0.638	0.17	0.258	1.683	Cu	0.896	0.413	-0.017	1.292
Zn	-0.269	0.501	0.524	0.581	1.337	Zn	-0.575	0.752	0.121	-0.163	0.135	Zn	0.758	0.61	-0.145	1.223
Pb		0.89		0.35	1.24	Pb	-0.438	0.26	0.325	0.758	0.905	Pb	0.581	0.712	-0.263	1.039
pH	-0.628	-0.582	0.443	0.201	-0.566	pH	0.919		-0.306		0.613	pH	0.509	-0.004	0.744	1.245
EC	0.137	0.881		-0.438	0.58	EC	-0.443		-0.726	0.419	-0.75	BD	-0.558	0.378	-0.267	-0.447
DO	-0.488	-0.229	0.68	0.484	0.447	COD		-0.652	0.537	0.49	0.375	EC	0.967	-0.062	0.088	0.993
						TDS	0.287	-0.812	0.4	-0.195	-0.32	Avail N	-0.224	0.725	-0.203	0.298
												SOC	0.886	0.212	0.121	1.219
Initial Eigen value	4.909	3.165	1.347	1.234		Initial Eigen value	5.79	2.518	1.708	1.359		Initial Eigen value	6.926	2.992	1.352	
% of variance	44.626	28.773	12.248	11.219		% of variance	48.251	20.987	14.232	11.323		% of variance	53.279	23.012	10.402	
Cumulative%	44.626	73.398	85.647	96.866		Cumulative%	48.251	69.238	83.47	94.793		Cumulative%	53.279	76.291	86.693	

4.7. Phytotoxicity study:

A total of 6 heavy metals were considered for the phytotoxicity study. The heavy metals are Copper (Cu), Iron (Fe), Manganese (Mn), Lead (Pb), Zinc (Zn), Cadmium (Cd). The main reason behind considering these elements is that from literature (Marchiol et al., 1999) we found that they are metals and metalloids which are known to impact seedling growth and germination. A total of 4 plant samples what plant samples - *Solanum lycopersicum* (tomato), *Brassica nigra* (mustard), *Spinacia oleraceae* (spinach), *Coriandrum sativum* (coriander) were considered for the germination test

Table.4.10. The physicochemical properties of two separate soil samples, sample soil and control soil.

Soil parameters	Control	Sample
pH	4.89±0.27	7.52±0.23
Electrical conductivity(mS/m)	0.05±0.01	0.42±0.12
Bulk density(g/cc)	1.21±0.05	1.20±0.10
Soil organic carbon (%)	0.55±0.38	0.75±0.32
Available nitrogen (%)	11.2±5.6	7.46±3.23
Available Phosphorus (%)	66.21±3.65	96.89±0.22
Available potassium (%)	130.53±0.77	172.39 ±0.53

This table shows that the sample soil has greater values for the characteristics (pH, electrical conductivity, bulk density, soil organic carbon, available nitrogen, available phosphorus, and available potassium) than the control soil.

4.8.1. Pot experiments

Table 4.11. Seed germination number in the pot experiment with control and sample soil,

Species name	Sample	Mean±St.Dev	Control	Mean±St.Dev
Brassica nigra (mustard)	15	12±2.16	16	16±2.16
Spinacia oleraceae (spinach)	12		17	
Coriandrum sativum (coriander)	10		13	
Solanum lycopersicum (tomato)	11		18	

Where, the number of seeds germinated of *Solanum lycopersicum* (tomato), *Brassica nigra* (mustard), *Spinacia oleraceae* (spinach), *Coriandrum sativum* (coriander) in control soil was more than in sample soil.

Table 4.12. The values for root length, shoot length, and number of leaves in a pot experiment between sample soil and control soil.

	Sample			Control		
Species name	Root length	Shoot length	Number of leaves	Root length	Shoot length	Number of leaves
Brassica nigra (mustard)	1.43±0.51	4.61±1.52	2.81±0.83	2.06±0.37	5.9±1.15	2.6±0.63
Spinacia oleraceae (spinach)	1.52±0.41	5.72±1.48	2.64±0.70	2±0.47	6.10±0.78	2.58±0.79
Coriandrum sativum (coriander)	1.57±0.44	4.8±1.63	2.61±0.76	1.8±0.25	5.78±0.76	2.8±0.79
Solanum lycopersicum (tomato)	1.5±0.37	4.93±2.41	2.37±0.74	1.90±0.43	6.22±0.78	2.81±0.87

It can be concluded that the root length, shoot length, and number of leaves of *Brassica nigra* (Mustard) are higher in the control soil than in the sample soil, but the number of leaves were greater in the sample soil.

Second, the root and shoot lengths of *Spinacia oleracea* (Spinach) are higher in the control soil, but the number of leaves is more in the sample soil. *Coriandrum sativum* (Coriander) root length, shoot length, and leaf number are all higher in control soil than in sample soil. Furthermore, the root length, shoot length, and number of leaves of *Solanum lycopersicum* (tomato) are greater in control soil than in sample soil.

Table 4.13. The RRG, RSG and GI of four plant samples from the pot experiment: Brassica nigra (mustard), Spinacia oleracea (spinach), Coriandrum sativum (coriander), and Solanum lycopersicum (tomato).

Species name	RRG	Mean±St.Dev	RSG	Mean±St.Dev	GI	Mean±St.Dev
Brassica nigra (mustard)	69.08%	77.94±7.74	93.75%	75.59±13.73	64.76%	58.53±9.11
Spinacia oleraceae (spinach)	76%		70.58%		53.64%	
Coriandrum sativum (coriander)	87.77%		76.92%		67.51%	
Solanum lycopersicum (tomato)	78.94%		61.11%		48.24%	

The values show that the RRG is highest in Coriandrum sativum (Coriander), the RSG is highest in Brassica nigra (mustard), and Coriandrum sativum (coriander) has the highest GI.

Table 4.14. The concentrations of heavy metals (Cu, Fe, Mn, Zn) in Spinacia oleracea (Spinach) roots, shoots, and leaves in the pot experiment in MSW soil.

Solanum lycopersicum (tomato)						
Heavy metals	Root		Shoot		Leaves	
	Conc (µg/L)	St.dev	Conc (µg/L)	St.dev	Conc (µg/L)	St.dev
Cu	53.14	0.332	21.09	0.19	75.00	0.57
Fe	254.5	3.99	48.96	1.11	21.60	0.36
Mn	319.8	1.69	223.1	1.09	32.09	1.6
Zn	189.6	0.29	183.1	0.76	189.2	0.83

Where it can be concluded that Cu, Fe, Mn concentration is highest in roots, Zn concentrations are highest in the shoots.

Table.4.15. The concentrations of heavy metals (Cu, Fe, Mn, Zn,) in Coriandrum sativum (Coriander) roots, shoots, and leaves in MSW soil.

Coriandrum sativum (coriander)						
Heavy metals	Root		Shoot		Leaves	
	Conc (µg/L)	St.dev	Conc (µg/L)	St.dev	Conc (µg/L)	St.dev
Cu	28.80	0.48	18.63	0.99	72.34 µg/L	0.53
Fe	28.80	0.48	31.84	0.71	22.78 µg/L	0.39
Mn	237.9	5.27	106.8	0.58	21.60 µg/L	0.36
Zn	109.6	1.16	141.5	2.21	178.1 µg/L	0.74

Where it can be concluded that Cu concentration is highest in leaves, Fe concentration is highest in shoots, Mn concentration is highest in roots, and Zn concentration is highest in leaves.

Table 4.16. The concentrations of heavy metals (Cu, Fe, Mn, Zn) in Solanum lycopersicum (tomato) roots, shoots, and leaves in the pot experiment in MSW soil.

Spinacia oleraceae (spinach)						
Heavy metals	Root		Shoot		Leaves	
	Conc (µg/L)	St.dev	Conc (µg/L)	St.dev	Conc (µg/L)	St.dev
Cu	107.4	2.06	58.14	0.379	64.00	0.402
Fe	255.7	2.06	131.0	2.66	32.87	0.72
Mn	255.7	2.85	209.3	1.23	26.68	0.452
Zn	249.1	3.9	321.9	1.96	157.9	0.12

Where, it can be concluded that Cu concentration is highest in leaves, Fe, Mn, Zn concentration is highest in roots and Cd and Pb are not present.

Table 4.17. The concentrations of heavy metals (Cu, Fe, Mn, Zn) in Brassica nigra (mustard) in the pot experiment in MSW soil.

Brassica nigra (mustard)						
Heavy metals	Root		Shoot		Leaves	
	Conc (µg/L)	St.dev	Conc (µg/L)	St.dev	Conc (µg/L)	St.dev
Cu	110.9	1.05	44.91	0.28	69.55	0.57
Fe	186.3	3.15	69.05	0.56	30.12	0.50
Mn	533.0	6.77	14.13	3.63	40.68	0.22
Zn	258.4	1.29	197.4	0.36	154.3	0.11

Indicating that Cu, Fe , Mn , Zn concentration is highest in roots.

Table 4.18. The concentrations of heavy metals (Cu, Fe, Mn, Zn) in control condition of *Spinacia oleracea* (Spinach) roots, shoots, and leaves in the pot experiment

Spinacia oleraceae (spinach)						
Heavy metals	Root		Shoot		Leaves	
	Conc(µg/L)	St.dev	Conc (µg/L)	St.dev	Conc (µg/L)	St.dev
Cu	3.330	0.2023	3.320	0.7714	67.15	5.382
Fe	38.98	0.15	214.5	4.14	105.1	1.59
Mn	133.9	1.1	70.38	1.012	988.8	7.1
Zn	70.96	0.548	73.38	0.793	228.8	1.98

Where it can be concluded that Cu, Fe, Mn and Zn concentration is highest in leaves.

Table 4.19. The concentrations of heavy metals (Cu, Fe, Mn, Zn) in Coriandrum sativum (Coriander) in the pot experiment in control condition.

Coriandrum sativum (coriander)						
Heavy metals	Root		Shoot		Leaves	
	Conc (µg/L)	St.dev	Conc (µg/L)	St.dev	Conc (µg/L)	St.dev
Cu	26.42	0.392	38.77	3.45	64.77	5.214
Fe	156.1	3.54	227.3	4.87	121.2	1.69
Mn	156.1	3.09	80.79	1.2	673.8	6.99
Zn	108.6	2.03	104.7	1.58	232.3	2.13

Indicating that Cu, Mn and Zn concentration is highest in leaves, Fe concentration is highest in roots.

Table 4.20. The concentrations of heavy metals (Cu, Fe, Mn, Zn) in Solanum lycopersicum (tomato) in the pot experiment in control condition.

Solanum lycopersicum (tomato)						
Heavy metals	Root		Shoot		Leaves	
	Conc(µg/L)	St.dev	Conc(µg/L)	St.dev	Conc(µg/L)	St.dev

Cu	4.568	0.02	33.09	2.58	10.13	0.754
Fe	25.84	0.14	213.4	4.16	18.78	0.209
Mn	94.88	1.50	79.80	1.08	364.7	8.86
Zn	68.43	0.17	121.3	1.61	71.93	0.797

Indicating that Cu, Fe and Zn concentration is highest in shoots, Mn concentration is highest in leaves.

Table 4.21. The concentrations of heavy metals (Cu, Fe, Mn, Zn) in Brassica nigra (mustard) in the pot experiment in control condition.

Brassica nigra (mustard)						
Heavy metals	Root		Shoot		Leaves	
	Conc (µg/L)	St.dev	Conc (µg/L)	St.dev	Conc (µg/L)	St.dev
Cu	6.995	0.05	36.05	2.87	11.98	0.39
Fe	30.12	0.15	195.67	3.44	15.58	0.43
Mn	87.60	1.42	78.23	1.05	347.33	2.09
Zn	69.02	0.18	112.7	1.39	75.22	0.58

Indicating that Cu, Fe, Zn concentration is highest in shoots, Mn concentration is highest in leaves.

4.8.2. Petri dish experiments:

Table 4.22. The seed germination number in the petri dish experiment with control and leachate.

Species name	Leachate	Mean±St.Dev	Control	Mean±St.Dev
Brassica nigra (mustard)	19	6.5±8.42	20	8±8.28
Spinacia oleraceae (spinach)	2		3	
Coriandrum sativum (coriander)	1		2	
Solanum lycopersicum (tomato)	4		7	

Where the number of seeds germinated in control soil was more than in leachate.

Table 4.23. The values for root length, shoot length, and leaf count between the leachate and control groups in a petri dish experiment.

	Leachate			Control		
Species name	Radical length	Plumule length	Number of leaves	Radical length	Plumule length	Number of leaves
Brassica nigra (mustard)	3.45±2.85	2.35±0.96	1.27±0.44	1.27±0.44	2.77±1.36	1.3±0.47

Spinacia oleraceae (spinach)	1±0	1.25±1.06	1.25±1.06	4.5±0.70	8.5±2.12	2±0
Coriandrum sativum (coriander)	3.5±0	0.5±0	1±0	3.66±1.04	4±0	1±0
Solanum lycopersicum (tomato)	2.85±0.85	2.37±0.25	1.28±0.48	4±0.70	7.87±1.75	1.75±0.5

The results reveal that while leachate increases the root length of Brassica nigra (mustard), the shoot length and leaf count increase in the control group. Second, in the control than in the leachate, Spinacia oleracea (Spinach) has longer roots, longer shoots, and more leaves overall. In Coriandrum sativum (coriander), root and branch length are greater in the control than in the leachate, but leaf count is the same in both. The root length, shoot length, and number of leaves in Solanum lycopersicum (tomato) are significantly higher in control than in leachate.

Table 4.24. The RRG, RSG and GI in petri dish of four plant samples: *Brassica nigra* (mustard), *Spinacia oleracea* (spinach), *Coriandrum sativum* (coriander), and *Solanum lycopersicum* (tomato).

Species name	RRG	Mean±St.Dev	RSG	Mean±St.Dev	GI	Mean±St.Dev
Brassica nigra (mustard)	86.68 %	68.88±32.66	95%	67.26±19.70	82.34%	46.43±27.81
Spinacia oleraceae (spinach)	22.22%		66.66%		14.81%	
Coriandrum sativum (coriander)	95.36%		50%		47.68%	
Solanum lycopersicum (tomato)	71.25%		57.41%		40.9%	

The results show that *Coriandrum sativum* (coriander) had the highest RRG, while *Brassica nigra (*mustard) had the highest RSG and highest GI is recorded in *Brassica nigra* (mustard).

Table 4.25. The values of heavy metals (Cu, Fe, Mn, Zn) concentration of *Brassica nigra* (mustard), *Solanum lycopersicum* (tomato) , *Coriandrum sativum* (coriander) and *Spinacia oleracea* (Spinach) in leachate in the petridish experiment.

Heavy metals	*Spinacia oleraceae* (spinach)	*Coriandrum sativum* (coriander)	*Solanum lycopersicum* (tomato)	*Brassica nigra* (mustard)

	Conc (µg/L)	St.dev	Conc (µg/L)	St.dev	Conc (µg/L)	St.dev	Conc (µg/L)	St.dev
Cu	0.281	0.0731	10.71	0.111	8.078	0.1138	4.910	0.0999
Mn	30.83	0.111	52.66	0.115	53.93	0.756	76.55	0.22
Zn	86.37	0.685	84.43	0.71	84.91	0.997	69.82	0.672

Where it can be concluded that, Cu concentration is higher in *Coriandrum sativum* (coriander), Mn concentration is higher in *Brassica nigra* (mustard), Pb, Fe and Zn concentration is higher in *Spinacia oleracea* (Spinach).

4.9. Summary of this chapter:

The objective of the study was to evaluate the ranks of harmful metals (Zn, Cd, Cr, Pb, and Ni) across various environmental factors (groundwater, soil, and leachates) and to assess the impact of a solid waste disposal site on the local population. Soil enrichment factor calculations revealed that the high levels of hazardous metals present in landfill dumping sites pose a significant ecological risk. Heavy metals can enter the human body through inhalation, skin contact, and direct ingestion, increasing the risk of cancer due to their carcinogenic properties. Notably, children had hazard index (HI) values 6.5 times greater than adults, although both landfill workers and residents in the target area were found to be at a safe level (HI ≤1). However, adults in the residential area exhibited a higher Incremental Lifetime Cancer Risk (ILCR) than children. Hierarchical clustering analysis (HCA) was applied to the water quality dataset, dividing the monitoring locations into three statistically independent groups: Low pollution (LP), High pollution (HP), and Moderate pollution (MP). Subsequently, principal component analysis (PCA) was used to extract principal components from these clusters, providing a detailed understanding of the pollution sources and their impacts on environmental and human health.

According to the physico-chemical characteristics of soil and leachate, a pH of roughly 7.5, most nutrients are also more readily available in this pH range, which promotes plant growth and seed germination. The number of seeds that germinated in the pot experiment were highest in control soil of *Solanum lycopersicum* (tomato). *Brassica nigra* (mustard) roots were found to have the highest concentration of heavy metals in the pot experiment. Lead and cadmium were not present in the saline solution. And on the other hand, in petri dish experiment, the highest number of seeds germinated was in control of *Brassica nigra* (mustard) and highest metal concentration was found to be Zinc in *Spinacia oleracea* (spinach) whereas, Fe, Pb and Cd were absent in control, no heavy metals were present. Heavy metal levels in dumping site soil were substantially higher than in control soil. The control soil had more organic carbon and nutrient availability, which was associated with increased plant growth, whereas the dumping site soil was unsuitable for plant growth due to heavy metal contamination, and in the presence of landfill leachate, seed root and shoot lengths were significantly reduced, inhibiting seed germination compared to the control.

References:

1. Kumar, D., & Alappat, B. J. (2005). Evaluating leachate contamination potential of landfill sites using leachate pollution index. *Clean Technologies and Environmental Policy*, *7*(3), 190–197. https://doi.org/10.1007/s10098-004-0269-4
2. Malunguja, G. K., Thakur, B., & Devi, A. (2022). Heavy Metal Contamination of Forest Soils by Vehicular Emissions: Ecological Risks and Effects on Tree Productivity. In *Environmental Processes* (Vol. 9, Issue 1). Springer International Publishing. https://doi.org/10.1007/s40710-022-00567-x
3. Turekian, K. K., Haven, N., Hans, K., & Universitat, W. M. Der. (1961). KARL K. TUREKIAN Dept. Geology, Yale University, New Haven, Conn. KARL HANS WEDEPOHL Mineralogische-Institut der Universitat, Gottingen, Germany Distribution of the Elements in Some Major Units of the Earth's Crust. *America*, *February*, 175–192.
4. Usero, J., Morillo, J., & Gracia, I. (2005). Heavy metal concentrations in molluscs from the Atlantic coast of southern Spain. *Chemosphere*, *59*(8), 1175–1181. https://doi.org/10.1016/j.chemosphere.2004.11.089
5. Mohan, S. V., & Nithila, P. (1996). Journal of Environmental Science and Health. Part A : Environmental Science and Engineering and Toxicology : Toxic / Hazardous Substances and Environmental Engineering Estimation of heavy metals in drinking water and development of heavy metal pollution. *Journal of Enviromental Science Health*, *2*(October 2013), 283–289.
6. akhmiri, R., & Albourine, A. (2020). Elaboration of novel polyaniline@Almond shell biocomposite for effective removal of hexavalent chromium ions and Orange G dye from aqueous solutions. *Environmental Science and Pollution Research*, *27*(13), 15245–15258. https://doi.org/10.1007/s11356-020-08039-1
7. Mishra, D., Singh, S. K., Adhikari, A., & Chatterjee, S. (2022). Polyaniline and polypyrrole impregnated polyethersulfone based composite polymer beads for defluoridation application. *Journal of Environmental ChemicalEngineering*, *10*(5). https://doi.org/10.1016/j.jece.2022.108283
8. Naiya, T. K., Bhattacharya, A. K., & Das, S. K. (2008). Adsorption of Pb(II) by sawdust and neem bark from aqueous solutions. *Environmental Progress*, *27*(3), 313–328. https://doi.org/10.1002/ep.10280
9. Gujre, N., Mitra, S., Soni, A., Agnihotri, R., Rangan, L., Rene, E. R., & Sharma, M. P. (2021). Speciation, contamination, ecological and human health risks assessment of heavy metals in soils dumped with municipal solid wastes. *Chemosphere*, *262*, 128013.