Research Article

Comparative Assessment of Physico-Chemical Properties and Heavy Metal Pollution in Soils at Dumpsites in Chennai: An Environmental Evaluation

Swetha N M[1], Gopal V[1], Gladia Vimsal E[1], Kamalipriya R[1], Krishnamurthy R R[1] Bhuvaneswari M[1] and Suresh Gandhi M[2]

[1]Department of Applied Geology, School of Earth and Atmospheric Sciences, University of Madras, Guindy Campus, Chennai 600025, India
[2]Department of Geology, School of Earth and Atmospheric Sciences, University of Madras, Guindy Campus, Chennai 600025, India

Article history
Received: 07-01-2025
Revised: 04-08-2025
Accepted: 24-12-2025

Corresponding Author:
Swetha N M
Department of Applied Geology, School of Earth and Atmospheric Sciences, University of Madras, Guindy Campus, Chennai 600025, India
Email: swethanmsv@gmail.com

Abstract: The disposal of municipal waste in urban areas such as Kodungaiyur and Perungudi is a significant concern. This study aimed to compare the environmental quality and potential impact on human health between these two dumpsites. To achieve this objective, the research focused on evaluating the concentration of specific heavy metals and conducting physico-chemical analyses of the soil at both Kodungaiyur and Perungudi dumpsites. This evaluation was conducted using X-ray fluorescence (XRF) spectrometry. Soil samples were analyzed from 32 locations in Kodungaiyur and 23 locations in Perungudi, with samples collected at various sites during September 2022**.** The contents of several heavy metals in the Kodungaiyur and Perungudi samples were measured in the following order: Pb > Zn > Cu > Mn > Cr > Cu > Ni > As > Fe for Kodungaiyur and Zn > Cu > Pb > Ni > Cr > Fe > Mn > As for Perungudi. This assessment utilized the Geo-accumulation Index (Igeo), Enrichment Factor (EF), and Contamination Degree (CD) to evaluate soil contamination. The analysis of heavy metal concentrations and associated pollution indices reveals significant contamination in soils around the Kodungaiyur and Perungudi dumpsites, primarily attributed to anthropogenic sources, notably indiscriminate refuse dumping. It is recommended to implement measures for monitoring uncontrolled landfills and improving solid waste management and disposal practices to mitigate this pollution within acceptable limits.

Keywords: Solid Waste, Landfills, Dumpsite, Heavy Metals, Environmental Quality

Introduction

The relationship between humans and the environment is inherently symbiotic, necessitating a delicate balance in all aspects. However, in recent decades, this equilibrium has been disrupted due to rapid industrialization (Lagerkvist, 2019). The consequence of this disruption is the substantial increase in the disposal of solid waste on land, which has emerged as a prevalent method for waste management. Unfortunately, the volume of municipal and industrial waste generated by society continues to rise, with Municipal Solid Waste (MSW) generation in India growing at a rate that outpaces population growth. The inadequate disposal and management of solid waste have severe consequences, posing risks to both groundwater and residents in affected areas (Kumar et al., 2017). Soil pollution is defined by the degradation of soil's structural and biological qualities due to a variety of human activities and natural processes. This degradation disrupts soil functions and reduces its ability to support ecosystems and human needs (Heavy metal contamination in dump site soils exerts a lasting influence on the microbial communities within, potentially disrupting their structure and function (Kumar et al., 2017). Toxic substances such as heavy metals, pesticides, and hydrocarbons present in this liquid frequently lead to the contamination of soil and water resources (Aralu et al., 2022).

DOI:10.3844/ajessp.2026.11.24

Dumpsites receive a continuous influx of waste and cover materials from various sources, resulting in a complex mixture of contaminants that can leach into and pollute the surrounding soil. This diversity and complexity of waste types contribute to significant soil contamination, which, in turn, disrupts the ecological balance of local ecosystems. There can be different sources for heavy metals from MSW, such as electronic goods, painting waste, electroplating waste, fertilizers, and pesticides from yard waste, etc., (Esakku et al. 2003).

Open dumping, characterized by the reckless disposal of solid waste without adequate safeguards, gives rise to a host of environmental problems. These problems include soil contamination, reduced crop yields, the emission of noxious odors, and the deterioration of groundwater and soil quality. The ramifications of unregulated waste dumping extend to human health, especially among those residing near these dumpsites. This includes scavengers who come into direct contact with the waste (Akanchise et al., 2020, Kasassi et al., 2008; Aja et al., 2021).

In India, the surge in solid waste generation is alarming, with urbanization expected to reach 60% by 2025. Currently, India produces approximately 100,000 metric tons of MSW daily, a figure projected to exceed 125,000 metric tons by 2030 (CPCB, 2012). Chennai, the fourth largest metropolitan city in India, has experienced a significant increase in MSW generation, reaching 3,500 tons per day within two decades (Esakku et al., 2007). Inadequate waste management infrastructure, typified by open dumpsites like Kodungaiyur and Perungudi, has raised grave concerns about the ecological and health impacts of such practices. The heavy metal composition found in these waste dumps further exacerbates environmental problems. Heavy metals, stemming from various sources such as geological, agricultural, metallurgical, waste disposal, and industrial activities, have the capacity to persist in soils, contaminating the environment (Salvia et al., 2021; Mavakala et al., 2016; Bhat et al., 2022). Notable metals like lead (Pb), cadmium (Cd), chromium (Cr), and others pose substantial risks as they can leach into groundwater, accumulate in crops, and ultimately affect human health.

The primary aim of this study was to evaluate the contamination levels in soils impacted by uncontrolled waste dumping and to analyze associated environmental risks. This was achieved through:

(i) Measuring the concentrations of toxic metals, including Fe, Mn, Cr, Co, Cu, Zn, As, and Pb, in soil samples from the dumpsites
(ii) Assessing environmental risks by calculating pollution indicators such as the Geoaccumulation Index (Igeo), Contamination Factor (CF), and Enrichment Factor (EF)
(iii) Determining the physico-chemical properties of the soils. Collectively, these evaluated parameters serve as crucial tools for analyzing, interpreting, and presenting environmental data to inform decision-makers, waste management professionals, and the general public. Such insights are intended to improve solid waste management systems and help reduce potential risks to human health and the environment

Study Area

Chennai hosts several dumping sites, with Perungudi and Kodungaiyur serving as the city's primary waste disposal locations. Perungudi is situated in the southern region of Chennai at coordinates 12° 05' 13.5" N and 80° 01' 05.8" E on the Coromandel Coast, spanning an area of approximately 65 square kilometers. Recent urban expansion in Chennai has largely occurred in this southern region. The site is an unmanaged, low-lying open dump, appearing as a massive pile of waste. There are four villages situated in close proximity to the Perungudi landfill. Figure 2 shows the Perungudi area sample collections. The city generates around 3,500 tons of garbage daily, with approximately 60% being dumped in the ecologically sensitive Pallikaranai marshland. Solid waste disposal is managed by the Chennai City Municipal Corporation.

Kodungaiyur, situated in the northernmost part of Chennai, Tamil Nadu, is a residential locality that hosts one of the city's largest dump yards, maintained by the Greater Chennai Corporation. Kodungaiyur area sample Locations are in Fig. 1. The latitude and longitude of Kodungaiyur are 13° 08' 02" N and 80° 16' 09" E. The Kodungaiyur dump site covers about 350 acres, of which

approximately 250 acres are used for waste dumping, with a current rate of 3,600 metric tons per day. This site primarily receives waste from densely populated areas such as Korukkupet and Tondiarpet, as well as from heavy industries located 2 km away in Manali. Kodungaiyur dump site is the largest dump site maintained by Chennai City Corporation. The dump site is an open landfill and lacks proper lining to prevent leachate from contaminating the surrounding groundwater.

Geology of Chennai

The study area is primarily underlain by a variety of consolidated and fissured formations, including the oldest Archean rocks, and is followed by unconsolidated alluvial formations of Quaternary age (Miocene to Pliocene). In Chennai, soil composition varies from sandy loam near the coast to clay-rich soils further inland. Coastal sandy soils are well-drained, while inland clayey soils have poor drainage, leading to waterlogging during heavy rainfall. The rapid pace of urbanization has increased the demand for construction materials and land, impacting the natural geological and hydrological systems of the region. This development has also introduced challenges such as land subsidence and an increased risk of flooding.

Sampling Procedure

Sediment samples were collected from a total of 55 locations: 32 from Kodungaiyur and 23 from Perungudi, as detailed in Figs. 1 and 2. A grid map was prepared to guide sample collection at 1 km intervals. The total area covered was approximately 250 sq km for Kodungaiyur and 174 sq km for Perungudi landfills. Due to high-security restrictions at certain industrial sites, samples could not be obtained from all grid locations. Samples were collected using the V-shaped method to ensure representative sub-sampling.

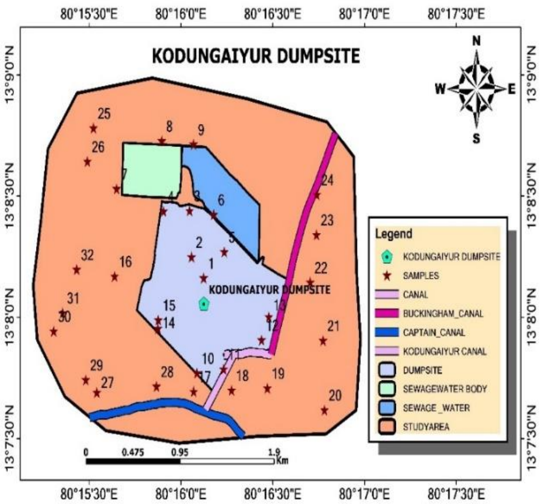

Fig. 1: Study area map of Kodungaiyur sample locations

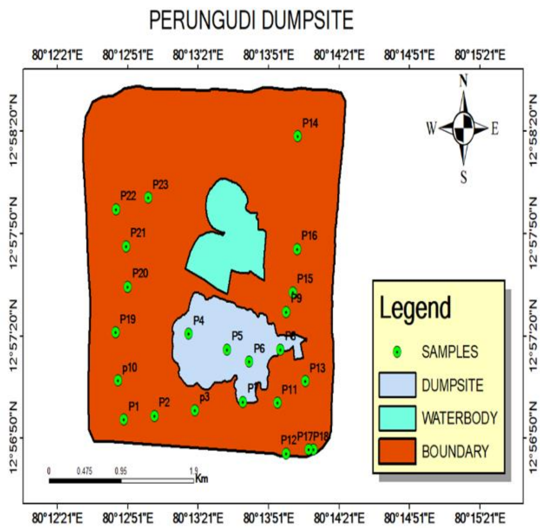

Fig. 2: Study area map of Perungudi samples

A spade was used to extract the samples, which were then transferred carefully sealed in zip-lock bags to prevent contamination and moisture loss. The sediments were dried in direct sunlight for two days prior to analysis. For each sample, the coning and quartering method was used to achieve uniformity. This process involved thoroughly mixing the soil and dividing it into four equal portions. One of these portions was selected for analysis and stored separately.

The dried samples were pulverized and sieved (2mm) to eliminate coarser sediments (Ingram 1970). Calcium carbonate content was measured following the procedure outlined by while organic matter content was assessed using the method described by Gaudette and Flight (1974). The percentages of sand, silt, and clay were determined using the pipette method. Heavy metals were analysed using the ED-XRF procedure, as described by To prepare the pressed powder pellet, surface soil samples were first dried in an oven at 105°C for 24 hours. Once dried, they were finely ground using a pestle and mortar until the particles could pass through a 63-μm sieve. The powdered sample was then combined with 1.5 mL of a polyvinylpyrrolidone-methylcellulose binding agent. This mixture was subjected to 10-ton pressure to form a uniform, flat-cylinder pellet. To eliminate any residual moisture that could affect signal detection, the pellet underwent an additional 24-hour drying process at 105°C.

XRF Analysis and Quality Control

Heavy metal concentrations in the sediments were determined using X-ray fluorescence (XRF) spectrometry. The instrument was calibrated prior to analysis using appropriate certified reference materials (CRM) and factory-set standards. Instrument performance was monitored by analyzing calibration standards and blank samples at regular intervals. To further validate the accuracy of the results, a certified reference material (e.g., NIST SRM 2711a, Montana II Soil) was analyzed alongside the sediment samples. The measured values for CRMs were within ±5% of the certified concentrations, indicating acceptable analytical precision and reliability.

Pollution Assessment Indices

Contamination Factor

The contamination factor is determined by comparing the concentration of heavy metals found in the sediment of a water body to the pre-industrial reference value for those same metals (Hakanson, 1980). It serves as a valuable tool for tracking pollution over time and is calculated as follows:

$$CFn = (Cn/Bn) \quad (1)$$

Where *Cn* denotes the concentration of metal *n* in the contaminated soil, and *Bn* represents the background concentration for metal *n*:

CF < 1 (low contamination)
1 < CF < 3 (moderate contamination)
3 < CF < 6 (considerable contamination)
6 < CF (very high contamination)

Geoaccumulation Indices

The Geo-accumulation Index (I-geo) was calculated using the formula established by Müller, as detailed in the work (Müller, 1969):

$$I - geo = \log_2 (C_n / 1.5Bn) \quad (2)$$

Where:

Cn = Measured concentration of heavy metal
Bn = Geochemical background value

The factor of 1.5 accounts for potential variations in background data caused by lithological differences. The I-geo index is categorized into seven levels:

Grade 0 (≤ 0) unpolluted
Grade 1 (0 ≤ 1) slightly polluted
Grade 2 (1≤ 2) moderately polluted
Grade 3 (2 ≤ 3) moderately severely polluted
Grade 4 (3 ≤ 4) severely polluted
Grade 5 (4 ≤ 5) severely extremely polluted
Grade 6 (>5) extremely polluted

Enrichment Factor

The Enrichment Factor (EF) indicates the level of pollution or contamination. It is commonly used in studies to assess the relative contributions of natural versus anthropogenic heavy metal inputs to soils. However, it has been suggested that high EF values may not always reliably reflect the extent of human impact on the global environment (Ololade, 2014; Adamo et al., 2005):

$$EFS - = (CM / CX\ scmple) / (CM / C_X\ Earth's\ crust) \quad (3)$$

Where CM is the content of essence studied, and CX is the content of the immobile element. Immobile rudiments may be Al or Fe:

EF =<2: deficiency to minimal enrichment
EF = 2 - 5 moderate enrichment
EF = 5 - 20 significant enrichment
EF = 20 to 40 indicates very high enrichment
EF = >40: extremely high enrichment

Results and Discussion

This section presents and analyzes the results of the physico-chemical properties of soils collected from the Kodungaiyur and Perungudi dumpsites. The primary focus is on understanding the impact of waste disposal on soil characteristics, including organic matter content and soil texture, as well as the broader implications for contamination and environmental quality. By comparing soil samples from different locations within and around the landfill sites, we aim to elucidate the effects of waste management practices on soil composition and contamination levels.

Physico-Chemical Properties

The physico-chemical analysis of soils from the Kodungaiyur and Perungudi dumpsites provides critical insights into soil characteristics and contamination levels. The assessment of organic matter is crucial for understanding the impact of pollution, especially given that the waste in these areas predominantly consists of biodegradable residential waste from Chennai metropolitan city.

The pH of the Kodungaiyur dumpsite soil is 8.21(K24) to 5.96 (K15). This result indicated that the dumpsite soil is acidic in nature. At Kodungaiyur, the Organic Matter (OM) content in soil samples from the landfill ranges between 0.68% (K11) and 8.73% (K28), as shown in Table 1. High range values are at a location farthest from the landfill. This relatively low level of organic contamination is consistent with findings by Poté et al. (2008). The dump soils exhibit a significant accumulation of organic matter, primarily due to the decomposition of organic waste residues prevalent in the area. These residues undergo microbial decay, contributing to the enrichment of organic content in the soil matrix, reflecting the impact of waste composition and decomposition processes on soil properties. The relatively elevated levels of organic carbon in the refuse dump soils indicate the presence of substantial quantities of degradable and compostable waste materials. This suggests that organic matter from these wastes undergoes decomposition, contributing significantly to the organic carbon content within the soil (Gairola and Soni, 2010; Moorberg and Crouse, 2017). Additionally, soil texture varies across the site, with 40% of the areas exhibiting a silty texture and 60% showing sandy characteristics. The K23 sample exhibits a high concentration of calcium carbonate, likely attributed to the presence of calcareous organisms originating from the Buckingham Canal. This suggests a biologically influenced sediment composition, where the canal's ecological dynamics contribute significantly to the carbonate content in the sample (Buscaroli et al., 2019). Calcium carbonate ($CaCO_3$) levels in dumpsite soil are often elevated due to the decomposition of calcareous materials such as construction debris, lime, and other carbonate-containing waste. For Kodungaiyur, the maximum value is in K23 of 30%, and the minimum value is in K6 of 1.5%. The K23 soil sample, collected from a nearby canal, exhibited the highest calcium carbonate ($CaCO_3$) levels, likely due to the deposition of carbonate-rich runoff from the surrounding environment.

Table 1: Physico-Chemical results of Kodungaiyur dumpsite

Sample No	PH	Calciumc Arbonate	Organic Matter	Sand	MUD
K1	6.61	110	1.6	3.8	1.2
K2	7.01	12.5	3.09	4.1	0.9
K3	7.41	89.5	4.12	3.82	1.18
K4	7.14	45	3.09	4.07	0.93
K5	6.74	14	1.37	4.31	0.69
K6	7.17	1.5	7.3	4.705	0.295
K7	6.77	31	5.88	4.7	0.3
K8	6.79	92	3.13	3.7	1.3
K9	7.24	60	1.47	3.85	1.15
K10	7.69	40	1.86	4.63	0.37
K11	7.1	7	0.68	3.97	1.03
K12	7	46	1.07	3.99	1.01
K13	7.18	22.5	4.9	4.2	0.8
K14	7.14	73	1.8	3.3	1.7
K15	5.96	14.5	3.5	4.17	0.83
K16	7.3	22.5	6.3	3.98	1.02
K17	7.63	7	3.5	4.48	0.52
K18	7.14	7	6.3	4.03	0.97
K19	7.59	9	3.5	4.403	0.6
K20	6.8	45	1.5	3.8	1.2
K21	7.61	2	1.9	4.78	0.22
K22	7.06	10	7.4	3.32	1.68
K23	7.56	30	2.2	4.68	0.32
K24	8.21	2.5	2.8	4.81	0.19
K25	7.45	17	2.8	3.43	1.57
K26	6.96	17	3.4	4.1	0.9
K27	7.3	34.5	2.8	4.1	0.9
K28	6.7	55	8.73	3.37	1.63
K29	7.62	14.5	1.7	4.5	0.5
K30	6.82	6.5	2.45	4.74	0.26
K31	7.8	2	4.6	4.63	0.37
K32	6.83	21	3.4	4.39	0.61
MAX	8.21	110	8.73	4.81	1.7
MIN	7.16	33.06	3.34	4.17	0.84
AVERAGE	5.96	1.5	0.68	3.3	0.19

In contrast, the K6 sample, obtained from within the dumpsite, recorded the lowest $CaCO_3$ levels. This variation suggests that waste decomposition within the dumpsite influences the $CaCO_3$ percentage, with the canal potentially serving as a receptor for leachates and materials contributing to elevated $CaCO_3$ concentrations. Soils within dumpsites often exhibit elevated physico-chemical values due to the accumulation and decomposition of heterogeneous waste materials. These processes significantly alter soil composition, structure, and chemical properties. In contrast, surrounding soils typically display intermediate value ranges, reflecting lower levels of contamination and reduced waste impact.

A pH range of 6.8 to 7.92 in Perungudi dumpsite soil represents slightly acidic to slightly alkaline conditions, which are relatively moderate compared to more extreme pH fluctuations typically observed in contaminated environments. This range indicates the combined effects of mixed waste decomposition and the soil's inherent buffering capacity. In Perungudi, the average organic matter content is notably higher, at 2.9%. The minimum organic matter content recorded was 1.03% (P4), at a location farthest from the landfill, while the maximum content reached 6.6%(P14) at a site within the landfill, as indicated in Table 2. This trend suggests an increase in organic matter content closer to the landfill, reflecting the impact of bio-waste disposal. Notably, despite being within the landfill, some areas have only moderate organic matter levels. This can be attributed to waste segregation practices, where specific zones are designated for plastic waste, which does not contribute to organic matter content. This differentiation highlights the influence of waste management practices on soil composition. Calcium carbonate levels were found to be the highest 42.5% within the dumpsite soil P4 and showed significant correlation with the nearby Pallikaranai marshland, suggesting that the $CaCO_3$ concentration in the marshland soil is influenced by the adjacent Perungudi dumpsite. The particle size of soil, which significantly influences plant species establishment, development, and various physical parameters of the soil, was analyzed in the study site based on the proportions of sand, silt, and clay.

Table 2: Physico-Chemical results of Perungudi dumpsite

SAMPLE NO	PH	CALCIUM CARBONATE	ORGANIC MATTER	SAND	MUD
p1	7.5	10	5.39	4.54	0.46
p2	7.35	22.5	3.91	3.99	1.01
p3	7.4	27.5	2.06	4.46	0.54
p4	6.86	42.5	1.03	3.91	1.09
p5	7.38	28.5	6.6	4.48	0.52
p6	7.66	5	5.39	4.53	0.47
p7	7.17	20	3.19	4.07	0.93
p8	7.68	30	2.67	3.5	1.5
p9	7.6	17.5	1.82	4.25	0.75
p10	7.72	40	1.3	4.39	0.61
p11	7.81	5	2.54	4.41	0.59
p12	7.25	20	3.53	4.29	0.71
p13	7.5	17.5	4.5	4.38	0.62
p14	7.53	72.5	4.6	2.91	2.09
p15	7.61	29.5	3.2	4.1	0.9
p16	6.8	21.5	1.03	3.8	1.2
p17	7.34	26	1.11	4.65	0.35
p18	7.81	30	1.23	3.5	1.5
p19	7.62	27.5	0.19	4.2	0.8
p20	7.91	21	2.57	4.06	0.94
p21	7.52	2.5	2.8	3.43	1.54
p22	7.92	10	3.82	3.8	1.2
p23	7.68	5	3.09	4.4	0.6
MINIMUM	6.8	2.5	0.19	2.91	0.35
MAXIMIM	7.92	72.5	6.6	4.65	2.09
AERAGE	7.4936	24.26	2.9744	4.0644	0.9344

The refuse dump soil, heavily impacted by waste decomposition, exhibited notable alterations in particle size distribution. The analysis revealed that the dumpsite soil had a high sand content of 4.65 (P17) and a clay content of 2.09 (P14), reflecting the influence of waste decomposition on its textural properties.

The physico-chemical analysis of Dumpsite Kodungaiyur and Dumpsite Perungudi reveals notable variations and similarities in soil quality. Both sites exhibit elevated levels of organic matter and calcium carbonate, indicating significant waste decomposition and leachate infiltration. However, Dumpsite Kodungaiyur has a slightly acidic pH range of 8.21 to 5.96, while Dumpsite Perungudi shows a more alkaline range of 6.8 to 7.92, likely due to the presence of construction debris and ash in the latter. Additionally, Dumpsite Kodungaiur has higher concentrations of heavy metals such as lead and cadmium, suggesting greater contamination from electronic and industrial waste, compared to Dumpsite Perungudi, which shows lower heavy metal levels but elevated salinity. These differences may result from variations in waste composition and site management practices. The findings underscore the need for targeted remediation strategies, with Dumpsite Kodungaiyur requiring heavy metal stabilization and Dumpsite Perungudi addressing salinity control.

Overall, the findings from Kodungaiyur and Perungudi reveal variability in soil texture and organic matter content based on proximity to landfill sites and waste management practices. These results underscore the importance of effective waste management in influencing soil characteristics and mitigating contamination.

Heavy Metal Concentrations

Kodungaiyur

The average concentrations and ranges of heavy metals in soil samples from the 32 sampling sites are presented in Table 3. Overall, there were significant variations in heavy metal concentrations across different sampling areas. Notably, concentrations of Fe, Mn, Zn, and Cr were substantially higher in most soil samples compared to background values. The order of heavy metals detected in the soils is as follows: *Fe > Mn > Zn > Cr > Cu > Pb > Ni > As*. Maximum values at Location of Fe 55392 (K2), Mn 4625 (K25), Zn 1104 (K4), Cr 699.2 (K32), Cu 561.3 (K4), Pb 503 (K3), Ni 96.6 (K1), and As 15.7 (K3). Biennial variation of iron was in the order as Residual fraction > Bound to Fe and Mn oxide Fraction bound to organic matters > Bound to carbonate fraction > Exchangeable fraction. The fraction of Fe accounts for greater metal content in the residual form, and this level is toxicologically insignificant to cause any adverse effect on biota. This result was in good agreement with data reported by several research works carried out in other marine systems (Usero et al., 1998; Yuan et al., 2004; Takarina, 2010).

Table 3: Heavy metal results of Kodungaiyur dumpsite

SAMPLE NO	Fe (ppm)	Mn (ppm)	Cu (ppm)	Pb (ppm)	Zn (ppm)	Cr (ppm)	Ni (ppm)	As (ppm)
K1	40425	775	277.6	110.6	533.5	228.3	96.6	10.2
K2	55392	767	140	55.3	197	248	88	5.5
K3	41265	581	192	503.2	396.3	171.9	54.4	15.7
K4	34690	852	561.3	217.4	1104	338	94.3	12.1
K5	36439	620	251.9	118.2	401.2	299.3	62.6	3.7
K6	32942	387	540.2	127.7	565	246.9	56.7	5
K7	22017	212	257.1	73.4	274.8	129.3	28.4	3.4
K8	31893	697	164	75.8	325.7	169.2	54.3	5.7
K9	49867	775	177.6	92.9	304.5	276.6	73.8	10.1
K10	31543	542	117.1	61	275.5	247.7	43.2	5
K11	45251	697	217.7	110.8	445.4	228.7	68.4	9.2
K12	44622	775	215.9	106	456.8	195.1	66.6	9.4
K13	17695	465	125.9	112.8	216.1	95.4	37	7
K14	36299	620	299.4	106.5	637	581.6	78.1	6.4
K15	32592	465	255.7	52.9	288.9	298.4	51.2	3.9
K16	39166	620	157.4	68.2	400.3	179.3	65.5	6.4
K17	30704	37	93.6	70.3	238.5	129.7	33.3	3.2
K18	31333	465	105.5	31.2	280.9	121.3	38.4	3.9
K19	39428	610	297	110.2	466.5	653	45.6	4.2
K20	47489	852	273.2	78.2	468.3	249	79.9	6.8
K21	42593	852	97.6	61.1	303	148.4	58.9	5.8
K22	31543	620	156	78.4	965.2	206.7	52.4	4.1
K23	29375	465	91.6	40.8	252.5	95	34.6	3.2
K24	32102	542	84.9	54.6	515.5	153.8	40.9	3.4
K25	28536	4625	187.1	74.8	327.4	218.7	53.6	5.5
K26	27766	620	58.5	32.4	233	96.1	41.6	3.9
K27	32102	620	75.5	56.7	700.1	109	45.3	4.6
K28	24899	387	264.8	97.5	763.2	94.2	37.2	3.5
K29	25178	465	55.9	36.2	170.8	96.9	44.2	3.9
K30	29095	387	34.3	33.6	139.3	72.1	22	3.4
K31	25178	465	45.7	33.7	191.8	115.2	29.6	1.7
K32	38747	387	294	96.1	490	699.2	74.9	4.5
MAX	55392	4625	561.3	503.2	1104	699.2	96.6	15.7
MIN	17695	37	84.9	31.2	197	95	28.4	3.2
AVERAGE	36527.71	595.54	214.59	104.90	429.68	237.11	58.46	6.39

The pollution observed at locations K1, K2, K3, K4, and K5 shows the highest ranges of heavy metal concentrations, likely linked to the extensive industrial operations in the vicinity. These five sampling sites within the dumpsites exhibit the highest levels of pollution, with metal concentrations predominantly in the upper range. The behavior of heavy metals and soil properties significantly influences their concentrations at depths of 0-15 cm.

Perungudi

The average concentrations and ranges of heavy metals in soil samples from 23 sampling sites are presented in Table 4. There were notable variations in concentrations across different sample locations. Iron (Fe) concentrations were significantly higher in most soil samples compared to background values. This elevated iron level at the Perungudi landfill is likely due to the disposal of iron-containing materials and industrial waste, including discarded metal objects, construction debris, and waste from nearby industrial activities. Additionally, the natural presence of iron in the soil may be exacerbated by these anthropogenic inputs. In contrast, concentrations of other metals such as Mn, Zn, Cr, Cu, Ni, Pb, and as were within background values, indicating that these metals are not significantly impacted by anthropogenic activities at the landfill. The order in which various heavy metals were measured in the soil is as follows: Fe> Mn> Zn > Cr> Cu> Ni > Pb> As. Maximum concentrations are Fe 41894 (P4), Mn 620 (P4), Zn 241.3 (P12), Cr 231 (P13), Ni 80.4 (P7), Pb 43.7 (P6), and as 3.8 (P6).

Geoaccumulation Index (Igeo), Enrichment Factor (EF), and Contamination Degree (CD)

Kodungaiyur

The Enrichment Factor (EF) and the Geo-accumulation Index (Igeo), Tables 5 and 6, are commonly applied metrics for assessing the degree of anthropogenic contamination in soils. Surface soils in and around the Kodungaiyur Dumpsite exhibited average metal concentrations that were generally higher than natural background levels during the post-monsoon season.

Table 4: Heavy metal results of the Perungudi dumpsite

SAMPLE NO	Fe	Mn	Cu	Pb	Zn	Cr	Ni	As
p1	26864	465	37.5	17.5	96.7	101	32.3	1
p2	31753	542	73.5	24.5	188.9	131.6	39.4	1.6
p3	27277	465	53.2	20.1	109.8	94	35.1	2.2
p4	41894	620	56.5	23.6	166.5	127.3	47.4	2
p5	32732	620	71.3	24.5	192	108	43.4	1.7
p6	26018	465	85.1	43.7	207.9	89.3	41.9	3.8
p7	30004	542	117.8	43.2	237.4	111.6	80.4	3.1
p8	19863	387	286.2	15.9	238.5	60.8	24.1	1.2
p9	19863	387	69.9	31.9	162	103	35.3	2.4
p10	26717	465	68.7	22.2	123.6	101.7	50.5	2.3
p11	30284	465	71.3	20.5	136.3	86.6	30.6	1.1
p12	25108	465	101.2	29.3	241.3	116.9	69.4	2.1
p13	25808	387	90.9	39.3	235	231	40.1	3.7
p14	26458	387	91.2	25.7	154.8	84.5	33.9	2.3
p15	37278	542	55.2	23.3	160.2	107.7	30	1.3
p16	19372	310	52.6	21.8	139.6	78.4	28.4	2.7
p17	19443	387	39.7	24	129.3	74.6	28.6	2.7
p18	31473	542	57.8	18	135.7	95.8	39.1	1.5
p19	23989	387	39.6	18.9	124.4	73.3	31.2	0.9
p20	28885	465	77.1	23.4	148.8	91.6	30.9	2
p21	25318	465	55.8	38	198.4	91	37	1.5
p22	24969	387	31.9	13.4	123.4	82.3	31.5	0.9
p23	30214	465	56.9	22.4	156.9	85.7	31.5	1.4
MIN	19372	310	31.9	13.4	96.7	60.8	24.1	0.9
MAX	41894	620	286.2	43.7	241.3	231	80.4	3.8
AVE	27714	461.68	82.36	25.688	165.81	104.78	39.86	2.004

According to the calculated Contamination Factor (CF), Table 7, the soils can be classified as considerably to very highly contaminated, particularly with respect to Ni, Cu, Mn, Cr, Pb, and Zn. The Geo-accumulation Index (Igeo) revealed strong pollution levels for Pb and Zn at several sampling sites, with Igeo values reaching up to 4.3 for both metals, classifying the soils as "strongly polluted to extremely polluted" (Class 5). Similarly, EF values indicated significant to very high enrichment of Pb and Zn in numerous locations, confirming substantial anthropogenic influence.

When compared to similar studies conducted on dumpsites and landfill soils, the contamination levels observed in this study are relatively high. For instance, (Mavakala et al., 2016) reported moderate enrichment of Pb and Zn near urban dumpsites in South Africa, while (Mata et al., 2020) found lower EF values for Zn in municipal landfills of Spain. In contrast, our study recorded EF values as high as 25.8 for Pb and 17.1 for Zn, indicating more severe contamination possibly due to unregulated waste disposal practices and industrial activities near the Kodungaiyur landfill.

Similarly, studies conducted by Singh et al. (2018) in Indian urban soils reported Igeo values for Pb up to 2.7, lower than the 4.3 observed in this study, suggesting that Kodungaiyur soils are under greater anthropogenic stress. These comparisons highlight that the Kodungaiyur landfill poses a significant environmental concern relative to other reported dumpsites, both nationally and internationally.

The elevated EF values for metals such as Pb, Zn, and Cr suggest a predominant anthropogenic source, likely stemming from industrial effluents, vehicular emissions, battery waste, and other urban activities.

Perungudi

At the Perungudi dumpsite, the Enrichment Factor (EF) and Geoaccumulation Index (Igeo) were utilized to evaluate the extent of anthropogenic contamination in soils, as shown in Tables 8, 9 and 10.

The Igeo ranking of heavy metal pollution in surface soils follows the order: Zn > Cu > Pb > Cr > Ni > As > Mn > Fe. Zinc exhibited moderate pollution at four sites (P7, P8, P12, and P13), with Igeo values around 1.2–1.3. Approximately 90% of the sites were categorized as unpolluted to moderately polluted (Class 1).

Copper showed moderate pollution at P8, while Pb, Cr, Ni, As, Mn, and Fe remained mostly within unpolluted to moderately polluted categories across the studied locations.

EF analysis revealed significant enrichment of Cu (EF = 10.4) at site P8 and Zn (EF = 6.5) at the same site, indicating substantial anthropogenic input.

Table 5: Geoaccumulation factor values for Kodungaiyur

Sample	Fe	Mn	Cu	Pb	Zn	Cr	Ni	As
k1	-0.4	-0.1	1.9	2.1	3.3	0.73	0.5	0.5
k2	0.0	-0.2	0.9	1.1	1.8	0.85	0.3	-0.4
k3	-0.4	-0.6	1.4	4.3	2.8	0.32	-0.4	1.1
k4	-0.6	0.0	2.9	3.1	4.3	1.29	0.4	0.7
k5	-0.6	-0.5	1.7	2.2	2.9	1.12	-0.2	-1.0
k6	-0.7	-1.1	2.8	2.3	3.3	0.84	-0.3	-0.5
k7	-1.3	-2.0	1.8	1.5	2.3	-0.09	-1.3	-1.1
k8	-0.8	-0.3	1.1	1.6	2.6	0.29	-0.4	-0.3
k9	-0.1	-0.1	1.2	1.9	2.5	1.00	0.1	0.5
k10	-0.8	-0.7	0.6	1.3	2.3	0.84	-0.7	-0.5
k11	-0.3	-0.3	1.5	2.1	3.0	0.73	0.0	0.4
k12	-0.3	-0.1	1.5	2.1	3.0	0.50	-0.1	0.4
k13	-1.6	-0.9	0.7	2.1	2.0	-0.53	-0.9	0.0
k14	-0.6	-0.5	2.0	2.1	3.5	2.08	0.1	-0.2
k15	-0.7	-0.9	1.8	1.1	2.4	1.11	-0.5	-0.9
k16	-0.5	-0.5	1.1	1.4	2.9	0.38	-0.1	-0.2
k17	-0.8	-4.5	0.3	1.5	2.1	-0.09	-1.1	-1.2
k18	-0.8	-0.9	0.5	0.3	2.3	-0.19	-0.9	-0.9
k19	-0.5	-0.5	2.0	2.1	3.1	2.24	-0.6	-0.8
k20	-0.2	0.0	1.9	1.6	3.1	0.85	0.2	-0.1
k21	-0.3	0.0	0.4	1.3	2.4	0.10	-0.3	-0.3
k22	-0.8	-0.5	1.1	1.6	4.1	0.58	-0.4	-0.8
k23	-0.9	-0.9	0.3	0.7	2.2	-0.54	-1.0	-1.2
k24	-0.8	-0.7	0.2	1.1	3.2	0.16	-0.8	-1.1
k25	-0.9	2.4	1.3	1.6	2.6	0.66	-0.4	-0.4
k26	-1.0	-0.5	-0.4	0.3	2.1	-0.52	-0.8	-0.9
k27	-0.8	-0.5	0.0	1.2	3.7	-0.34	-0.6	-0.6
k28	-1.1	-1.1	1.8	1.9	3.8	-0.55	-0.9	-1.0
k29	-1.1	-0.9	-0.4	0.5	1.6	-0.51	-0.7	-0.9
k30	-0.9	-1.1	-1.1	0.4	1.3	-0.94	-1.7	-1.1
k31	-1.1	-0.9	-0.7	0.4	1.8	-0.26	-1.3	-2.1
k32	-0.5	-1.1	2.0	1.9	3.1	2.34	0.1	-0.7
k32	-0.5	-1.1	2.0	1.9	3.1	2.34	0.1	-0.7

Table 6: Enrichment factor values for Kodungaiyur dumpsite

Sample	Mn	Cu	Pb	Zn	Cr	Ni	As
k1	1.2	2.7	5.8	7.1	2.2	1.8	1.9
k2	0.9	1.0	2.1	1.9	1.8	1.2	0.7
k3	0.9	1.8	5.8	5.2	1.6	1.0	2.9
k4	1.6	6.3	13.3	17.1	3.8	2.1	2.6
k5	1.1	2.7	6.9	5.9	3.2	1.3	0.8
k6	0.7	6.4	8.2	9.2	2.9	1.3	1.1
k7	0.6	4.6	7.1	6.7	2.3	1.0	1.2
k8	1.4	2.0	5.0	5.5	2.1	1.3	1.3
k9	1.0	1.4	3.9	3.3	2.2	1.1	1.5
k10	1.1	1.5	4.1	4.7	3.1	1.0	1.2
k11	1.0	1.9	5.2	5.3	2.0	1.2	1.5
k12	1.1	1.9	5.0	5.5	1.7	1.1	1.6
k13	1.7	2.8	13.5	6.6	2.1	1.6	3.0
k14	1.1	3.2	6.2	9.4	6.3	1.6	1.3
k15	0.9	3.1	3.4	4.8	3.6	1.2	0.9
k16	1.0	1.6	3.7	5.5	1.8	1.3	1.2
k17	0.1	1.2	4.8	4.2	1.7	0.8	0.8
k18	0.9	1.3	2.1	4.8	1.5	0.9	0.9
k19	1.0	2.9	5.9	6.4	6.5	0.9	0.8
k20	1.1	2.3	3.5	5.3	2.1	1.3	1.1
k21	1.3	0.9	3.0	3.8	1.4	1.1	1.0
k22	1.2	1.9	5.3	16.4	2.6	1.3	1.0
k23	1.0	1.2	2.9	4.6	1.3	0.9	0.8

k24	1.1	1.0	3.6	8.6	1.9	1.0	0.8
k25	10.2	2.6	5.6	6.2	3.0	1.4	1.4
k26	1.4	0.8	2.5	4.5	1.4	1.1	1.1
k27	1.2	0.9	3.7	11.7	1.3	1.1	1.1
k28	1.0	4.2	8.3	16.5	1.5	1.1	1.1
k29	1.2	0.9	3.0	3.6	1.5	1.3	1.2
k30	0.8	0.5	2.4	2.6	1.0	0.6	0.9
k31	1.2	0.7	2.8	4.1	1.8	0.9	0.5
k32	0.6	3.0	5.3	6.8	7.1	1.5	0.9

Table 7: Contamination factor values for Kodungaiyur dumpsite

Sample	Fe	Mn	Cu	Pb	Zn	Cr	Ni	As
k1	1.1	1.4	5.6	1.6	3.0	2.5	19.3	0.7
k2	1.5	1.3	2.8	0.8	1.1	2.8	17.6	0.4
k3	1.1	1.0	3.8	7.2	2.3	1.9	10.9	1.0
k4	1.0	1.5	11.2	3.1	6.3	3.8	18.9	0.8
k5	1.0	1.1	5.0	1.7	2.3	3.3	12.5	0.2
k6	0.9	0.7	10.8	1.8	3.2	2.7	11.3	0.3
k7	0.6	0.4	5.1	1.0	1.6	1.4	5.7	0.2
k8	0.9	1.2	3.3	1.1	1.9	1.9	10.9	0.4
k9	1.4	1.4	3.6	1.3	1.7	3.1	14.8	0.7
k10	0.9	1.0	2.3	0.9	1.6	2.8	8.6	0.3
k11	1.3	1.2	4.4	1.6	2.5	2.5	13.7	0.6
k12	1.2	1.4	4.3	1.5	2.6	2.2	13.3	0.6
k13	0.5	0.8	2.5	1.6	1.2	1.1	7.4	0.5
k14	1.0	1.1	6.0	1.5	3.6	6.5	15.6	0.4
k15	0.9	0.8	5.1	0.8	1.7	3.3	10.2	0.3
k16	1.1	1.1	3.1	1.0	2.3	2.0	13.1	0.4
k17	0.9	0.1	1.9	1.0	1.4	1.4	6.7	0.2
k18	0.9	0.8	2.1	0.4	1.6	1.3	7.7	0.3
k19	1.1	1.1	5.9	1.6	2.7	7.3	9.1	0.3
k20	1.3	1.5	5.5	1.1	2.7	2.8	16.0	0.5
k21	1.2	1.5	2.0	0.9	1.7	1.6	11.8	0.4
k22	0.9	1.1	3.1	1.1	5.5	2.3	10.5	0.3
k23	0.8	0.8	1.8	0.6	1.4	1.1	6.9	0.2
k24	0.9	1.0	1.7	0.8	2.9	1.7	8.2	0.2
k25	0.8	8.1	3.7	1.1	1.9	2.4	10.7	0.4
k26	0.8	1.1	1.2	0.5	1.3	1.1	8.3	0.3
k27	0.9	1.1	1.5	0.8	4.0	1.2	9.1	0.3
k28	0.7	0.7	5.3	1.4	4.4	1.0	7.4	0.2
k29	0.7	0.8	1.1	0.5	1.0	1.1	8.8	0.3
k30	0.8	0.7	0.7	0.5	0.8	0.8	4.4	0.2
k31	0.7	0.8	0.9	0.5	1.1	1.3	5.9	0.1
k32	1.1	0.7	5.9	1.4	2.8	7.8	15.0	0.3

Table 8: Geoaccumulation index values for Perungudi dumpsite

SAMPLE NO	Fe	Mn	Cu	Pb	Zn	Cr	Ni	As
p1	-1.0	-0.9	-1.9	-0.5	-0.1	-0.5	-1.1	-2.8
p2	-0.8	-0.7	-0.9	-0.1	0.9	-0.1	-0.8	-2.2
p3	-1.0	-0.9	-1.4	-0.3	0.1	-0.6	-1.0	-1.7
p4	-0.4	-0.5	-1.3	-0.1	0.7	-0.1	-0.6	-1.8
p5	-0.7	-0.5	-1.0	-0.1	0.9	-0.4	-0.7	-2.1
p6	-1.1	-0.9	-0.7	0.8	1.0	-0.6	-0.8	-0.9
p7	-0.8	-0.7	-0.2	0.8	1.2	-0.3	0.2	-1.2
p8	-1.4	-1.1	1.1	-0.7	1.2	-1.2	-1.5	-2.6
p9	-1.4	-1.1	-1.0	0.3	0.7	-0.4	-1.0	-1.6
p10	-1.0	-0.9	-1.0	-0.2	0.3	-0.4	-0.5	-1.6
p11	-0.8	-0.9	-1.0	-0.3	0.4	-0.7	-1.2	-2.7
p12	-1.1	-0.9	-0.4	0.2	1.3	-0.2	0.0	-1.8
p13	-1.1	-1.1	-0.6	0.6	1.2	0.7	-0.8	-1.0
p14	-1.0	-1.1	-0.6	0.0	0.6	-0.7	-1.1	-1.6

DOI:10.3844/ajessp.2026.11.24

p15	-0.5	-0.7	-1.3	-0.1	0.7	-0.4	-1.2	-2.5
p16	-1.5	-1.5	-1.4	-0.2	0.5	-0.8	-1.3	-1.4
p17	-1.5	-1.1	-1.8	-0.1	0.4	-0.9	-1.3	-1.4
p18	-0.8	-0.7	-1.3	-0.5	0.4	-0.5	-0.9	-2.3
p19	-1.2	-1.1	-1.8	-0.4	0.3	-0.9	-1.2	-3.0
p20	-0.9	-0.9	-0.8	-0.1	0.6	-0.6	-1.2	-1.8
p21	-1.1	-0.9	-1.3	0.6	1.0	-0.6	-0.9	-2.3
p22	-1.1	-1.1	-2.1	-0.9	0.3	-0.7	-1.2	-3.0
p23	-0.8	-0.9	-1.3	-0.2	0.6	-0.7	-1.2	-2.4

Table 9: Enrichment factor values for Perungudi dumpsite

SAMPLE NO	Mn	Cu	Pb	Zn	Cr	Ni	As
p1	1.1	1.0	1.4	1.9	1.5	0.9	0.3
p2	1.1	1.7	1.6	3.2	1.6	1.0	0.4
p3	1.1	1.4	1.6	2.2	1.3	1.0	0.6
p4	0.9	1.0	1.2	2.1	1.2	0.9	0.4
p5	1.2	1.6	1.6	3.2	1.3	1.0	0.4
p6	1.1	2.4	3.6	4.3	1.3	1.2	1.1
p7	1.1	2.8	3.0	4.3	1.5	2.1	0.8
p8	1.2	10.4	1.7	6.5	1.2	0.9	0.5
p9	1.2	2.5	3.4	4.4	2.0	1.4	0.9
p10	1.1	1.9	1.8	2.5	1.5	1.4	0.6
p11	1.0	1.7	1.4	2.4	1.1	0.8	0.3
p12	1.2	2.9	2.5	5.2	1.8	2.1	0.6
p13	0.9	2.5	3.2	4.9	3.5	1.2	1.1
p14	0.9	2.5	2.1	3.1	1.2	1.0	0.7
p15	0.9	1.1	1.3	2.3	1.1	0.6	0.3
p16	1.0	2.0	2.4	3.9	1.6	1.1	1.0
p17	1.3	1.5	2.6	3.6	1.5	1.1	1.0
p18	1.1	1.3	1.2	2.3	1.2	1.0	0.4
p19	1.0	1.2	1.7	2.8	1.2	1.0	0.3
p20	1.0	1.9	1.7	2.8	1.2	0.8	0.5
p21	1.2	1.6	3.2	4.2	1.4	1.1	0.4
p22	1.0	0.9	1.1	2.7	1.3	1.0	0.3
p23	1.0	1.4	1.6	2.8	1.1	0.8	0.3

Table 10: Contamination factor values for Perungudi dumpsite

Sample No	Fe	Mn	Cu	Pb	Zn	Cr	Ni	As
p1	0.7	0.8	0.9	0.9	1.0	0.9	1.2	0.7
p2	0.9	1.0	0.9	1.0	0.9	1.1	0.8	1.4
p3	0.8	0.8	0.9	0.9	1.1	0.8	1.3	0.7
p4	1.2	1.1	1.1	1.0	1.1	1.0	1.1	0.9
p5	0.9	1.1	0.8	1.3	0.6	2.0	0.3	6.4
p6	0.7	0.8	0.9	0.9	1.0	1.0	1.0	1.0
p7	0.8	1.0	0.9	1.1	0.8	1.3	0.6	2.2
p8	0.6	0.7	0.8	0.8	1.0	0.9	1.1	0.8
p9	0.6	0.7	0.8	0.8	1.0	0.9	1.1	0.8
p10	0.7	0.8	0.9	0.9	1.0	0.9	1.1	0.8
p11	0.8	0.8	1.0	0.8	1.3	0.6	2.1	0.3
p12	0.7	0.8	0.9	1.0	0.9	1.1	0.8	1.3
p13	0.7	0.7	1.1	0.6	1.6	0.4	4.2	0.1
p14	0.7	0.7	1.1	0.6	1.7	0.4	4.7	0.1
p15	1.0	1.0	1.1	0.9	1.2	0.7	1.8	0.4
p16	0.5	0.5	1.0	0.5	1.8	0.3	5.9	0.1
p17	0.5	0.7	0.8	0.9	0.9	0.9	1.0	0.9
p18	0.9	1.0	0.9	1.0	0.9	1.2	0.8	1.5
p19	0.7	0.7	1.0	0.7	1.4	0.5	2.9	0.2
p20	0.8	0.8	1.0	0.8	1.2	0.7	1.7	0.4
p21	0.7	0.8	0.9	0.9	0.9	1.0	0.9	1.2
p22	0.7	0.7	1.0	0.7	1.5	0.4	3.6	0.1
p23	0.8	0.8	1.0	0.8	1.3	0.6	2.1	0.3

Moderate enrichment of Pb, Cr, and Ni was observed at several sites. The Contamination Factor (CF) values for all eight metals suggested moderate contamination across the dumpsite, but the contamination levels were notably lower than those observed at the Kodungaiyur site.

The relatively lower contamination at Perungudi may be influenced by its location within the Pallikaranai marshland, where natural hydrological processes could dilute and attenuate heavy metal concentrations in leachates (Esakku et al., 2007).

Comparatively, studies such as (Esakku et al., 2007) and (Yap et al., 2021) reported moderate enrichment of Zn and Cu in landfill sites located in marshy or coastal regions, where the natural groundwater movement aids in pollutant dispersion. For example, in the Chittaranjan landfill site (India), Zn enrichment factors ranged from 2.0 to 4.5 (Singh et al., 2017), which is comparable to the moderate enrichment observed in this study at Perungudi. However, unlike Kodungaiyur, no extremely high enrichment or very high contamination was detected, highlighting the relatively less anthropogenic pressure at Perungudi compared to other urban landfills. These metals are often associated with urban waste, including electronic waste, discarded batteries, construction debris, and municipal solid waste.

Conclusion

This study assessed heavy metal contamination at the Kodungaiyur and Perungudi dumpsites using pollution indices such as the Geoaccumulation Index (Igeo), Enrichment Factor (EF), and Contamination Factor (CF). The results indicate varying degrees of contamination influenced by waste composition and site-specific factors.

At Kodungaiyur, significantly high concentrations of lead (Pb), zinc (Zn), copper (Cu), and iron (Fe) were observed, with many sites falling into the categories of very high enrichment and extreme pollution. For example, Pb exhibited EF values >25 at site K3, and Zn showed high Igeo values (>4) at sites K4 and K22. These levels suggest a dominant contribution from anthropogenic sources such as electronic waste, batteries, and industrial by-products. The contamination levels at Kodungaiyur exceed permissible limits in multiple samples, indicating serious risks to the surrounding ecosystem and human health.

In contrast, the Perungudi dumpsite showed lower contamination levels, with most heavy metals falling into moderate enrichment or unpolluted to moderately polluted categories. Significant enrichment was observed only at isolated locations (e.g., Cu at P8, Zn at P8 and P13), and CF values were generally in the moderate range. The presence of natural vegetation and the marshland environment may help in phytostabilization and leachate attenuation, reducing the mobility of toxic metals in Perungudi.

A comparison reveals that Kodungaiyur experiences more severe contamination, likely due to the co-disposal of municipal and industrial waste. In contrast, Perungudi, which predominantly handles municipal solid waste, exhibits more stable and contained pollution levels. Furthermore, the neutral to alkaline leachate pH in Perungudi reduces metal solubility, while Kodungaiyur's higher soil permeability increases the risk of leachate migration and groundwater contamination.

From an ecological and health perspective, the elevated concentrations of Pb, Zn, and Cu in Kodungaiyur soil pose serious risks. These metals are known for their persistence and bioaccumulative potential, which can affect microbial communities, soil fertility, and crop quality. Human exposure through contaminated water, food, or dust inhalation can lead to neurological, renal, and developmental disorders, particularly in vulnerable populations such as children and pregnant women.

When compared to studies from similar environments, such as the Ghazipur landfill in Delhi or the Dhaka municipal dumpsite in Bangladesh (Ahmed et al., 2015), the contamination levels at Kodungaiyur are comparable or higher, particularly for Pb and Zn. These similarities highlight the widespread issue of poor waste segregation and hazardous waste dumping in rapidly urbanizing regions.

This study contributes to the broader scientific understanding of soil contamination in urban waste dumpsites by providing a comprehensive, comparative analysis of heavy metal pollution across two major landfill sites in Chennai. By integrating pollution indices with site-specific environmental factors, the study highlights the critical influence of waste composition, surrounding ecology, and hydrological characteristics on contamination levels. The methodology and findings presented here can serve as a model for environmental monitoring in other urban areas facing similar waste management challenges. The data also support the development of location-specific mitigation and policy strategies to address soil degradation and public health risks linked to landfill operations.

In conclusion, Kodungaiyur requires urgent intervention through waste segregation, soil remediation, and leachate management. Perungudi, though less contaminated, should be monitored regularly to ensure long-term environmental safety. This comparative assessment underscores the necessity of site-specific strategies to manage and mitigate heavy metal contamination in urban landfill environments.

Data Availability Statement

Data may be accessed by contacting the corresponding author.

Funding Information

This study did not receive any funding

Author's Contributions

All authors contributed equally to this study.

References

Adamo, P., Arienzo, M., Imperato, M., Naimo, D., Nardi, G., & Stanzione, D. (2005). Distribution and partition of heavy metals in surface and sub-surface sediments of Naples city port. *Chemosphere*, *61*(6), 800–809. https://doi.org/10.1016/j.chemosphere.2005.04.001

Ahmed, M. K., Shaheen, N., Islam, M. S., Habibullah-al-Mamun, M., Islam, S., Mohiduzzaman, M., & Bhattacharjee, L. (2015). Dietary intake of trace elements from highly consumed cultured fish (Labeo rohita, Pangasius pangasius and Oreochromis mossambicus) and human health risk implications in Bangladesh. *Chemosphere*, *128*, 284–292. https://doi.org/10.1016/j.chemosphere.2015.02.016

Aja, D., Okolo, C. C., Nwite, N. J., & Njoku, C. (2021). Environmental risk assessment in selected dumpsites in Abakaliki metropolis, Ebonyi state, southeastern Nigeria. *Environmental Challenges*, *4*, 100143. https://doi.org/10.1016/j.envc.2021.100143

Akanchise, T., Boakye, S., Borquaye, L. S., Dodd, M., & Darko, G. (2020). Distribution of heavy metals in soils from abandoned dump sites in Kumasi, Ghana. *Scientific African*, *10*, e00614. https://doi.org/10.1016/j.sciaf.2020.e00614

Aralu, C. C., Okoye, P. A. C., Abugu, H. O., & Eze, V. C. (2022). Toxicity and distribution of polycyclic aromatic hydrocarbons in leachates from an unlined dumpsite in Nnewi, Nigeria. *International Journal of Environmental Analytical Chemistry*, *104*(18), 6220–6231. https://doi.org/10.1080/03067319.2022.2140415

Bhat, R. A., Singh, D. V., Qadri, H., Dar, G. H., Dervash, M. A., Bhat, S. A., Unal, B. T., Ozturk, M., Hakeem, K. R., & Yousaf, B. (2022). Vulnerability of municipal solid waste: An emerging threat to aquatic ecosystems. *Chemosphere*, *287*(3), 132223. https://doi.org/10.1016/j.chemosphere.2021.132223

Buscaroli, E., Sciubba, L., Falsone, G., Cavani, L., Brecchia, M., Argese, E., Marzadori, C., Pourrut, B., & Braschi, I. (2019). Calcium chloride washing of calcareous sediment from a freshwater canal: effect on the removal of potentially toxic elements and water aggregate stability. *Journal of Soils and Sediments*, *19*(7), 3098–3107. https://doi.org/10.1007/s11368-019-02298-3

Esakku, S., Palanivelu, K., & Joseph, K. (2003). Assessment of heavy metals in a municipal solid waste dumpsite. *Proceeding of the Workshop on Sustainable Landfill Management*, 1–9.

Esakku, S., Swaminathan, A., Karhtikeyan, O. P., Kurain, J., & Palanivelu, K. (2007). Municipal solid waste management in Chennai city, India. *Proceedings Sardinia 2007, Eleventh International Waste Management and Landfill Symposium*, 1–9.

Gairola, S. U., & Soni, P. (2010). Role of soil physical properties in ecological succession of restored mine land – A case study. *International Journal of Environmental Sciences*, *1*(4), 475–480.

Gaudette, H. E., & Flight, W. R. (1974). An Inexpensive Titration Method for the Determination of Organic Carbon in Recent Sediments. *SEPM Journal of Sedimentary Research*, *44*(1), 249–253. https://doi.org/10.1306/74d729d7-2b21-11d7-8648000102c1865d

Hakanson, L. (1980). An ecological risk index for aquatic pollution control.a sedimentological approach. In *Water Research* (Vol. 14, Issue 8, pp. 975–1001). https://doi.org/10.1016/0043-1354(80)90143-8

Kasassi, A., Rakimbei, P., Karagiannidis, A., Zabaniotou, A., Tsiouvaras, K., Nastis, A., & Tzafeiropoulou, K. (2008). Soil contamination by heavy metals: Measurements from a closed unlined landfill. *Bioresource Technology*, *99*(18), 8578–8584. https://doi.org/10.1016/j.biortech.2008.04.010

Kumar, S., Smith, S. R., Fowler, G., Velis, C., Kumar, S. J., Arya, S., Rena, Kumar, R., & Cheeseman, C. R. (2017). Challenges and opportunities associated with waste management in India. *Royal Society Open Science*, *4*(3), 160764. https://doi.org/10.1098/rsos.160764

Lagerkvist, D. (2019). Solid Waste Generation and Characterization. *Recovery of Materials and Energy from Urban Wastes*, *10*, 7–20. https://doi.org/10.1007/978-1-4939-7850-2_110

Mata, H. K., Al Salah, D. M. M., Ngweme, G. N., Konde, J. N., Mulaji, C. K., Kiyombo, G. M., & Poté, J. W. (2020). Toxic metal concentration and ecotoxicity test of sediments from dense populated areas of Congo River, Kinshasa, Democratic Republic of the Congo. *Environmental Chemistry and Ecotoxicology*, *2*, 83–90. https://doi.org/10.1016/j.enceco.2020.07.001

Mavakala, B. K. M., Le Faucheur, S., Mulaji, C. K., Laffite, A., Devarajan, N., Biey, E. M., Giuliani, G., Otamonga, J.-P., Kabatusuila, P., Mpiana, P. T., & Poté, J. (2016). Leachates draining from controlled municipal solid waste landfill: Detailed geochemical characterization and toxicity tests. *Waste Management*, *55*, 238–248. https://doi.org/10.1016/j.wasman.2016.04.028

Moorberg, C. J., & Crouse, D. A. (2017). *Soil laboratory manual*.

Müller, G. (1969). Muller "Index of geoaccumulation in the sediments of the Rhine River. *GeoJournal*, *2*(2), 108–118.

Ololade, I. A. (2014). An Assessment of Heavy-Metal Contamination in Soils within Auto-Mechanic Workshops Using Enrichment and Contamination Factors with Geoaccumulation Indexes. *Journal of Environmental Protection*, *05*(11), 970–982. https://doi.org/10.4236/jep.2014.511098

Poté, J., Haller, L., Loizeau, J.-L., Garcia Bravo, A., Sastre, V., & Wildi, W. (2008). Effects of a sewage treatment plant outlet pipe extension on the distribution of contaminants in the sediments of the Bay of Vidy, Lake Geneva, Switzerland. *Bioresource Technology*, *99*(15), 7122–7131. https://doi.org/10.1016/j.biortech.2007.12.075

Salvia, G., Zimmermann, N., Willan, C., Hale, J., Gitau, H., Muindi, K., Gichana, E., & Davies, M. (2021). The wicked problem of waste management: An attention-based analysis of stakeholder behaviours. *Journal of Cleaner Production*, *326*, 129200. https://doi.org/10.1016/j.jclepro.2021.129200

Singh, G., Kumar, B., & Chandra, R. (2017). Impact of municipal solid waste dumps on surrounding environment: A case study of India. *Environmental Monitoring and Assessment*, *189*(8), 384.

Singh, G., Kumar, B., & Chandra, R. (2018). Assessment of ecological risk associated with heavy metals in municipal solid waste dumpsite soil. *Environmental Earth Sciences*, *77*(12), 447.

Takarina, N. D. (2010). Geochemical fractionation of toxic trace heavy metals (Cr, Cu, Pb, and Zn) from the estuarine sediments of 5 river mouths at Jakarta Bay, Indonesia. *Journal of Coastal Development*, *13*(2), 26–36.

Usero, J., Gamero, M., Morillo, I., & Gracia, I. (1998). Comparative study of three sequential extraction procedures for metals in marine sediments. *Environment International*, *24*(4), 487–496. https://doi.org/10.1016/s0160-4120(98)00028-2

Yap, C. K., Chew, W., Al-Mutairi, K. A., Nulit, R., Ibrahim, Mohd. H., Wong, K. W., Bakhtiari, A. R., Sharifinia, M., Ismail, M. S., Leong, W. J., Tan, W. S., Cheng, W. H., Okamura, H., You, C. F., & Al-Shami, S. A. (2021). Assessments of the Ecological and Health Risks of Potentially Toxic Metals in the Topsoils of Different Land Uses: A Case Study in Peninsular Malaysia. *Biology*, *11*(1), 2. https://doi.org/10.3390/biology11010002

Yuan, C., Shi, J., He, B., Liu, J., Liang, L., & Jiang, G. (2004). Speciation of heavy metals in marine sediments from the East China Sea by ICP-MS with sequential extraction. *Environment International*, *30*(6), 769–783. https://doi.org/10.1016/j.envint.2004.01.001