Journal of Engineering and Sustainable Development
Vol. 29, No. 05, A*ugust* 2025
https://jeasd.uomustansiriyah.edu.iq/index.php/jeasd
ISSN 2520-0917
Research Article
https://doi.org/10.31272/jeasd.2741

Analysis And Spatial Distribution of Heavy Metals in Soil at A Sanitary Landfill in Kedah

Nur Firdaus Abdul Rashid*, Nur Fatihah Shahirah Yuzaimi, Chuah Tse Seng

Faculty of Plantation and Agrotechnology, Universiti Teknologi MARA Perlis Branch, Arau Campus, 02600 Arau, Perlis, Malaysia

*Email: nurfirdaus@uitm.edu.my

Article Info

Received 31/05/2024
Revised 29/07/2025
Accepted 21/08/2025

Abstract

Environmental contamination by toxic heavy metals has emerged as a significant issue for preserving the quality and sanitation of water and soil. The disposal of industrial effluents via landfilling poses a risk to human health and the environment. The research is to assess heavy metal pollution in soil and delineate its distribution by geostatistical mapping at the Padang Cina Sanitary Landfill in Kulim, Kedah. Boiling aqua regia, an acid digestion process, is used to evaluate the type, concentration, spatial distribution, and waste disposal sources of soil heavy metals. ICP-OES was used to examine 30 soil samples collected at a depth of 15 cm from the dump site. With Fe (300 mg/kg) > Zn (10.28 mg/kg), Cu (3.95 mg/kg), Pb (0.702 mg/kg), and Cr (0.56 mg/kg) > Ni (0.117 mg/kg), landfill heavy metal concentrations decreased. Inverse distance weighting interpolation was used in ArcGIS 10.6 to investigate heavy metal distribution. Most coverage regions had variable quantities of Cr (0.139–0.12 mg/kg), Cu (0.078–0.492 mg/kg), Fe (244–263 mg/kg), Pb (0.27–0.36 mg/kg), Ni (0.02-0.04 mg/kg), and Zn (1.40–2.50 mg/kg). In conclusion, Padang Cina Sanitary landfill soil heavy metal concentrations are below the Malaysian Department of Environment land contamination limit.

Keywords: Heavy Metals, Inverse Distance Weighting, Landfill, Spatial Distribution, Soil Contamination.

1. Introduction

Arsenic (As), chromium (Cr), cadmium (Cd), cobalt (Co), copper (Cu), iron (Fe), mercury (Hg), manganese (Mn), nickel (Ni), lead (Pb), and zinc (Zn) are examples of recalcitrant, toxic, and pervasive pollutants associated with increasing human activity. Waste is proportional to population and economic growth. Emissions from rapidly expanding industrial areas, mine tailings, disposal of high metal wastes, land application of fertilizers, animal manures, sewage sludge, pesticides, wastewater irrigation, coal combustion residues, petrochemical spills, and atmospheric deposition can introduce heavy metals and metalloids into soil [1], [2]. Soils contribute to food production, ecological services, nutrient recycling, and human well-being. Despite their significance, little is known about anthropogenic or lithological soil contaminants. Landfills generate heavy metal pollution. Waste management in low-income countries like Malaysia usually involves landfills. Numerous uncontrolled landfills lack bottom liners, leachate collection systems, and treatment systems [3]. A Study by [3] observed that Malaysian non-sanitary dumps dispose of refuse without an engineering plan or a bottom liner. Pollutants exert a great deal of pressure on the ecosystem because they are noxious and detrimental to all forms of life [4].

Municipal solid garbage contains plastics. Malaysia, like many Southeast Asian countries, has inadequate waste management systems to handle the large amount of plastic trash produced. Plastic garbage is disposed of in landfills or burned domestically. According to [5], Malaysians generate 0.85 kg to 1.5 kg of household garbage daily, depending on geography and socioeconomic status. Malaysia generates 0.22 kg and 0.4 kg of household garbage per inhabitant per day, higher than Indonesia and the Philippines. Malaysia tracks global plastic waste production and disposable plastic use. Malaysia produced 19% of its garbage in 2007 as plastic [5]. This study examined 74% of single-use plastic film trash. 17% and 9% were rigid and foam plastics. Malaysia is currently known for its land and marine pollution due to inadequate waste management and disposal practices. This study addresses the issue of dump sites polluting soils and affecting plant health due to unrestricted heavy metal uptake. This analysis found that this landfill site could threaten the ecosystem because it is near Sungai Jarak and the oil palm plantation. This study examines landfill soil heavy metal concentrations to determine if they are safe for the ecosystem.

2. Materials and Methods

2.1. Soil Sampling

Kulim Sanitary Landfilling, also known as "*Tapak Pelupusan Sisa Pepejal Sanitari Kulim,*" was coordinated at latitude 5.41916˚N and longitude 100.61881˚E, as shown in Fig. 1. The soil samples were collected only at sanitary cell 1, where the owner authorized the area. The area was separated into two, which are source 1 and source 2. Source 1 covers the area from station S1 to S15, while source 2 covers the area from station S16 to S30. The location of the whole landfill is about 200 acres sanitary cell 1 is 1.54 ha.

Figure 1. The study area map of the landfill site.

Soil samples were collected from Kulim Sanitary Landfill. Thirty (30) soil samples had been collected from these zones from the surface to a depth of 15 cm by using an auger boring. It is because of the properties and significance of the topsoil layer (up to 15 cm), particularly about organic matter, nutrients, and root activity [6].

The spacing between the sample points collected was 2 meters. All the samples were air-dried, ground using a pestle and mortar, and passed through a 2 mm sieve. The. The evaluation of heavy metal contaminants, such as Cr, Cu, Fe, Ni, Pb, and Zn, in soil samples was conducted through the acid digestion method.

2.2. Heavy Metals Analysis

Acid digests of soil samples have been created in accordance with the NEPM, 1999-recommended technique. Boiling aqua regia (3:1 hydrochloric acid/nitric acid) was used to remove the metals from the samples in order to determine the overall metal content. Inorganic metals can be extracted using a strong and concentrated acid mixture [6], [7].

Using a 3:1 ratio of concentrated HCl and concentrated HNO_3. The extract was filtered through Whatman No. 42 filter paper after cooling, and 50 ml of distilled water was added. Before all the samples were run using the Optima 8000 ICP-OES, Inductively Coupled Plasma-Optical Emission spectroscopy (PerkinElmer model), each sample was filtered using a nylon filter syringe (NY 0.45μm) and the sample solution was transferred to a 15 ml centrifuge tube, which was labelled. The elements of Cr, Cu, Fe, Pb, Ni, and Zn were analyzed using ICP-OES. A calculation has been made to determine the concentration of heavy metals in the soil and solid waste samples. The results from running the sample have been collected and recorded.

2.3. Interpolation Methods using GIS Software

The geographic information system (GIS) software employed in the current study is ArcGIS. ArcGIS Spatial Analyst offers a wide range of geoprocessing tools that facilitate the analysis and modelling of spatial data. One such tool is surface interpolation, which is employed to estimate values for raster cells based on a limited set of sampled data points. The selection of the Inverse Distance Weighting (IDW) interpolation method in this study is based on its widespread usage and deterministic nature within the domain of soil science [8]. Hence, the Inverse Distance Weighting (IDW) method is employed to produce a spatial representation of the soil chemical properties within the landfill regions at Kulim Sanitary Landfills, located in Kulim, Kedah. The criteria for the IDW interpolation technique were selected due to the nature of IDW as a weighted distance average; the resulting average can't exceed the value of the highest input or fall below the value of the lowest input. Consequently, the absence of prior sampling of extreme values precludes the generation of ridges or valleys [9].

3. Results and Discussions

3.1. Concentration of Heavy Metals in Landfill

The concentration of heavy metals in the soil at Kulim Sanitary Landfill, Kulim, Kedah, with descriptive statistics results, is listed in Table 1. All data of six heavy metals chromium Cr), copper (Cu), iron (Fe), nickel (Ni), lead (Pb), and zinc (Zn) in Table 1 were compared with levels for contaminated land by DOE (2009) from Table 2. The landfill soil samples had high Fe levels followed by Zn, Cu, Pb, Cr, and the lowest was Ni. The mean concentration of heavy metals analyzed in landfill soil samples, in descending order, was Fe > Zn > Cu > Pb > Cr >Ni. From Table 2, which is Malaysia Recommended Site Screening Levels for Contaminated Land by the Department of Environment Malaysia, the mean concentrations of all heavy metals (Cr, Cu, Fe, Pb, Ni, and Zn) were below the levels of contaminated land in soil by [10]. This Table is adopted by DOE, Malaysia (2009), Contaminated Land Management and Control Guidelines No. 1: Malaysian Recommended Site Screening Levels for Contaminated Land.

When compared to Table 1, the concentrations of all the heavy metals (Cr, Cu, Fe, Ni, Pb, and Zn) in Kulim Sanitary Landfill are under the limit levels suggested by DOE. The concentration of chromium in the landfill soil ranges from 0.085 to 0.56 mg/kg, and the range stated by DOE is between 0.02 and 14.40 mg/kg in soil. The concentration of Cu (0.076 – 3.95 mg/kg), Fe (118.1 – 300 mg/kg), Ni (0.117 mg/kg), Pb (0.058 – 0.702 mg/kg), and Zn (0.27 – 10.28 mg/kg). The comparison with Table 2 shows that the concentration level of heavy metals in Kulim Sanitary Landfill is under the maximum allowable limit and safe for the environment.

Table 1 below shows the results from descriptive statistics tests, including the minimum, maximum, mean, and standard deviation in mg/kg for six elements of heavy metals (Cr, Cu, Fe, Pb, Ni, and Zn) for 30 samples.

Table 1. Some soil parameters were analyzed for samples at 15 cm depth.

Heavy metals	Max concentration (mg/kg)	Mean concentration (mg/kg)	Min concentration (mg/kg)	SD* concentration (mg/kg)
Chromium, Cr	0.56	0.17	0.09	0.085
Copper, Cu	3.95	0.41	0.08	0.73
Iron, Fe	300.00	241.92	118.1	63.14
Nickel, Ni	0.120	0.038	0.001	0.130
Lead, Pb	0.70	0.29	0.06	0.029
Zinc, Zn	10.28	1.69	0.27	1.93

*SD = Standard Deviation.

3.2. Distribution of Heavy Metals in Soils

From Table 3 below, Fe had the highest values of all heavy metals measured. The highest concentration of all the heavy metals under study varies at different soil sampling points. The lowest concentration (mg/kg) of Cu (0.08) and Ni (ND) was observed at soil sample point S30. Pb (0.06) and Zn (0.27) showed the lowest concentration (mg/kg) at the S21 soil sampling point. While Cr (0.09) showed the lowest concentration at the S22 soil sampling point, and Fe (118.10) showed the lowest concentration at the S27 soil sampling point. Soil sampling points of S4, S6, and S10 on the left side of sanitary cell 1 showed the highest concentration (mg/kg) of Zn (10.28), Pb (0.70), Cr (0.56), and Ni (0.12). Finally, Cu (3.95) showed the highest concentration (mg/kg) at S20 of the soil sampling point. [11] also reported significant Pb (1.7), Cu (0.25), and Ni (0.312) concentrations in their studies in Kulim (Kedah) landfills.

Table 2. Malaysia Recommended Site Screening Levels for Contaminated Land by the Department of Environment Malaysia.

Heavy metals	Max	Min	Arithmetic Mean
Chromium, Cr	14.40	0.02	6.00
Copper, Cu	19.8	4.0	13.8
Iron, Fe	44500	301	12140
Nickel, Ni	28.90	0.70	5.77
Lead, Pb	36.00	0.18	10.37
Zinc, Zn	54.3	6.9	21.9

*Source: DOE (2009).

Table 3. The minimum and maximum concentrations of heavy metals (Cr, Cu, Fe, Pb, Ni, and Zn) at the soil sampling point.

Parameter of Heavy Metal	Soil Sampling point (Min concentration)	Min (mg/kg)	Soil Sampling point (Max concentration)	Max (mg/kg)	Mean (mg/kg) Data 2010 [11]
Chromium, Cr	S22	0.09	S10	0.56	0.32
Copper, Cu	S30	0.08	S20	3.95	0.25
Iron, Fe	S27	118.10	S2	300.00	225.00
Nickel, Ni	S30	0.06	S6	0.70	0.312
Lead, Pb	S21	0.001	S10	0.12	1.7
Zinc, Zn	S21	0.27	S4	10.28	0.336

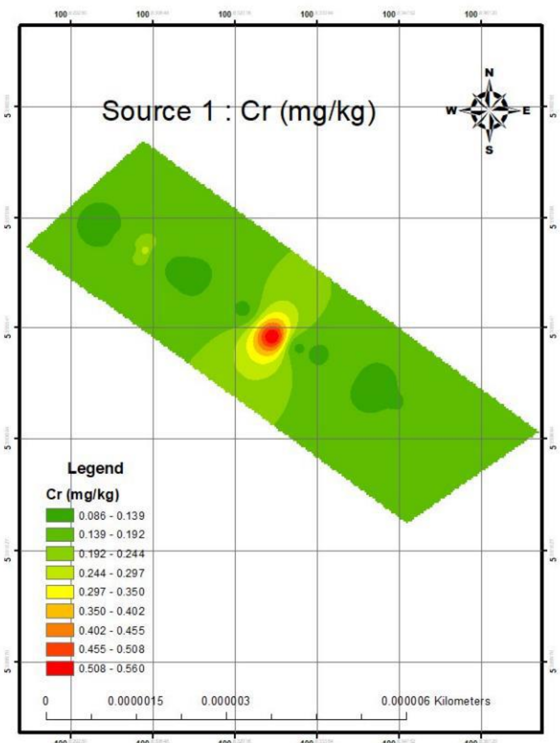
*S = station point

3.2.1. Distribution of chromium (Cr) in soils

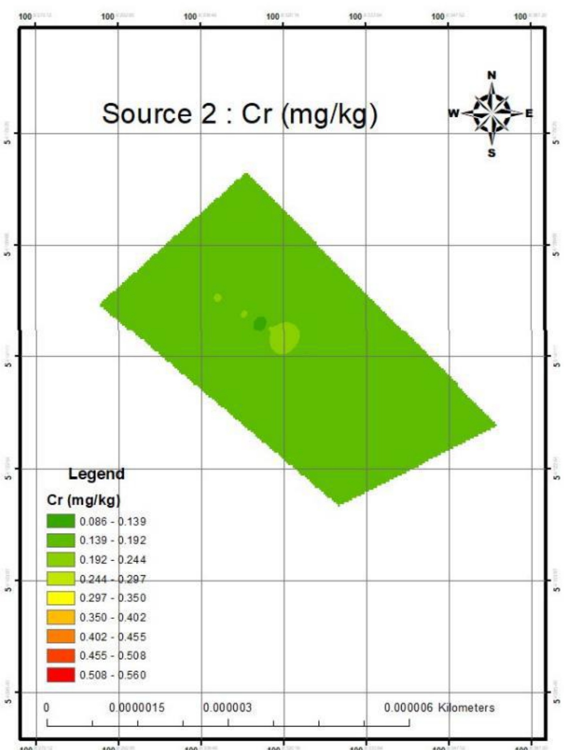
The distribution of metal concentration is a valuable method to identify hotspots with high metal contamination and thus define the potential sources. The distribution characteristics of all metals were explained using the IDW interpolation method within the ArcGIS software. From Fig. 2 (a), the concentration of Cr is the highest in source 1 where the range is between 0.139 and 0.192 mg/kg, and for the lowest concentration, the range 0.088 to 0.139 mg/kg only covers

a small area, which is at station 1(0.089 mg/kg). From Fig. 2 (b), the tone shades color only in three shades of green, indicating the lowest concentration of Cr. The maximum concentration of Cr at source 2 is 0.232 mg/kg (station S24), and the minimum concentration of Cr at source 2 is 0.085 mg/kg (station S22).

Although by referring to Table 2, the level of contamination by DOE, the concentration of Cr at source 1 and source 2 is under the limit value and is considered safe for the environment, where the value of contaminants of Cr in soil is in the range of (0.02 -14.40 mg/kg). The industries mentioned in this context are significant contributors to the contamination of soils with Cr, primarily through the disposal of solid and liquid waste [12]. In light of the present circumstances, there is a growing interest in the issue of chromium (Cr) contamination in soils due to its potential to pose health risks to humans through various pathways. These pathways include the incorporation of Cr into the food chain, inhalation of soil dust containing Cr, and the transfer of Cr to ground and surface waters [12], [13].



(**a**)



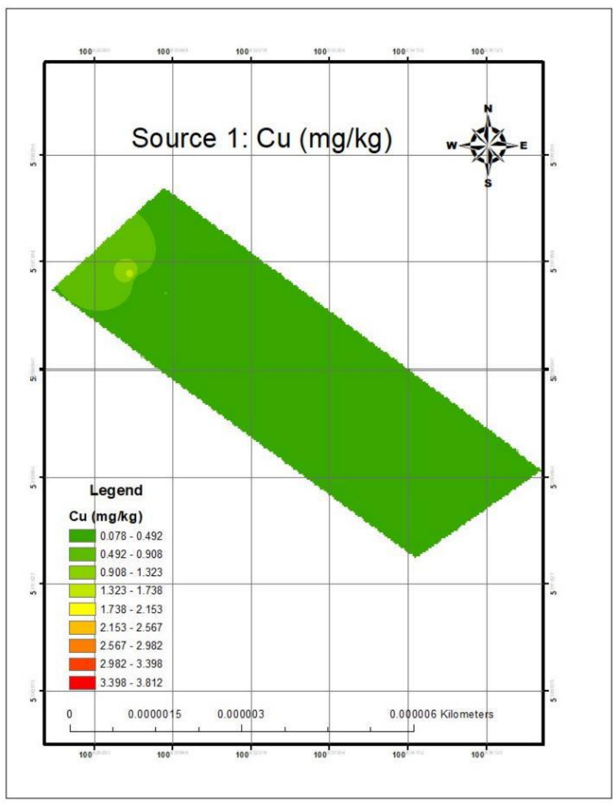
(**b**)

Figure 2. (**a**) The distribution of Cr at source 1 in soil at Kulim Sanitary landfill; (**b**) The distribution of Cr at source 2 in soil at Kulim Sanitary landfill.

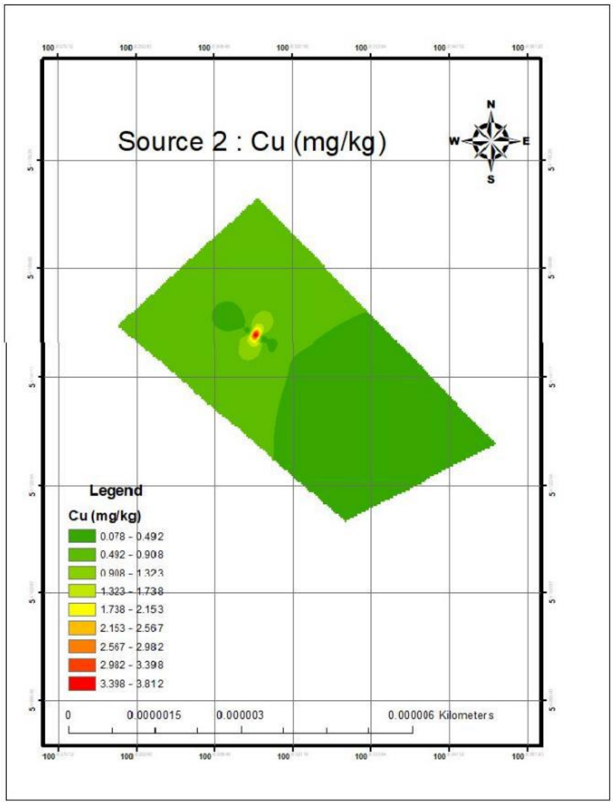
3.2.2. Distribution of copper (Cu) in soils

From Fig. 3 (b), the coverage distribution of Cu in source 2 is larger, but the range is at lower concentrations, where the value is 0.078 to 0.492 mg/kg. The high concentration of Cu is in a smaller range of 3.398 to 3.812 mg/kg. From the observation based on Fig. 3 (a), Cu concentration is lower compared to source 2. Landfills are the recipients of substantial quantities of waste materials, encompassing a diverse range of substances.

The dilution of Cu concentration in landfills can occur due to the presence of various materials, including organic matter, plastics, and other metals. The process of Cu leaching from waste materials can result in its migration into the surrounding environment. Within landfill environments, the presence of precipitation or other liquid substances has the potential to facilitate the dissolution of copper ions, thereby enabling their mobility alongside the leachate [14]. The leachate, which contains Cu in a dissolved state, can be gathered and subjected to treatment before its release into the surrounding ecosystem. This process serves to diminish the Cu concentration within the landfill further. This range for high concentration of Cu is still under the limit value, which is 19.80 mg/kg, as shown in Table 2, the typical range of naturally occurring metals concentration by [10].



(**a**)

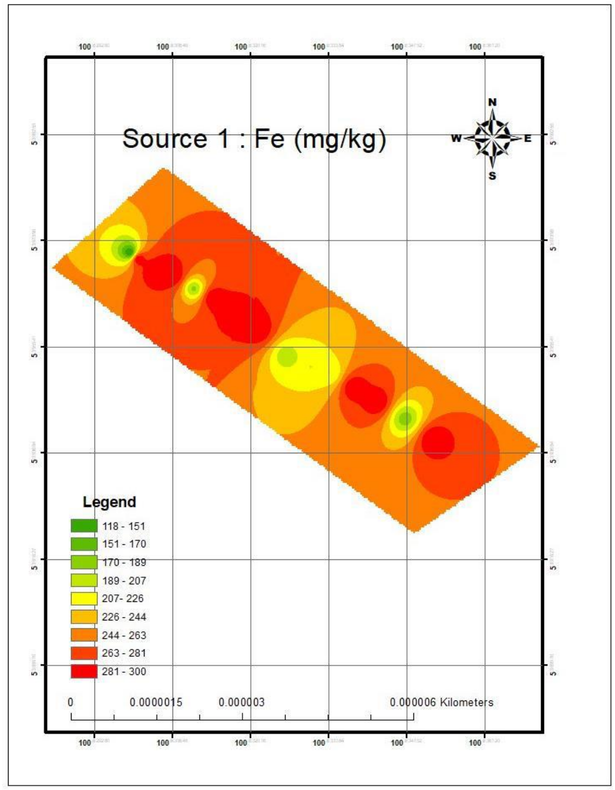


(**b**)

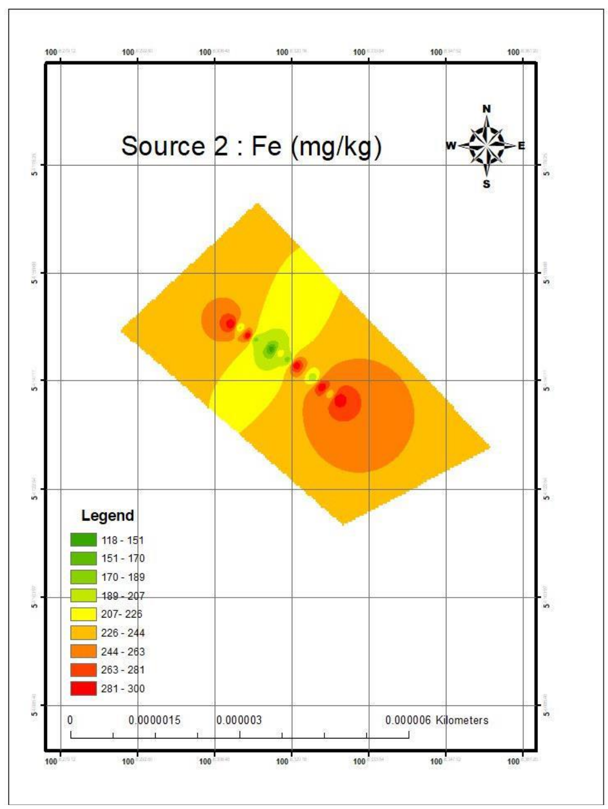
Figure 3. (**a**) The distribution of Cu at source 1 in soil at Kulim Sanitary landfill; (**b**) The distribution of Cu at source 2 in soil at Kulim Sanitary landfill.

3.2.3. Distribution of iron (Fe) in soils

From Fig. 4 (a), source 1, and Fig. 4 (b), source 2 of Fe, each area shows high concentration, with the shade color approaching and mostly red, indicating a value of 300 mg/kg. While from source 2, the distribution of iron in the high concentration range of 281 to 300 mg/kg was non-uniformly observed in most stations, albeit with a slight variation. When comparing areas, Source 1 shows a higher distribution of high iron concentration, whereas Source 2 does not. The area of the sampling site for source 1 was near hilly land areas. According to [15], higher total iron concentrations were found in the soils of hilly land areas compared to those of colluvium soils. However, the concentration of iron at source 1 does not exceed the limit concentration of heavy metals stated by DOE. The distribution of Fe on both sources shows the most coverage in the range of 244 mg/kg to 263 mg/kg.



(**a**)

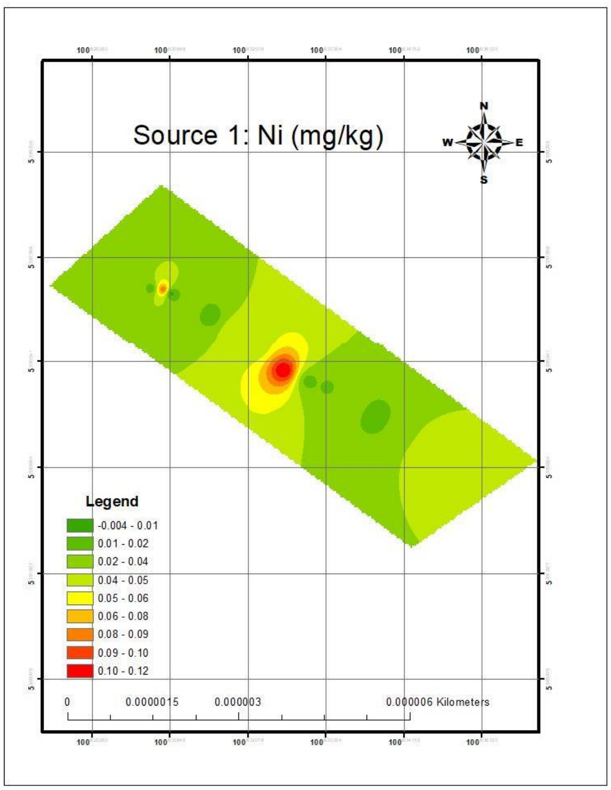


(**b**)

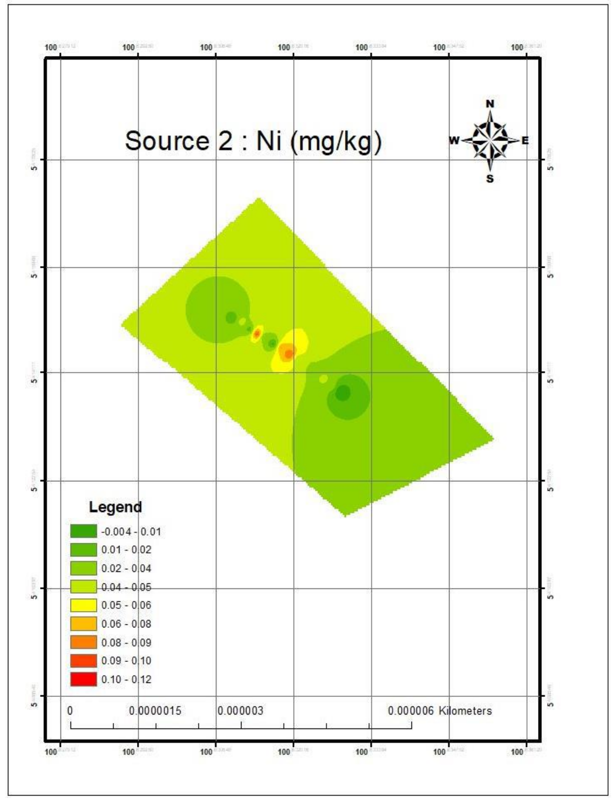
Figure 4. (**a**) The distribution of Fe at source 1 in soil at Kulim Sanitary landfill; (**b**) The distribution of Fe at source 2 in soil at Kulim Sanitary landfill.

3.2.4. Distribution of nickel (Ni) in Ssoils

Fig. 5 (a) and Fig. 5 (b) show the various distributions of Ni, ranging from 0.09 to 0.10 mg/kg. The Cr and Ni at source 1 in surface soils showed a remarkably similar pattern, where the highest concentration of both metals is in the same region. The levels of Cr and Ni with higher concentrations were mainly distributed in the region S10. However, the lowest concentrations of Cr and Ni were found at stations S22 and S30, respectively. The high Cr and Ni are attributed to common sources or anthropogenic activities [16]. Ni is an element known for its toxic properties, commonly found in leachate produced within landfills containing hazardous waste. The substance in question is obtained through the processes of metal plating, electroplating, biosolids, and the residual byproducts resulting from the combustion of fossil fuels [17]. Ni is a naturally occurring metal that is relatively abundant, with a wide distribution throughout the earth's crust. The presence of Ni in soils is greatly influenced by the concentration of nickel in the parent rocks. However, in surface soils, the amount of Ni is also indicative of soil formation processes and pollution [18]. The distribution of Ni on both sources shows the most coverage in the range of 0.02 mg/kg to 0.04 mg/kg.



(**a**)



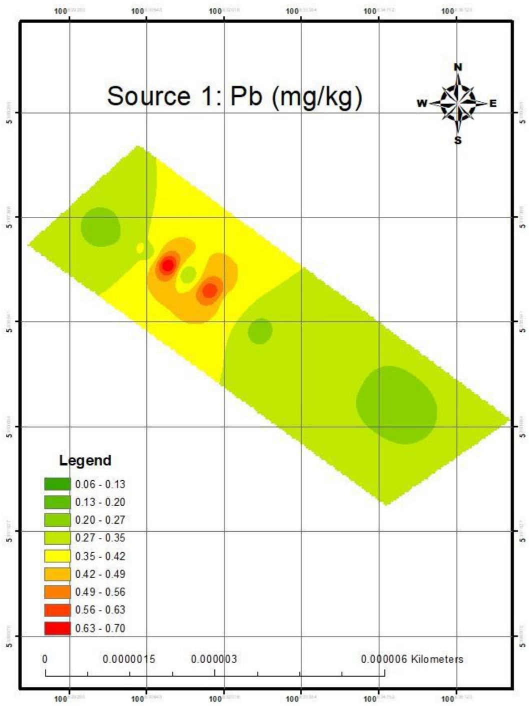
(**b**)

Figure 5. (**a**) The distribution of Ni at source 1 in soil at Kulim Sanitary landfill; (**b**) The distribution of Ni at source 2 in soil at Kulim Sanitary landfill.

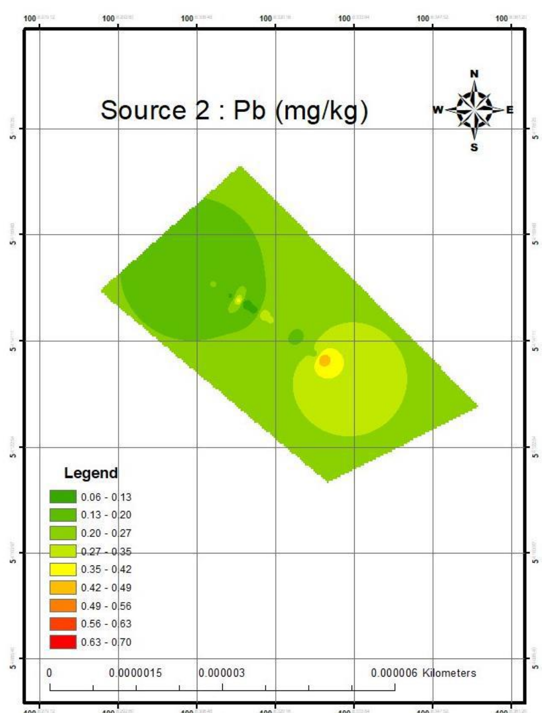
3.2.5. Distribution of lead (Pb) in soils

Fig. 6 (b) shows the distribution of Pb in source 2, with a range of 0.20 to 0.27 mg/kg, covering a large area. The high concentration of Pb is in the range 0.49 to 0.58 mg/kg. The high Pb levels in this landfill, Fig. 6 (a), are distributed in the region S6 and S8, where the concentration of Pb was around 0.49 to 0.70 mg/kg. The distribution of Pb on both sources shows the most coverage in a range of 0.27 mg/kg to 0.36 mg/kg.

The distribution of Pb within the soil is influenced by various factors, encompassing chemical mechanisms like oxidation and reduction reactions, the adsorption of cations on the exchange complex, chelation facilitated by organic matter and metal oxides, as well as the cycling facilitated by vegetation [19]. The solubility of lead in soil is enhanced due to its strong affinity for organic and colloidal substances, resulting in its availability for uptake by plants [19]. When considering the detrimental effects of pollution, soil pollution is deemed more harmful than atmospheric and water pollution due to its inherent characteristics of concealment, stagnation, and accumulation. Heavy metals are extensively distributed, challenging to remove, and have the potential to persist in the soil environment for extended periods [20]. When present in sufficient quantities, these substances can be detrimental to the soil ecosystem, resulting in soil degradation and a subsequent decrease in agricultural productivity. Furthermore, it is worth noting that these organisms have the potential to relocate to subterranean environments, thereby contributing to the contamination of groundwater through the processes of surface runoff and leaching [21]. Consequently, the detrimental effects of toxic metals on the soil environment have garnered worldwide recognition.



(**a**)

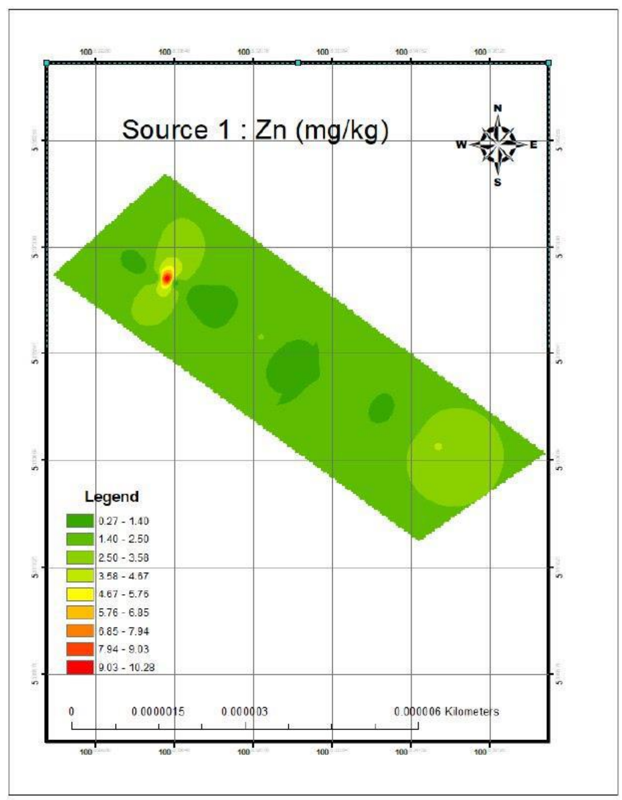


(**b**)

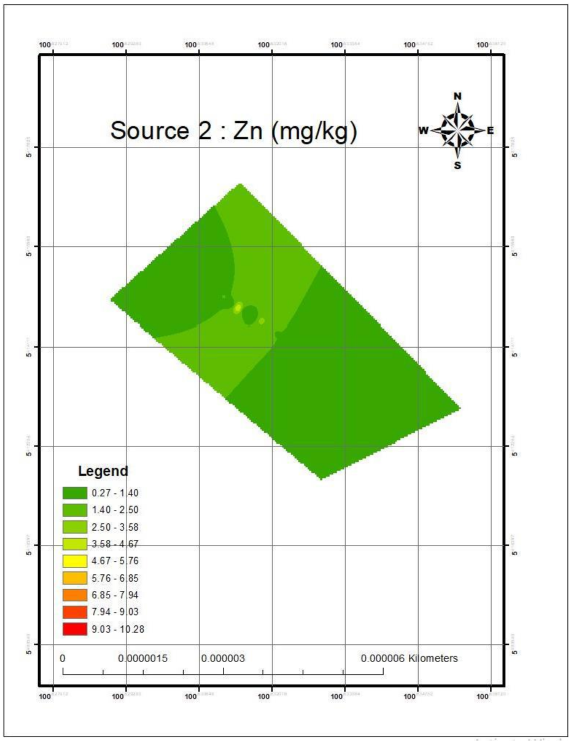
Figure 6. (**a**) The distribution of Pb at source 1 in soil at Kulim Sanitary landfill; (**b**) The distribution of Pb at source 2 in soil at Kulim Sanitary landfill.

3.2.6. Distribution of zinc (Zn) in soils

For Zn, there was a small coverage distribution of the highest level of pollution, with the highest concentration level found in the region S4 at 10.28 mg/kg. The distribution of Zn from Fig. 7 (a) and Fig. 7 (b) shows Zn was a regional pollutant with the lowest level of pollution and coverage (concentration 0.31 to 1.40 mg/kg). Compared to other metals, Cu's pollution level is less apparent. Partially as a result of an increase in industrial activities, landfill soil contamination is becoming progressively worse. The distribution of Zn on both sources shows the most coverage in the range of 1.40 mg/kg to 2.50 mg/kg. So, all the concentrations of heavy metals in each source area were still under the limit suggested by DOE. Zn deficiencies are commonly observed in calcareous soils with high pH levels that have been levelled using machinery to ensure uniform irrigation application. The removal of topsoil and organic matter, which are rich in micronutrients, occurs primarily due to the levelling of fields, particularly in calcareous soils [22]. Furthermore, it has been observed that deficiencies are prevalent in soils characterized by a low overall Zn content, such as sandy soils, or soils that exhibit relatively high levels of available phosphorus [23]. Nevertheless, the overall Zn content is an unreliable indicator for assessing the soil's ability to provide Zn for plant absorption.



(**a**)



(**b**)

Figure 7. (**a**) The distribution of Zn at source 1 in soil at Kulim Sanitary landfill; (**b**) The distribution of Zn at source 2 in soil at Kulim Sanitary landfill.

4. Conclusions

Although the Malaysian Recommended Site Screening Levels for Contaminated Land (MRSSL-CL) by DOE has been vital in evaluating the pollution impacts of leachate on soil, it has several limitations, namely, it provides an inaccurate rating for leachate in developing countries and open dumpsites. MRSSL-CL overcomes this, as it takes into account the specific leachate and landfill characteristics of developing countries. For instance, the Pollution Index (PI) value for the Kulim Sanitary Landfill (KLS) was 15.32, which was a better rating than most engineered landfills. This is due to the leachate of KLS being diluted; KLS produces 600 m^3 of leachate daily. MRSSL-CL overcomes this, as it takes important parameters like leachate volume and landfill liners into account.

Although the case studies reaffirm that the MRSSL-CL provides a more precise evaluation of the pollution impact of leachate in developing countries, it is still highly encouraged that the MRSSL-CL should only serve as a general guideline. A region's specific leachate characteristics must be considered when evaluating its pollution impact. A more precise leachate pollution index could be developed based on specific regions by making the necessary changes to the Leachate Pollution Index for Developing Countries (LPIDC).

The analysis of the total concentration of heavy metals and their distribution shows that landfill soils from Kulim Sanitary Landfill are contaminated with heavy metals, resulting from intensive anthropogenic stress in the area. The falling trend of heavy metals is Fe > Zn > Cu > Pb > Cr > Ni, with an average concentration of 241.917 > 1.689 > 0.406 > 0.285 > 0.173 > 0.0378 mg/kg, respectively. The maximum value concentration of heavy metals is Fe (300 mg/kg), Zn (10.28 mg/kg), Cu (3.95 mg/kg), Pb (0.702 mg/kg), Cr (0.56 mg/kg), and Ni (0.117 mg/kg). According to the Department of Environment, all six elements of heavy metal concentration in soils studied in this landfill area were lower than the allowable limit. The landfill area was safe for the environment. In addition, the concentration of heavy metals in the landfill area was identified as above the level of contaminated land for groundwater. When comparing the limit concentrations of heavy metals in soils and groundwater, the limit concentrations in water are usually limited to a few specific concentrations. It is recommended to investigate more about the leachate in this landfill area. Pb, Cr, and Ni concentrations were over the limit suggested by DOE. Therefore, it is crucial to consistently evaluate and monitor the concentrations of heavy metals in the environment due to human activities to assess human exposure and ensure environmental sustainability.

5. Recommendations

The analysis of the total concentration of heavy metals and their distribution shows that the heavy metal pollution in the current study was mapped using GIS software and interpolation methods. Pollution of heavy metals is a significant concern as these elements are both potent and discrete, and even considered as 'poison of king of poisons'. Therefore, it is clear from this study that the problem of non-sanitary landfills must be prioritized and solved. Segregation of waste disposed of in landfills must also be practiced, and replacing open dumpsites with sanitary landfills is necessary to avoid such long-term pollution. A systematic environmental monitoring and precautionary action should also be imposed to prevent future complications.

Acknowledgements

The authors acknowledge Universiti Teknologi MARA, Perlis branch, for its continuous support to improve the research quality.

Conflict of Interest

No conflicts of interest exist, according to the authors, with the publishing of this work.

Author Contribution Statement

Nur Firdaus Abdul Rashid: suggested the problem of the research, developed the theory, verified the analytical methods, conducted the structure of the manuscript, organized the outcomes of this study, performed the experimental work, and conducted the calculations.

Nur Fatihah Shahirah Yuzaimi: conducted the experimental work and calculations.

Chuah Tse Seng: supervised the experimental work.

All authors contributed to the final text and commented on the findings.

References

[1] J. M. Nyika, E. K. Onyari, M. O. Dinka, and S. B. Mishra, "Heavy Metal Pollution and Mobility in Soils within a Landfill Vicinity: A South African Case study," *Oriental Journal Of Chemistry*, vol. 35, no. 4, pp. 1286–1296, Aug. 2019, doi: https://doi.org/10.13005/ojc/350406.

[2] E. Najih Mohsen, T. K. Hussien, and N. A. Jasim, "Cd+2 Sorption From Aqueous Solution Using Rosemary Plant: Performance And Isotherm Study," *Journal of Engineering and Sustainable Development*, vol. 27, no. 3, pp. 407–416, May 2023, doi: https://doi.org/10.31272/jeasd.27.3.10.

[3] M. Hussein, K. Yoneda, Z. Mohd-Zaki, A. Amir, and N. Othman, "Heavy metals in leachate, impacted soils and natural soils of different landfills in Malaysia: An alarming threat," *Chemosphere*, vol. 267, p. 128874, Nov. 2020, doi: https://doi.org/10.1016/j.chemosphere.2020.128874.

[4] Z. Samer Hadi and K. Abdulhussein Saeed, "Microbial-Induced Calcite Precipitation" As A Potential Sustainable Technique For Polluted Soil Bioremediation: A Review," Journal of Engineering and Sustainable Development, vol. 26, no. 4, pp. 18–29, Jul. 2022, doi: https://doi.org/10.31272/jeasd.26.4.2.

[5] H. L. Chen, T. K. Nath, S. Chong, V. Foo, C. Gibbins, and A. M. Lechner, "The plastic waste problem in Malaysia: Management, recycling and disposal of local and global plastic waste," SN Applied Sciences, vol. 3, no. 4, 2021, doi: https://doi.org/10.1007/s42452-021-04234-y.

[6] N. C. Brady and R. R. Weil, The nature and properties of soils. Harlow: Pearson, 2014.

[7] B. K. Mavakala et al., "Evaluation of heavy metal content and potential ecological risks in soil samples from wild solid waste dumpsites in developing country under tropical conditions," Environmental Challenges, vol. 7, p. 100461, Apr. 2022, doi: https://doi.org/10.1016/j.envc.2022.100461.

[8] F. Obiri-Nyarko, A. A. Duah, A. Y. Karikari, W. A. Agyekum, E. Manu, and R. Tagoe, "Assessment of heavy metal contamination in soils at the Kpone landfill site, Ghana: Implication for ecological and health risk assessment," Chemosphere, vol. 282, p. 131007, Nov. 2021, doi: https://doi.org/10.1016/j.chemosphere.2021.131007.

[9] G. Sankar Bhunia, P. Kumar Shit, and R. Maiti, "Comparison of GIS-based interpolation methods for spatial distribution of soil organic carbon (SOC)," Journal of the Saudi Society of Agricultural Sciences, vol. 17, no. 2, 2018. https://doi.org/10.1016/j.jssas.2016.02.001.

[10] Esri. (n.d.). IDW (Inverse Distance Weighted). ArcGIS Pro. https://pro.arcgis.com/en/pro-app/latest/tool-reference/spatial-analyst/idw.htm

[11] M. Umar, H. A. Aziz, and M. S. Yusoff, "Variability of Parameters Involved in Leachate Pollution Index and Determination of LPI from Four Landfills in Malaysia," International Journal of Chemical Engineering, vol. 2010, pp. 1–6, 2010, doi: https://doi.org/10.1155/2010/747953.

[12] Contaminated Land Management and Control Guidelines No. 1: Malaysian Recommended Site Screening Levels for Contaminated Land. 2009. Available: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.doe.gov.my/wp-content/uploads/2021/07/Contaminated-Land-Management-and-Control-Guidelines-No-1_Malaysian-Recommended-Site-Screening-Levels-for-Contaminated-Land.pdf

[13] W. Ahmad, R. D. Alharthy, M. Zubair, M. Ahmed, A. Hameed, and S. Rafique, "Toxic and heavy metals contamination assessment in soil and water to evaluate human health risk," Scientific Reports, vol. 11, no. 1, p. 17006, Aug. 2021, doi: https://doi.org/10.1038/s41598-021-94616-4.

[14] Del Real, A. Pérez-Sanz, P. García-Gonzalo, H. Castillo-Michel, M.J. Gismera, and M. C. Lobo, "Evaluating Cr behaviour in two different polluted soils: Mechanisms and implications for soil functionality," Journal of environmental management, vol. 276, pp. 111073–111073, Dec. 2020, doi: https://doi.org/10.1016/j.jenvman.2020.111073.

[15] M. D. Vaverková, "Landfill Impacts on the Environment—Review," Geosciences, vol. 9, no. 10, Oct. 2019, doi: https://doi.org/10.3390/geosciences9100431

[16] J. Habibah, J. Khairiah, B. S. Ismail, and M.D. Kadderi, "Iron Speciation in Selected Agricultural Soils of Peninsular Malaysia," Journal of Environmental Science and Technology, vol. 7, no. 3, pp. 154–165, Apr. 2014, doi: https://doi.org/10.3923/jest.2014.154.165.

[17] C. S. Lwin, Y.-N. Kim, M. Lee, and K.-R. Kim, "Coexistence of Cr and Ni in anthropogenic soils and their chemistry: implication to proper management and remediation," Environmental Science and Pollution Research, vol. 29, no. 42, pp. 62807–62821, Jul. 2022, doi: https://doi.org/10.1007/s11356-022-21753-2.

[18] P. Makuleke and V. M. Ngole-Jeme, "Soil Heavy Metal Distribution with Depth around a Closed Landfill and Their Uptake by Datura stramonium," Applied and Environmental Soil Science, vol. 2020, pp. 1–14, Sep. 2020, doi: https://doi.org/10.1155/2020/8872475.

[19] Yahaya Ahmed Iyaka, "Nickel in soils: A review of its distribution and impacts," Scientific Research and Essays, vol. 6, no. 33, Dec. 2011, doi: https://doi.org/10.5897/srex11.035.

[20] A. Kushwaha, N. Hans, S. Kumar, and R. Rani, "A critical review on speciation, mobilization and toxicity of lead in soil-microbe-plant system and bioremediation strategies," Ecotoxicology and Environmental Safety, vol. 147, pp. 1035–1045, Jan. 2018, doi: https://doi.org/10.1016/j.ecoenv.2017.09.049.

[21] N. T. Mahlangeni, R. Moodley, and S. B. Jonnalagadda, "Heavy metal distribution in Laportea peduncularis and growth soil from the eastern parts of KwaZulu-Natal, South Africa," Environmental Monitoring and Assessment, vol. 188, no. 2, Jan. 2016, doi: https://doi.org/10.1007/s10661-015-5044-y.

[22] A. Castaño-Sánchez, G. C. Hose, and A. S. P. S. Reboleira, "Ecotoxicological effects of anthropogenic stressors in subterranean organisms: A review," Chemosphere, vol. 244, p. 125422, Apr. 2020, doi: https://doi.org/10.1016/j.chemosphere.2019.125422.

[23] C. Noulas, M. Tziouvalekas, and T. Karyotis, "Zinc in soils, water and food crops," Journal of Trace Elements in Medicine and Biology, vol. 49, pp. 252–260, Sep. 2018, doi: https://doi.org/10.1016/j.jtemb.2018.02.009.