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RESEARCH ARTICLE

Evaluation of heavy metal contamination and pollution indices in soil from selected dumpsites in Kelantan, Malaysia

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ABSTRACT

Heavy metal contamination was one of the most important environmental issues, and the dumping of municipal waste at the dumpsites led to the contamination. Hence, this study focused on three dumpsites in Kelantan which were Beris Lalang Dumpsite, Kok Bedollah Dumpsite, and Bukit Che Ros Dumpsite. This study aimed to determine the concentration of selected heavy metals and to examine the soil quality using pollution indices. The soil samples were analysed using Atomic Absorption Spectroscopy (AAS). This study revealed the mean concentration of heavy metals in soil at Beris Lalang Dumpsite as following order, Cu (16.00 $mgkg^{-1}$) > Cr (11.87 $mgkg^{-1}$) > Zn (10.54 $mgkg^{-1}$) > Mn (6.69 $mgkg^{-1}$) > Pb (5.72 $mgkg^{-1}$), while Kok Bedollah Dumpsite were Mn (64.86 $mgkg^{-1}$) > Zn (31.28 $mgkg^{-1}$) > Cu (18.92 $mgkg^{-1}$) > Pb (18.59 $mgkg^{-1}$) > Cr (3.52 $mgkg^{-1}$) and Bukit Che Ros Dumpsite, were Zn (17.46 $mgkg^{-1}$) > Cu (13.24 $mgkg^{-1}$) > Cr (8.60 $mgkg^{-1}$) > Mn (5.74 $mgkg^{-1}$) > Pb (4.89 $mgkg^{-1}$). Meanwhile for the pollution indices, the I_{geo} result showed that all stations were in class 0 except for one sampling point at Kok Bedollah Dumpsite. This is also supported by the Pollution Load Index (PLI) result for each dumpsite, which was also below 1, indicating that the areas were not polluted. If dumpsite management remains not managed correctly, this contamination may continue to have an impact on soil quality in the future. As a result, the data gained from this study was valuable in assisting authorities in managing dumpsites systematically to maintain the soil quality.

1. INTRODUCTION

Dumpsites were stated as any locations where municipal wastes were discarded, spilled in such a way that it caused a nuisance, posed a risk of environmental pollution or released harmful substances that were dangerous to human health. The most common method of municipal waste disposal was dumpsites (Hussein and Mona, 2018). It was because dumping was one of the simplest methods of disposing of rubbish and it was the most straightforward approach used in controlling municipal waste. The use of open dumping sites as a method of waste disposal was common in many low-income countries and has since become a neglected area by communities (Mansoor et al., 2020). Improper management of waste at the open dumping site has polluted the soil with heavy metals (Ferronato and Torretta, 2019). These dumpsites are generally non-sanitary landfills characterized by a critical absence of foundational environmental protection infrastructure, such as a proper liner system, gas control mechanisms and most importantly leachate collection and treatment system (Imran et al., 2019). This absence distinguishes open dumps from engineered sanitary landfills where multi-layered liners and effective drainage systems are mandatory barriers designed to prevent the migration of contaminants. The improper management of waste at these open dumping sites inevitably leads to the percolation of leachate that a highly concentrated toxic liquid into the surrounding environment. The uncontrolled release of leachate is a significant pathway for the polluting of groundwater, surface water, and natural habitats.

The burgeoning global population and accelerated pace of urbanization have resulted in an unprecedented increase in the generation of municipal solid waste. Municipal waste, also known as domestic waste, is the solid waste generated from homes, institutions and industries (USEPA, 2016). This waste included a variety of materials, such as food waste, paper, plastics and glass. These eventually are deposited in nearby soil and cause pollution. In many low-income and developing nations, the most common and often rudimentary method of municipal solid waste disposal remains the operation of open dumpsites.

In Malaysia, municipal solid waste is generated at a rate of about 2.01 billion metric tonnes per year, with 33% of it not being handled efficiently in an environmentally friendly manner. Malaysia's population was rapidly growing, resulting in a substantial amount of waste generated daily, equating to 1.17 kg of waste per capita or around 30,000 tonnes of municipal solid waste (MIDA, 2021). The volume of municipal waste was rapidly increasing due to urban lifestyles and the development of urbanization. The lack of robust solid waste management infrastructure in many regions means that these open dumping sites continue to proliferate, posing chronic environmental risks that escalate over time.

Soils are vital components of the socio-ecological system, acting as a crucial reservoir for ecological stability and safety (Wu et al., 2018). However, soils have a natural propensity to absorb and accumulate heavy metals released from both anthropogenic activities such as dumpsites and natural processes. The resulting heavy metal concentration in soil is considered one of the most serious environmental concerns due to the inherent nature of these contaminants. Heavy metals are a category of metallic elements with high atomic weight and densities that are naturally occurring but become toxic at elevated concentrations. Unlike organic pollutants, heavy metals are non-biodegradable and persistent, meaning these heavy metals cannot be broken down by natural processes and remain in the environment indefinitely, posing a continuous and long-term risk. Common heavy metal contaminants found at dumpsites include chromium (Cr), cobalt (Co), copper (Cu), lead (Pb), manganese (Mn), nickel (Ni), cadmium (Cd) and zinc (Zn) (Bienvenu et al., 2022; Dutta et al., 2022; Dusengemungu et al., 2022; Ismat et al., 2019; Shittu et al., 2018). The cumulative presence of these metals in soil can significantly impede the biodegradation of other organic contaminants, compounding the overall environmental damage and ultimately threatening the food chain through bioaccumulation.

To accurately analyze and evaluate soil health in areas impacted by anthropogenic activities, a rigorous soil assessment methodology employing contamination indices is indispensable. Relying solely on total measured concentrations and comparing them to regulatory limits can be misleading as natural geological must also be taken inti account. Over the years, a comprehensive suite of indices has been established for contamination analysis, which provides a normalised and comparative measure of contamination severity. A comprehensive suite of soil assessment indices used in contamination analysis including the Contamination Factor (CF), Enrichment Factor (EF), Geo-accumulation Index (Igeo), Pollution Load Index (PLI),Ecological risk index (RI), ecological risk factor, Degree of Contamination (DegC), Modified Degree of Contamination (MDC), and Nemerow Integrated Pollution Index (NIPI) (Afolagboye et al., 2020; Hamza et al., 2022; Oladejo et al., 2021; Kafle et al., 2022). A previous study conducted at a municipal waste dumpsite in Nigeria revealed that the Geo-accumulation Index (I_{geo}) value for Cr, reached 5 that classifying the site as extremely contaminated whereas the I_{geo} values for Cu, Ni and iron (Fe) were all negative that indicating an absence of contamination by these elements (Afolagboye et al., 2020). Meanwhile, a Geo-accumulation Index (I_{geo}) study at municipal waste dumpsites in Kumasi, Ghana, showed that the I_{geo} values for Zn at the Kronum and Amakom sites ranged from uncontaminated to moderately contaminated, reflecting spatial variability in Zn accumulation (Akanchise et al., 2020). At the Kpone municipal solid waste dumpsite in Ghana, the PLI was reported at 16.48, indicating severe heavy metal contamination across the entire site (Obiri-Nyarko, 2021). Similarly, extremely high PLI values were observed at electronic waste dumpsites in Lagos and Ibadan, Nigeria, where the highest recorded PLI reached 109 that signifying extensive pollution from accumulated toxic metals (Adeyi and Oyeleke, 2017). In contrast, a previous study conducted at a municipal waste dumpsite in Ondo State, Nigeria, reported PLI values ranging from 0.7 to 3.0 that suggesting conditions that ranged from slight to moderate pollution (Ogundele et al., 2020). Furthermore, an assessment of a municipal solid waste landfill in Morocco revealed a PLI value of 1.84, indicating moderate to high levels of contamination, primarily attributed to the enrichment of Cd and Pb in the surrounding soils (Hamza El Fadili et al., 2022). Hence, this study aims to determine the concentration of five selected heavy metals, namely Cu, Cr, Zn, Mn and Pb at the Beris Lalang Dumpsite, Kok Bedollah Dumpsite and Bukit Che Ros Dumpsite. These sites represent varying ages and scales of operation and providing a unique opportunity to evaluate the impact of operational duration on heavy metal accumulation. Furthermore, to provide a robust assessment of soil quality and the integrated impact of these metals, the contamination levels at the dumpsites were rigorously quantified using Geo-accumulation Index (Igeo) and Pollution Load Index (PLI).

2. MATERIALS AND METHODS

2.1. Study area

Three municipal waste dumpsites were selected, namely the Beris Lalang Dumpsite in Bachok District, the Kok Bedollah Dumpsite in Tumpat District and the Bukit Che Ros Dumpsite in Tanah Merah District, all of which are located in Kelantan State, Peninsular Malaysia. The three chosen sites, along with their general characteristic, are summarized in Table 1 and illustrated in Figure 1. It is noteworthy that three sites primarily handle domestic waste and have varying operational periods, with Kok Bedollah Dumpsite being the oldest site of these sites.

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Table 1: The general information about sampling dumpsite sites.

Location	Beris Lalang Dumpsite	Kok Bedollah Dumpsite	Bukit Che Ros Dumpsite
Area	76 acres	90 acres	10.280 hectares
Latitude	N05°55'45"	N06°11'41"	N05°47'06"
Longitude	E102°24'45"	E102°08'09"	E102°06'31"
Operation period	13 years	33 years	15 years
Amount of waste	400 tons/day	80 tons/day	51tons/day
Type of waste	Domestic waste	Domestic waste	Domestic waste

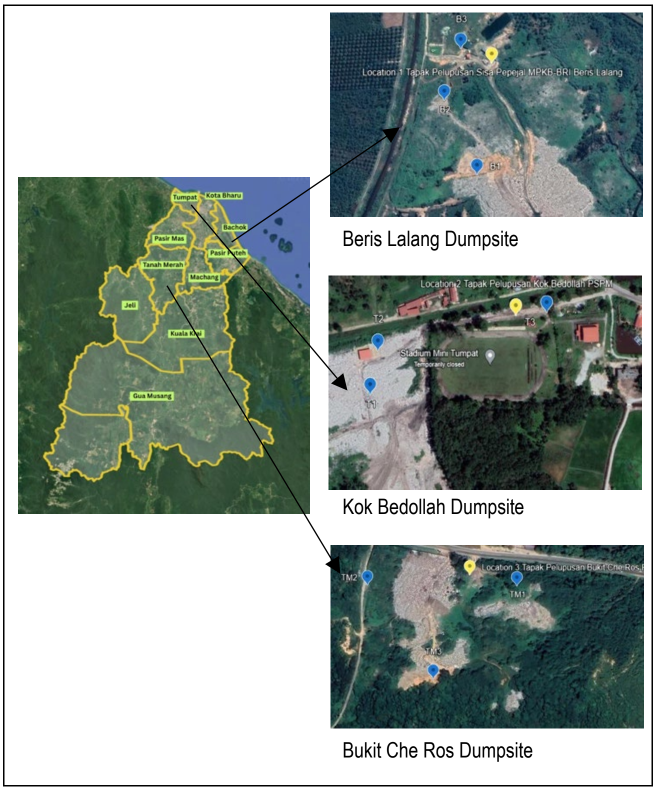

Figure 1: Location of the sampling sites.

2.2. Soil sampling

A consistent and systematic sampling strategy was employed to ensure representativeness across each dumpsite. The soil samples were collected at a depth of 20 cm using an auger from three sampling points at each site with duplicate sampling conducted. The soil samples were transported to the Universiti Malaysia Kelantan laboratory and stored in a 4°C freezer to prevent contamination for further analysis.

2.3. Acid digestion and preparation of sample

The process of acid digestion was critical to effectively extract the total metal content from the soil matrix and a necessary step before instrumental analysis. All glassware used in this study was rinsed and soaked in 10% nitric acid (HNO_3) for one hour to prevent external contamination of the soil samples. Soil samples were dried in the dry oven at 80°C for 48 hours. After that, the soil samples were ground with a postal slaved by passing through 500 µm mesh and subjected to acid digestion procedures. Four grams of soil samples were weighed into a 250 ml beaker and sufficient deionized water was added to moisten the sample. Then, 15 ml of concentrated HNO_3 was added into the sample, and the beaker was covered with a watch glass and placed on a hot plate where the temperature maintained at 100°C. Meanwhile, a digestion blank was prepared by adding the same amount of distilled water and concentrated HNO_3 to a beaker without a sample and was carried through the entire procedure. The samples were heated at 100°C for one hour and 5 ml of 30% H_2O_2 was added carefully when the beaker was slightly cool. The watch glass was replaced and the beaker on was set on the hotplate. After the vigorous boiling had subsided, the watch glass was removed, and over the period of 1 hour the liquid level was allowed to evaporate until about 10 ml remained.

After two hours, the sample was removed from the hotplate. About 25 ml of deionized water was added, the watch glass was replaced, and the sample allowed to cool in the hood. While the sample is cooling, folded No 2 or No 40 Whatman filter paper was folded in a funnel, and the paper was rinsed with 10% HNO_3. After that, the sample was filtered into a 100 ml volumetric flask. The residue was rinsed in the beaker with deionized water through the filter. Then, a small amount of deionized water was added into the volumetric flask to the 100 mL mark and mixed well by inverting the flask. After that, the sample was transferred to a clean, dry storage bottle and labelled properly. The prepared sample solutions were analyzed for the target heavy metals which are Cu, Pb, Zn, Mn and Cr using Atomic Absorption Spectrophotometer (AAS).

2.3. Pollution indices

In this study, soil quality was evaluated using the Geo-accumulation Index (I_{geo}) and the Pollution Load Index (PLI). The I_{geo} was calculated for detecting the contamination of heavy metals in soil samples. I_{geo} was calculated by equation below (Muller, 1969).

$$I_{geo} = \log_2 (C_i/1.5\ C_{background})$$

where C_i was the concentration of metal in soil samples from a dumpsite area. The $C_{background}$ was the background value for the metal where the background value for selected elements was Cu at 25ppm, Pb at 14.8 ppm, Zn at 65 ppm, Mn at 716 ppm and Cr at 126 ppm (Hans Wedepohl, 1995).

Meanwhile, the Pollution Load Index (PLI) is a metric used to assess heavy metal contamination in soil, which in turn affects soil structure (Siddiqui et al., 2020). It's a comprehensive measure that takes into account the concentrations of multiple heavy metals. The PLI is calculated for each location using a specific formula: the concentration of each metal is divided by the n-root of the product of the n Contamination Factors (CFs) for all the metals analyzed (Rabee et al., 2011). In simpler terms, the PLI provides a single value that reflects the overall degree of heavy metal pollution in the soil at a specific site

$$PLI = (CF1 \times CF2 \times CF3 \times .... \times CFn)^{1/n}$$

Where n represented the quantity of metals present and the CF represented the Contamination Factor, which calculated by dividing value of metal concentration in soil with background value of metal (Chakravarty and Patgiri, 2009). The I_{geo} and PLI classification are listed in Table 2.

Table 2: The classification of I_{geo} and PLI.

Index	Class	Level	Classification
Geo-accumulation Index (I_{geo})	0	$I_{geo} \leq 0$	Uncontaminated
	1	$0 \leq I_{geo} \leq 1$	Uncontaminated to moderately contaminated
	2	$1 \leq I_{geo} \leq 2$	Moderately contaminated
	3	$2 \leq I_{geo} \leq 3$	Moderately to strongly contaminated
	4	$3 \leq I_{geo} \leq 4$	Strongly contaminated
	5	$4 \leq I_{geo} \leq 5$	Strongly to extremely contaminated
	6	$I_{geo} \geq 5$	Extremely contaminated
Pollution Load Index (PLI)		PLI < 1	No pollution
		PLI > 1	Pollution

3. RESULT AND DISCUSSION

From this study, Beris Lalang Dumpsite revealed the mean concentration as followed, Cu (16.00 $mgkg^{-1}$) > Cr (11.87 $mgkg^{-1}$) > Zn (10.54 $mgkg^{-1}$) > Mn (6.69 $mgkg^{-1}$) > Pb (5.72 $mgkg^{-1}$), with the range Cu (14.60 $mgkg^{-1}$ to 16.88 $mgkg^{-1}$), Cr (7.75 $mgkg^{-1}$ to 14.49 $mgkg^{-1}$), Zn (4.76 $mgkg^{-1}$ to 18.64 $mgkg^{-1}$), Mn (4.49 $mgkg^{-1}$ to 9.00 $mgkg^{-1}$), and Pb (4.30 $mgkg^{-1}$ to 7.39 $mgkg^{-1}$). Meanwhile for the Kok Bedollah Dumpsite revealed the mean concentration as followed, Mn (64.86 $mgkg^{-1}$) > Zn (31.28 $mgkg^{-1}$) > Cu (18.92 $mgkg^{-1}$) > Pb (18.59 $mgkg^{-1}$> Cr (3.52 $mgkg^{-1}$), with the range Mn (54.64 $mgkg^{-1}$ to 70.74 $mgkg^{-1}$), Zn (15.91 $mgkg^{-1}$ to 39.11 $mgkg^{-1}$), Cu (14.78 $mgkg^{-1}$ to 23.95 $mgkg^{-1}$), Pb (14.16 $mgkg^{-1}$ to 26.36 $mgkg^{-1}$), and Cr (2.95 $mgkg^{-1}$ to 3.93 $mgkg^{-1}$) while for the Bukit Che Ros, Dumpsite revealed the mean concentration as followed, Zn (17.46 $mgkg^{-1}$) > Cu (13.24 $mgkg^{-1}$) > Cr (8.60 $mgkg^{-1}$) > Mn (5.74 $mgkg^{-1}$) > Pb (4.89 $mgkg^{-1}$), with the range Zn (5.64 $mgkg^{-1}$ to 32.45 $mgkg^{-1}$), Cu (8.24 $mgkg^{-1}$ to 19.00 $mgkg^{-1}$), Cr (5.40 $mgkg^{-1}$ to 12.63 $mgkg^{-1}$), Mn (4.55 $mgkg^{-1}$ to 7.71 $mgkg^{-1}$), and Pb (3.23 $mgkg^{-1}$ to 6.74 $mgkg^{-1}$) as showed in Table 3.

The Kok Bedollah Dumpsite revealed the highest mean concentration for all elements except for Cr element that show the lowest mean concentration at Kok Bedollah Dumpsite as shown in Table 3. This demonstrated that because Kok Bedollah Dumpsite was 33 years old, compared to the Bukit Che Ros Dumpsite, which was 15 years old, and Beris Lalang, Bachok Dumpsite, which is 13 years old.

A comparative study of heavy metals concentrations in soil samples from the present study with other dumpsites around the world was analyzed as presented in Table 4. The highest concentration of lead (Pb) was found in from Calabar, Nigeria, at 1489.32 $mgkg^{-1}$. It was due to the high quantities of dumped, scraped lead proof pipes, batteries and paint materials in the dumpsite. Lead-acid batteries commonly found in vehicles, which contain lead in both the electrodes and the electrolyte (Baca and Vanysek, 2023). Compared to the findings of this study, the highest concentration of Pb was 26.36 $mgkg^{-1}$ from T2 sampling point at Kok Bedollah Dumspite, which primarily originated from municipal waste disposed of 33 years ago. The Calabar Dumpsite also revealed the highest concentration in zinc (Zn) element (Ediene at al., 2017). In contrast, the present study that found only 39.11 $mgkg^{-1}$ at the T3 sampling point at Kok Bedollah Dumpsite. Mainly, the anthropogenic sources of zinc at the dumpsite originate from non- ferrous metal industry, the construction industry, agriculture practice and food waste (Scutarasu and Trinca, 2023).

The I_{geo} values across all stations generally indicated minimal contamination with most values falling below zero, classifying the soils as uncontaminated (Class 0), as shown in Figure 2. This finding suggested that the background concentrations of Cu, Pb, Zn, Mn, and Cr have not been significantly exceeded in the sampled areas. The only exception was station T2 (sampling station at Kok Bedollah Dumspite), which recorded a lead (Pb) I_{geo} value of 0.25 thus falling into Class 1 (uncontaminated to moderately contaminated). This slight elevation may be attributed to prolonged waste accumulation at the Kok Bedollah Dumspite, which has been operational for over 30 years. These results align with previous findings at the Kronum dumpsite in Kumasi, Ghana, where I_{geo} values for most heavy metals indicated no pollution except for zinc (Zn) which ranged from 0.11 to 1.58 (Akanchise et al., 2020). The elevated zinc (Zn) levels in Ghana were linked to improper disposal of electronic waste, metal scraps, and cosmetic products where the materials that typically contain zinc (Zn) and lead (Pb) as additives. Although Malaysian dumpsites in this study showed lower I_{geo} values for zinc (Zn) the potential for localized pollution remains if waste management practices are not improved. The negative I_{geo} values for chromium (Cr), manganese (Mn) and copper (Cu) across all stations further confirm a low anthropogenic impact, which may be due to the dominant composition of domestic and municipal waste rather than industrial effluents. Moreover, the relatively younger operational periods of Beris Lalang and Bukit Che Ros dumpsites compared to long-established foreign dumpsites, may also explain the lower contamination levels observed

The PLI values calculated for each dumpsite were also consistently low, which were PLI value 0.13 at Beris Lalang Dumpsite, 0.26 at Kok Bedollah Dumpsite and 0.12 at Bukit Che Ros Dumpsite which contributed to all of which fall under the no pollution category (PLI < 1) as shown in Figure 3. The PLI value less than 1 indicates that there is no significant heavy metal pollution at the site. Among the sites, Kok Bedollah Dumpsite exhibited the highest PLI value. This is consistent with its status as the oldest dumpsite where waste has been deposited over several decades. Prolonged operation increases the likelihood of metal leaching and accumulation in surrounding soils, especially in the absence of engineered containment systems. Conversely, Bukit Che Ros Dumpsite, which showed the lowest PLI value is characterized by a lower waste input (51 tons/day) and a more recent operational history suggesting limited exposure and shorter-term contamination potential.

The combination of low I_{geo} and PLI values implies that the three Kelantan dumpsites under current conditions, do not pose an immediate risk of heavy metal contamination. However, the presence of even moderate pollution indicators, such as the lead (Pb) levels at T2 (Kok Bedollah Dumpsite) highlights the importance of long-term monitoring and improved waste segregation especially for materials known to contain persistent toxic metals.

Table 3: The concentration of heavy metals in collected soil samples.

Dumpsite	Station	Cu	Pb	Zn ($mgkg^{-1}$)	Mn	Cr
Beris Lalang	B1	16.88	5.46	8.23	4.49	13.38
	B2	16.51	7.39	18.64	9.00	7.75
	B3	14.60	4.30	4.76	6.59	14.49
	Mean	16.00±1.22	5.72±1.56	10.54±7.22	6.69±2.26	11.87±3.61
	Range	14.60-16.88	4.30-7.39	4.76-18.64	4.49-9.00	7.75-14.49
Kok Bedollah	T1	14.78	14.16	38.81	69.21	3.93
	T2	23.95	26.36	15.91	54.64	3.68
	T3	18.04	15.24	39.11	70.74	2.95
	Mean	18.92±4.65	18.59±6.75	31.28±13.31	64.86±8.89	3.52±0.51
	Range	14.78-23.95	14.16-26.36	15.91-39.11	54.64-70.74	2.95-3.93
Bukit Che Ros	TM1	19.00	6.74	32.45	4.96	12.63
	TM2	12.48	4.69	14.28	7.71	5.40
	TM3	8.24	3.23	5.64	4.55	7.76
	Mean	13.24±5.42	4.89±1.76	17.46±13.68	5.74±1.72	8.60±3.69
	Range	8.24-19.00	3.23-6.74	5.64-32.45	4.55-7.71	5.40-12.63

B= Beris Lalang; T= Kok Bedollah; TM= Bukit Che Ros

Table 4: The comparison between the present data of mean concentration in soil with previous studies.

Area	Cu	Pb	Zn	Mn ($mgkg^{-1}$)	Cr	Reference
Kelantan, Malaysia						
Beris Lalang Dumpsite	16.00	5.72	10.54	6.69	11.87	This study
Kok Bedollah Dumpsite	18.92	18.59	31.28	64.86	3.52	This study
Bukit Che Ros Dumpsite	13.24	4.89	17.46	5.74	8.60	This study
Nigeria						
Calabar	26.08	1489.32	2123.20	NR	75.30	Ediene, et al. 2017
Nigeria, Africa	NR	149.67	224.07	NR	133.50	Nwaougu, et al. 2017
Makurdi	NR	7.59	NR	NR	73.3	Egwumah, et al., 2018
Ibadan	7.77	3.79	3.07	7.70	8.36	Ogundele, et al. 2019
Enugu	NR	34.29	168.44	NR	22.60	Ekere, et al., 2020
Ondo State	19.81	15.25	48.79	NR	41.18	Ogundele, et al., 2020
Other countries						
Tamil Nadu, India	36.52	154.27	NR	130.30	NR	Kanmani and Gandhimathi, 2013
Khamees-Mushait, Saudi Arabia	22.92	38.33	64.21	288.90	53.22	Ismat H. Ali, et al. 2019
Sunyani, Ghana	NR	0.40	0.43	NR	NR	Agbeshie, et al. 2020
Khulna, Bangladesh	NR	67.03	NR	499.91	17.40	Saha, et al. 2022

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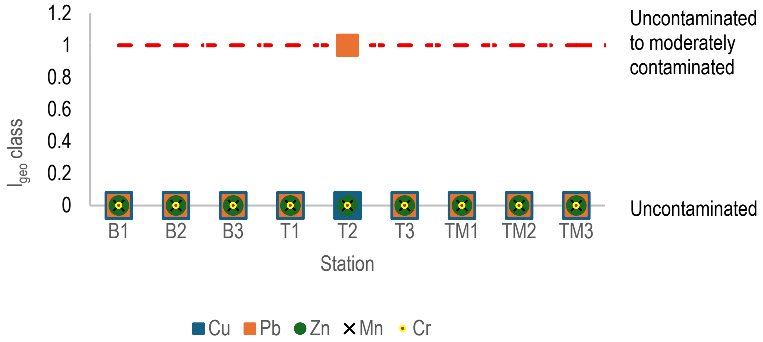

Figure 2: The class of I_{geo} at each station.

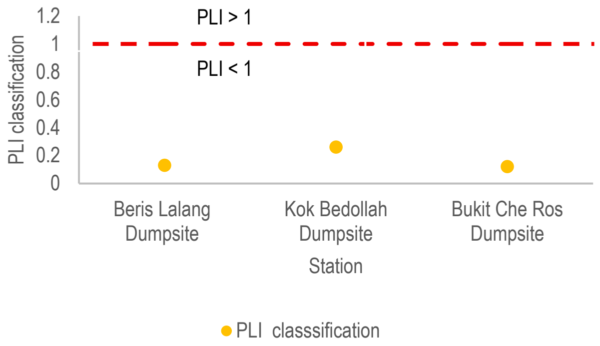

Figure 3: The class of PLI at each station.

4. CONCLUSION

This study provides vital insights into the level of heavy metal contamination at three municipal dumpsites in Kelantan, Malaysia which are Beris Lalang Dumpsite, Kok Bedollah Dumpsite and Bukit Che Ros Dumpsite through concentration profiling and pollution index assessments. Particularly for concentration profiling the elements were copper (Cu), chromium (Cr), zinc (Zn), manganese (Mn) and lead (Pb) and for the pollution index assessments are Geo-accumulation Index (I_{geo}) and Pollution Load Index (PLI).

The mean concentration at Beris Lalang Dumpsite as following order Cu > Cr > Zn > Mn > Pb while Kok Bedollah Dumpsite were Mn > Zn > Cu > Pb > Cr and Bukit Che Ros Dumpsite were Zn > Cu > Cr > Mn > Pb. The mean concentrations of Cu, Pb, Zn, Mn and Cr showed significant regional variation with Kok Bedollah Dumpsite appearing as the most harmed site due to its longer operating lifespan and higher cumulative waste load.

The assessments of the Geo-accumulation Index (I_{geo}) and the Pollution Load Index (PLI) provided a more nuanced understanding of contamination status. I_{geo} results primarily indicated uncontaminated soils (Class 0) except for lead (Pb) at station T2 (Kok Bedollah Dumpsite) which reached Class 1 (uncontaminated to moderately contaminated). Similarly, PLI results for all three dumpsites remained below the 1.0 threshold that indicates that those dumpsites are unpolluted. These findings indicate that environmental quality is currently manageable, but these dumpsites also indicate early signs of localized accumulation particularly for legacy contaminants like lead.

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