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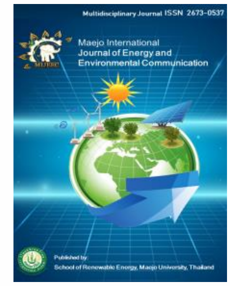

ARTICLE

Heavy metals concentration in undisturbed peat soil at Pekan District, Pahang, West Malaysia

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ABSTRACT

Soil is a mixture of various materials such as air, water, and organic matter. Soft soil (peat) has very deprived physical properties such as low shear strength, high moisture content, high compressibility, and permeability. In an engineering perspective it is considered as a weak soil, while an the agricultural context it is considered as a rich soil because of high amount of carbon. Heavy metals such as arsenic, chromium, cadmium, and lead are considered highly toxic, and it may produce mutagenic, carcinogenic, and genotoxic effects. This study examined the heavy metals concentration of peat soil. There were nine peat samples collected from three different sites which are Kampung Bahru (KB), Kampung Lancang I (KL I), and Kampung Lancang II (KL II), Pekan district, Pahang State, Malaysia. This research indicated that the average organic content were 97.8 % for KB, 95.88 % for KL I, and 98.48 % for KL II approximately for peat soil. It concluded that the concentration of As, Cu, Ni, Pb, and Zn exceeded the standard guidelines, and Mg concentration was observed below the recommended guidelines. It is essential to extract these metals and further assess their toxicological impact on the environment and human health.

1. Introduction

Soil is the combination of various complex, heterogeneous, accumulated different heavy metals due to its tendency to connect and attach several metals (Palansooriya et al., 2020). These elements persist in the soil in different shapes, surrounded by various forces (Umeh et al., 2020). There are multiple types of heavy metals found everywhere in the environment, such as soil, water, sediments, and plants (Appiah et al., 2019; Bhuyar, 2017).

However, soils having various chemical properties due to different formation conditions (Umeh et al., 2020). The toxic heavy metals concentration in agricultural soil is high because using other pesticides as fertilizers reduces food value and crop production, impacting the food chain, human health, and environmental quality (Wuana et al., 2014; Bhuyar et al., 2021).

As a nutrient, mostly the metals are essential in a low quantity, it acts as a cofactor and is involved in enzymatic and metabolic activities. Nevertheless, in all living organisms, including humans, animals, plants, and microorganisms, the large quantities of these metals can become strongly inhibiting. Few

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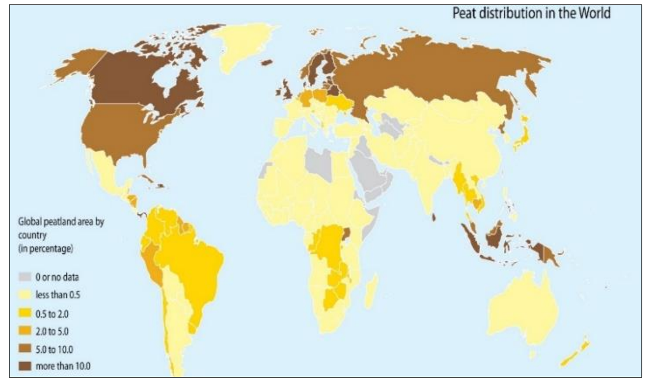
essential metals such as cadmium (Cd), arsenic (As), and mercury (Hg) are considered extremely toxic even at low concentrations (Mishra et al., 2019; Riser-Roberts et al., 2020). When a high concentration of heavy metals is accumulated in the soil, it may affect plants' productivity and fertility. Such toxic heavy metals may also transfer through air, water, and bioaccumulate for a long period (Aslam et al., 2019; Anning et al., 2021; Mishra et al., 2019). The accumulation of toxic metals in the human body creates several health issues, including carcinogenesis, neuromuscular defects, metals illness, growth, failure of metabolic activities, and development abnormalities (Chandra et al., 2011; Husain, 2019; Liu, 2011).

1.1. Peat soil distribution-globally

Generally, peat soil is found in all tropical parts of the globe (Abdel-Salam, 2018; Leng et al., 2019). Peat soil almost covers about 0.5 billion hectares (0.5×108 km2) 0r 4.0 % of the world's whole land, while about 95% of the peat has existed in the northern hemisphere, around 20.3% (36.9 million ha) of this area exist in Asia. There are two countries in the world with having a considerable amount of peat are present such as Canada contains about (170 mh) million hectares while Russia comprises approximately (150 mh) (Leng et al.2019; Rahgozar & Saberian 2015); the distribution of peatland worldwide can be seen in Figure 1 and Table 1.

Figure 1 The global peat-land distribution (Holden et al., 2018).



1.2. Peat soil distribution locally

Peat soil is considered a significant soil group that covers around 8% or 3 million hectares of Malaysia's total land. At the same time, Sarawak state comprises the largest peatland area, which covers about 1.66 million, Peninsular Malaysia about (0.98 m/ha) and Sabah state encompass (0.80 m/ha) peatland as can be seen in Figure 2 (Melling, 2016).

Table 1 The peatland distribution worldwide (Frolking et al., 2011; Xu et al., 2018).

Continents	Countries	Total land area(km2)	Peatland area(km2)
North America	Canada	9,084,977	1,132,614
	USA	9,161,923	197,841
	Other	6,462,100	8866
	Total	24,709,000	1,339,321
Asia	Russia (Asian part)	9,784,930	1,180,358
	Indonesia	1,811,569	148,331
	Malaysia	328,657	22,398
	China	9,326,410	136,963
	Other	23,327,434	135,132
	Total	44,579,000	1,623,182
Europe	Russia, (European parts)	6,592,812	185,809
	Sweden	410,335	60,819
	Finland	303,815	71,911
	UK	241,930	22,052
	Ireland	68,883	22,052
	Others	2,562,225	16,575
	Total	2,562,225	171,171
South America	Total	17,840,000	485,832
Africa	Total	30,370,000	187,061
Oceania	Total	7,692,024	68,636
Global	Total	148,647,000	4,232,369

Figure 2 The peatland in Malaysia (Melling, 2016).

1.3. Chemical properties of Malaysian peat

1.3.1. pH

The pH is the chemical characteristics that reveal the acidity or alkalinity of the soil. It shows the hydrogen ion concentration. Generally, a more excellent hydrogen ion concentration solution signifies a lower pH value. Hence a lower pH value retains the higher acidic nature. The peat acidity depends on the rocks, the plant's nature, oxygen supply, and humic acid concentration. The average pH value of several peat types varies from 3.2 to 7.2 (Kazemian et al., 2012; Paul et al., 2018). The lowest pH of Malaysian peat soil was measured at about 3.0, while the highest pH value was recorded at about 4.8 (Wahab et al., 2018; Adnan Zainorabidin & Mohamad 2017).

1.3.2. Heavy metals in soil

The distribution of different heavy metals such as Zn, Pb, Mn, Mg, Ar, Au, Co, and Cu has been investigated in several kinds of soil (Huang et al., 2020; Rao et al., 2018; Zhou et al., 2018 The extent of heavy metals was detected in a reduced fraction of soil particles (Rao et al., 2018). The heavy metals in the soil such as zinc (Zn), nickel (Ni), lead (Pb), copper (Cu), chromium (Cr), cadmium (Cd), arsenic (As), manganese (Mn), tin (Sn), silver, mercury (Hg), and vanadium (V) has been broadly stated by researchers and these heavy metals directed to growing apprehensions about the severe harmful impact on living organisms including humans (Li et al., 2015; Palansooriya et al., 2020; Wang et al., 2018).

1.3.3. Heavy metals in peat soil

Peat accumulates 100% unpolluted organic matter, comprising more than 65% organic material and less than 35% mineral content. The distribution of significant elements in peat soil such as (Si, Al, Na, K, Mg, Ca) and trace metals (Ni, V, Cr, Fe, Mn, Cu, U, Zn, Pb) are described, and factors affecting their extraction are analyzed. Heavy metals such as Pb, Cd, Cu, and Cr can affect human health (Y.M. Liu et al., 2020). Some hazardous metals such as As, Cd, Cr, Cu, Ni, Pb, Zn, and Hg have been considered a serious threat to the environment and are creating consistent problematic pollutants in the ecosystem (Belkin et al., 2008; Liu et al., 2020; Saikia et al., 2014). Additionally, the contaminants mentioned above are a serious threat to the health of humans and animals and the food chain through bio-accumulation (Ali et al., 2020; Liu et al., 2020; Nabulo et al., 2010; Pruvot et al., 2006).

1.3.4. Impact on human health and environment

There are several health effects of metal toxicities in the body. The body organs such as the brain, kidney, liver, lungs, and blood can directly affect heavy metals and change their effectiveness. It can cause a critical chronic effect on the human body. Its long-term effect can seriously damage muscular, physical and neurological degenerative processes that affect Parkinson's disease, multiple sclerosis, muscular dystrophy and Alzheimer's disease.The joint research of Institute for Health Metrics and Evaluation and World Health Organization reported that about 494,550 deaths and around 9.3 million people were disabled due to long-term lead (Pb) exposure of humans (Palansooriya et al., 2020). Throughout the prior decade, arsenic (As) poisoning, which negatively impacted health, has been reported in Bangladesh. Among the 125 million population countries, about 35 to 77 million people have been affected, which marked the largest mass poisoning by contamination in human history worldwide (Shakoor et al., 2019; Smith et al., 2000).

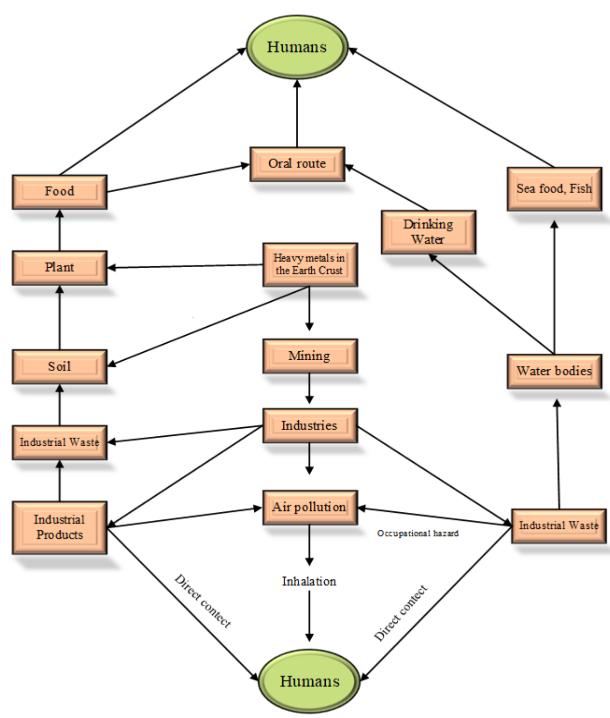


Figure 3 Mechanisms of heavy metal intoxication in humans (modified) (Engwa et al., 2019).

The joint research of Institute for Health Metrics and Evaluation and World Health Organization reported that about 494,550 deaths and around 9.3 million people were disabled due to long-term lead (Pb) exposure of humans (Palansooriya et al., 2020). Some heavy metals such as arsenic, nickel and cadmium may cause cancer, cardiovascular and neurological diseases (Caffo et al., 2014; Engwa et al., 2019; Hemdan et al., 2007). Figure 3 summarized the various mechanisms of heavy metal intoxication.

1.3.5. Heavy metals impact the economy

Minerals resources plays an vital role in mining sector growth and economy of every country. In the Malaysian national economy, the mineral resources such as gold, bauxite, clays, barite, tin, copper, lead, zinc, iron, manganese, and arsenic have played a significant role in mineral production even through the exploitation of some metals that had significantly decreased (Kusin et al., 2017).

2. Materials and Methods

2.1. Site description

West Malaysia is located in the tropical terrain between the latitudes of 1°N and 7°N and longitudes of 100°E–103°E. This region has an equatorial climate with consistently high temperatures, high humidity, comparatively light winds, and abundant rainfall throughout the year (Suhaila & Yusop 2018). Malaysia features a tropical rainforest climate with heavy rainfall throughout the year (Tan et al., 2020). The coasts usually have a sunny climate with temperatures ranging from 23 to 32 °C (Suhaila & Yusop 2018), humidity is the range between 70% to 90% (Tangang et al., 2012). The weather is affected by the north-eastern and south-western monsoons with the tropical wind that alternates during the whole year. The wind direction in inter-monsoon is changeable, and the average rainfall in the Pekan district in 2019 measured 27.63 mm (Adilah et al., 2020).

The Pekan district is located about 35 km from Kuantan, the capital city of Pahang state, Malaysia. Several industrial enterprises are in Pekan, including defence & security manufacturing division plant (Malaysia's largest military vehicle manufacturer), automotive plants, oil & gas, food, and woodworking industries.

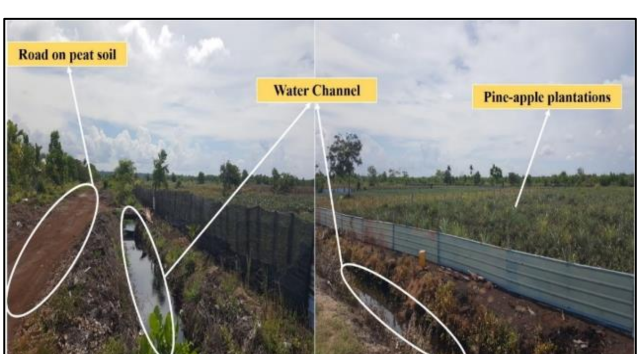


Figure 4 The surface topography of Pekan peat soil.

The Pekan area is comprised of a massive amount of swamp forest, including the Nenasi, Resak, Rompin, and Endau Swamp Forest in the southeastern Pahang State, stretches south from Kuantan to the Pahang-Johor border and extending some 40 km inland from the coast. Several rivers drain the forests in the Pekan area, such as Sungai Endau, Sungai Rompin, Sungai Pahang, Sungai Bebar, and Sungai Merchong River. The lower reaches of the rivers are brackish and acidic in peat areas. Pekan area is most familiar with several types of agricultural activities such as palm oil, pineapple, and banana plantation, which are the most common plantation in the area, as shown in Figure 4.

2.2. Field sampling and sampling preparation

Three sampling sites were precisely identified by a Garmin GPSMAP 64csx in the Pekan area, namely Kampung Bahru, Kampung Lancang I, and Kampung Lancang II, as shown in Figure 5 and the co-ordination as tabulated in Table 2. Three soil specimens were collected from each location involved in the agricultural activity. A manual sampling method was applied for accumulating peat specimens in a range of 20 - 60 cm depth of the topsoil. The steel measurement scale was used to ensure the depth measurement for the samples began at the top of the soil horizon using mattock and a stainless-steel shovel. The plant structures such as roots and wood are easily recognizable in the peat soil samples. The specimens were stored in a polyethylene bag to avoid any characterization loss, and the samples were brought back to the laboratory for analysis. Initially, the soil specimens were air-dried, passed through a 2 mm sieve to separate the coarse sediments, pebbles, roots, plant remains other unwanted materials, and subsamples were further ground to pass through a 0.25 mm sieve as shown in Figure 6 (a).

Some soil properties such as shear strength, moisture content, liquid limit, organic content, and degree of humification were existed to observe the peat's geotechnical properties. An Optima8000 (ICP-OES, model; Perkin Elmer) was applied for the elemental analysis to detect the heavy metals concentration in peat soil. An 18.2 MΩ deionized pure water treatment system (Millipore, USA) was used to prepare a deionized liquid sample.

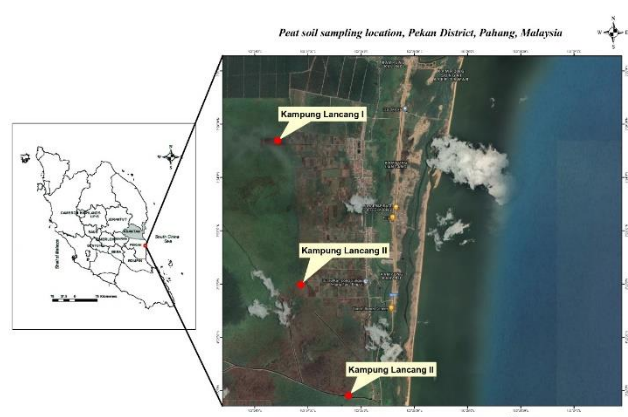


Figure 5 Sampling points (Malaysia Soil Map, 1970).

The soil sample of about 0.5 g (with an accuracy of 0.0001 g) was weighed and kept in a 50 mL Teflon vessel, as shown in Figure 6 (b). The concentrated nitric acid approximately (8 mL) and hydrofluoric acid (4 mL) were mixed. The closed vessel was placed in a microwave oven-assisted sample digestion system.

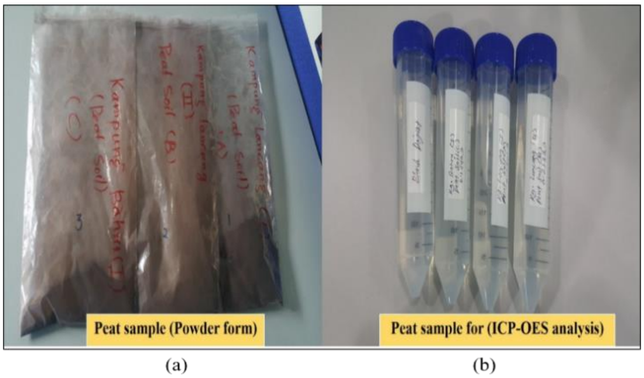


Figure 6 The peat sample for ICP-OES analysis.

Table 2. The GPS co-ordination of sampling locations.

Peat sampling location	GPS Co-ordination
Kampung Bahru	3°24'30. 0" N, 103°41'84. 37" E
Kampung Lancang I	3°24'18. 05" N, 103 °41'08. 25" E
Kampung Lancang II	3°23'49. 05" N, 103°41'51. 39" E

3. Results and Discussion

3.1. Chemical properties of peat soil

The elemental composition of peat soil was observed, followed by ICP-OES analysis, which shows the heavy metals concentration in peat soil. The high concentration of heavy metals is considered critical for influencing the potential impact on ecosystems, human health, and sustainable environmental protection (Kusin et al., 2018). Figure 7 shows the mean heavy metals concentration in the Pekan peat soil was detected to be in the order of As > Cu > Ni > Pb > Zn > Fe > Mn > Co. The concentration of As, Co, Ni, Pb, and Zn was present in higher peat soil concentrations. At the same time, Mn, Fe, and Co were present in low concentration to the Canadian Council of Ministers of Environment (2009), Interim Sediment Quality Guidelines (ISQG), Soil Quality Guidelines (SQG), Pre-Industrial Level, predicted effect level (PEL), Threshold effect level (TEL), and Crust Courage recommended standard value. Table 3 summarizes the concentration of the above-mentioned heavy metals in the peat soil of the Pekan district.

3.2. pH

The pH was observed for all three investigated sites. It was observed that the peat soils were very acidic with soil pH in the range of 3.1 and 3.93, whereas for Kampung Bahru peat soil, the pH was measured 3.2 and 3.6 for Kampung Lancang I while it was observed 3.8 for Kampung Lancang II peat soil. The pH for Sarawak peat soil is in the range of 3.23 and 3.40; the author declared that Sarawak peat contains high acidity level (Abat et al., 2012), while (Wahab et al., 2018; Adnan Zainorabidin & Mohamad 2017) indicated the lowest pH of Malaysian peat is 3.0, and 4.8 was the highest pH of Malaysian peat soil.

3.3. Arsenic (As)

A high concentration of arsenic was observed where the concentration of Kampung Bahru peat soil was 149.342 mg/kg Kampung Lancang I peat soil was 153.375 mg/kg. It was observed 152.829 mg/kg for Kampung Lancang II peat soil, and the arsenic value was exceeded the recommended guidelines value, which is 11 mg/kg recommended by the Canadian Council of Ministers of Environment (2009), 20 mg/kg recommended by the Australian Department of Environmental and Conservation (2010) and 12 mg/kg suggested by the SQG Soil Quality Guidelines. It may affect human health because its value is exceeded.

3.4. Copper (Cu)

The concentration for copper in peat soil was observed exceeded the recommended guidelines where Kampung Bahru peat soil indicates 159.573 mg/kg, Kampung Lancang I peat soil was 150.472 mg/kg, and it was observed 117.918 mg/kg for Kampung Lancang peat soil while CCME (2009) suggested standards are 63 mg/kg, ADEC 2009 recommended value is 100 mg/kg, and SQG for copper in the soil is 63 mg/kg. The copper value was also exceeded the recommended guidelines. The concentration of Cu in peat soil was investigated in between 44 mg/kg to 200 mg/kg in the depth of 15 to 30 cm (Sullivan et al., 2013), while (Abat et al., 2012) concluded that the concentration of Cu in Loagan Bunut National Park, Sarawak is in range of 016 mg/kg which consider the lowest concentration range the in peat soil.

3.5. Nickel (Ni)

The nickel concentration was also measured significantly higher than the recommended value. The concentration of Ni was observed 91.597 mg/kg for Kampung Bahru peat soil, where for Kampung Lancang I peat soil, the value was recorded 86.395 mg/kg and similarly it was observed 112.839 mg/kg for Kampung Lancang II peat soil while according to CCME (2009) the standard value for Ni in the soil is 37 mg/kg and ADEC 2009 suggested 50 mg/kg and Soil Quality Guidelines was also recommended 50 mg/kg. According to the mentioned standard, it has been concluded that the Ni concentration was also high, and it exceeded the guidelines, which may affect the ecosystem and human health.

3.6. Lead (Pb)

The concentration of lead was measured likewise exceeded, then proposed value where the Kampung Bahru peat soil contains 89 mg/kg, 101 mg/kg for Kampung Lancang I and it was observed 94 mg/kg for Kampung Lancang II peat soil while the recommended value is in between 45 to 70 mg/kg suggested by

CCME (2009) and SQG. It was analyzed that the lead concentration was higher than the suggested value, which may cause some environmental issues or human health issues. (Graham et al., 2006) demonstrated the concentration of lead in Scotland peat soil is in 11.4 g/ha-1 and (Rothwell et al., 2008) investigated the concentration of lead in peat soil from Peak District National Park, southern Pennines, UK is in between 4.43 mg/kg to 145 mg/kg.

3.7. Zinc (Zn)

The zinc concentration was also studied, and it was observed that zinc intensity was found in all three investigated sites where the concentration of zinc was 135 mg/kg in Kampung Bahru peat soil, 179 mg/kg for Kampung Lancang I, and it was examined 322 mg/kg in Kampung Lancang II peat soil. It concluded that the investigated amount is lower than standard except Kampung Lancang II peat soil while the suggested value is (200-290 mg/kg) recommended by the Canadian Council of Ministers of Environment (2009) and Australian Dept of Environmental and Conservation (2010). (Rothwell et al., 2008) studied the concentration of Zn in peat soil, which was ranged from 20 to 60 mg/kg. The authors (Sullivan et al., 2013) concluded that Zn's concentration in peat soil is 250 mg kg, in the standard value range. Zn's concentration in Loagan Bunut National Park, Sarawak peat soil, ranges from 1.70 mg/kg to 10.97 mg/kg (Abat et al., 2012).

3.8. Iron (Fe)

The Pekan peat soil comprises of iron concentration as well, but in the deceased form (lower than recommended value), where the concentration of iron was observed 4198 mg/kg in Kampung Bahru peat soil, 3107 mg/kg in Kampung Lancang I peat soil, and 7901 mg/kg in Kampung Lancang II peat soil. The recommended value for Fe by Crust Courage Martínez et al., 2020) is 50,000 mg/kg.

3.9. Manganese (Mn)

The manganese concentration was observed lower than the standard value; the concentration of Mn in Kampung Bahru peat was 111.439 mg/kg, 131.238 mg/kg for Kampung Lancang I peat, and it was examined 151.232 mg/kg for Kampung Lancang II peat soil where the recommended value by Australian Dept. of Environmental and Conservation (2010) for Mn was 500 mg/kg. (Sypalov et al., 2020) studied the chemistry of peat soil in Russia; his result indicated that Mn concentration in Russian peat was between 5 to 60 mg/kg.

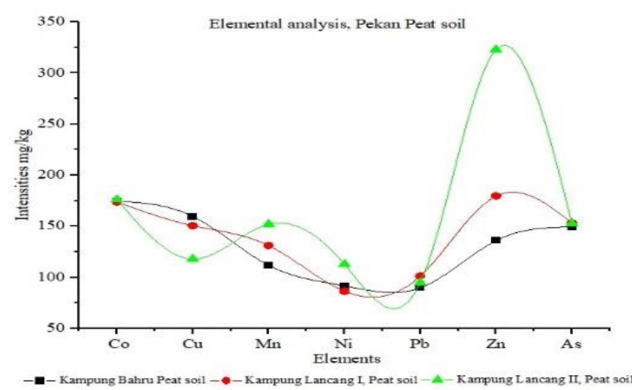


Figure 7 The heavy metals concentration in peat soil.

Table 3 The heavy metals concentration and its recommended value.

Location	Heavy Metals Concentration (mg/kg)							
	As	Cu	Ni	Pb	Zn	Mn	Fe	Co
Kampung Baharu	149.342	159.573	91.579	89.738	135.873	111.737	4198	74.348
Kampung Lancang I	153.375	150.472	86.395	101.302	179.637	131.073	3107	73.892
Kampung Lancang II	152.829	117.918	112.839	94.81	322.908	151.928	7901	76.385
Recommended value (mg/kg)								
Canadian Council of Ministers of Environment (2009)	59	35.7	37	35	123	-	-	-
Soil Quality Guidelines (SQG)	50	70	50	200	63	-	-	-
International Standard Quality Guidelines (*ISQG*) low	8	65	-	75	200	-	-	-
International Standard Quality Guidelines (*ISQG*) high	70	270	-	218	270	-	-	-
Pre-Industrial Level	15	70	80	175	50	-	-	-
Predicted effect level (PEL)	17	197	-	91.3	315	400	-	-
Threshold effect level (TEL)	5.9	36.7	18	35	123	-	-	-
Crust Courage Martínez et al. 2020)	18	70	80	13	132	950	50,000	38

4. Conclusion

The authors would like to acknowledge his appreciation to Institute of Postgraduate Studies (IPS), Universiti Malaysia Pahang for providing financial assistance (Doctoral Research Scheme, DRS) and all the facilities to ensure this research's success, gratitude also goes to those who assisted directly and indirectly. The authors would like to acknowledge his appreciation to Institute of Postgraduate Studies (IPS), Universiti Malaysia Pahang for providing financial assistance (Doctoral Research Scheme, DRS) and all the facilities to ensure this research's success, gratitude also goes to those who assisted directly and indirectly.

Future recommendation

Moreover, the heavy metals concentration exceeded the standard except for Mn, Fe, and Co. It is essential to be extracted the exceeded metals for long-term effect, and further assessment is needed to determine the impact of these elements on human health and the environment.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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References

Abat, M., McLaughlin, M. J., Kirby, J. K., & Stacey, S. P. (2012). Adsorption and desorption of copper and zinc in tropical peat soils of Sarawak, Malaysia. Geoderma, 175, 58-63.

Abdel-Salam, A. E. (2018). Stabilization of peat soil using locally admixture. HBRC Journal, 14(3), 294-299.

Adilah, A. N., Zarif, M. M., & Idris, A. M. (2020). Rainfall Trend Analysis using Box Plot Method: Case Study UMP Campus Gambang and Pekan. Paper presented at the IOP Conference Series: Materials Science and Engineering.

Appiah-Adjei, E. K., Baidu, E. E., Adjei, K. A., & Nkansah, M. A. (2019). Potential heavy metal pollution of soils from artisanal automobile workshops: the case of Suame Magazine, Ghana. Environmental Earth Sciences, 78(3), 62.

Aslam, F., Yasmin, A., & Sohail, S. J. I. M. (2019). Bioaccumulation of lead, chromium, and nickel by bacteria from three different genera isolated from industrial effluent. 1-9.

Atlas, R. M. (1998). Microbial ecology: fundamentals and applications: Pearson Education India.

Belkin, H. E., Zheng, B., Zhou, D., & Finkelman, R. B. (2008). Chronic arsenic poisoning from domestic combustion of coal in rural China: A case study of the relationship between earth materials and human health. In Environmental Geochemistry (pp. 401-420): Elsevier.

Bhuyar, P. (2017). Isolation, Partial Purification and Characterization of Protease Enzyme from Proteolytic Bacteria from Dairy Soil. Int J Res Appl Sci Eng Technol, 5, 4083-4095.

Bhuyar, P., Farez, F., Pragas Maniam, G., & Govindan, N. (2021). Removal of nitrogen and phosphorus from agro-industrial wastewater by using microalgae collected from coastal region of peninsular Malaysia. African Journal of Biological Sciences, 3(1), 58-66.

Bradl, H. B. (2004). Adsorption of heavy metal ions on soils and soils constituents. Journal of colloid and interface science, 277(1), 1-18.

Caffo, M., Caruso, G., La Fata, G., Barresi, V., Visalli, M., Venza, M., & Venza, I. J. C. G. (2014). Heavy metals and epigenetic alterations in brain tumors. 15(6), 457-463.

Cardwell, A., Hawker, D., & Greenway, M. (2002). Metal accumulation in aquatic macrophytes from southeast Queensland, Australia. Chemosphere, 48(7), 653-663.

Chandra, R., Bharagava, R. N., Kapley, A., & Purohit, H. J. J. B. t. (2011). Bacterial diversity, organic pollutants and their metabolites in two aeration lagoons of common effluent treatment plant (CETP) during the degradation and detoxification of tannery wastewater. 102(3), 2333-2341.

Deeb, B. E., & Altalhi, A. D. J. A. J. B. B. (2009). Degradative plasmid and heavy metal resistance plasmid naturally coexist in phenol and cyanide assimilating bacteria. 5(2), 84-93.

Dong, W. Q. Y., Cui, Y., & Liu, X. (2001). Instances of soil and crop heavy metal contamination in China. Soil and Sediment Contamination, 10(5), 497-510.

Dube, A., Zbytniewski, R., Kowalkowski, T., Cukrowska, E., & Buszewski, B. (2001). Adsorption and migration of heavy metals in soil. Polish journal of environmental studies, 10(1), 1-10.

Engwa, G. A., Ferdinand, P. U., Nwalo, F. N., & Unachukwu, M. N. (2019). Mechanism and health effects of heavy metal toxicity in humans. In Poisoning in the Modern World-New Tricks for an Old Dog? : IntechOpen.

Frolking, S., Talbot, J., Jones, M. C., Treat, C. C., Kauffman, J. B., Tuittila, E.-S., & Roulet, N. J. E. R. (2011). Peatlands in the Earth's 21st century climate system. 19(NA), 371-396.

Funakawa, S., Yonebayashi, K., Shoon, J. F., Khun, E. C. O. J. S. S., & Nutrition, P. (1996). Nutritional environment of tropical peat soils in Sarawak, Malaysia based on soil solution composition. 42(4), 833-843.

Graham, M. C., Vinogradoff, S. I., Chipchase, A. J., Dunn, S. M., Bacon, J. R., & Farmer, J. G. (2006). Using size fractionation and Pb isotopes to study Pb transport in the waters of an organic-rich upland catchment. Environmental science & technology, 40(4), 1250-1256.

Hemdan, N. Y., Emmrich, F., Faber, S., Lehmann, J., & Sack, U. J. A. o. t. N. Y. A. o. S. (2007). Alterations of TH1/TH2 reactivity by heavy metals: possible consequences include induction of autoimmune diseases. 1109(1), 129-137.

Huang, B., Yuan, Z., Li, D., Zheng, M., Nie, X., & Liao, Y. (2020).

Effects of soil particle size on the adsorption, distribution, and migration behaviors of heavy metal (loid) s in soil: a review. Environmental Science: Processes & Impacts, 22(8), 1596-1615.

Husain, Q. (2019). Remediation of phenolic compounds from polluted water by immobilized peroxidases. In Emerging and Eco-Friendly Approaches for Waste Management (pp. 329-358): Springer.

Järup, L. J. B. m. b. (2003). Hazards of heavy metal contamination. 68(1), 167-182.

Kazemian, S., Huat, B. B., & Moayedi, H. (2012). Undrained shear characteristics of tropical peat reinforced with cement stabilized soil column. Geotechnical and Geological Engineering, 30(4), 753-759.

Kusin, F. M., Abd Rahman, M. S., Madzin, Z., Jusop, S., Mohamat-Yusuff, F., & Ariffin, M. (2017). The occurrence and potential ecological risk assessment of bauxite mine-impacted water and sediments in Kuantan, Pahang, Malaysia. Environmental Science and Pollution Research, 24(2), 1306-1321.

Kusin, F. M., Azani, N. N. M., Hasan, S. N. M. S., & Sulong, N. A. (2018). Distribution of heavy metals and metalloid in surface sediments of heavily-mined area for bauxite ore in Pengerang, Malaysia and associated risk assessment. Catena, 165, 454-464.

Leng, L. Y., Ahmed, O. H., & Jalloh, M. B. (2019). Brief review on climate change and tropical peatlands. Geoscience Frontiers, 10(2), 373-380.

Li, N., Kang, Y., Pan, W., Zeng, L., Zhang, Q., & Luo, J. (2015). Concentration and transportation of heavy metals in vegetables and risk assessment of human exposure to bioaccessible heavy metals in soil near a waste-incinerator site, South China. Science of the total environment, 521, 144-151.

Liu, X., Shi, H., Bai, Z., Zhou, W., Liu, K., Wang, M., & He, Y. (2020). Heavy metal concentrations of soils near the large opencast coal mine pits in China. Chemosphere, 244, 125360.

Liu, Y.-M., Liu, D.-Y., Zhang, W., Chen, X.-X., Zhao, Q.-Y., Chen, X.-P., & Zou, C.-Q. (2020). Health risk assessment of heavy metals (Zn, Cu, Cd, Pb, As and Cr) in wheat grain receiving repeated Zn fertilizers. Environmental Pollution, 257, 113581.

Melling, L. (2016). Peatland in Malaysia. In Tropical Peatland Ecosystems (pp. 59-73): Springer.

Mishra, S., Bharagava, R. N., More, N., Yadav, A., Zainith, S., Mani, S., & Chowdhary, P. (2019). Heavy metal contamination: an alarming threat to environment and human health. In Environmental biotechnology: For sustainable future (pp. 103-125): Springer.

Nabulo, G., Young, S., & Black, C. (2010). Assessing risk to human health from tropical leafy vegetables grown on contaminated urban soils. Science of the total environment, 408(22), 5338-5351.

Palansooriya, K. N., Shaheen, S. M., Chen, S. S., Tsang, D. C., Hashimoto, Y., Hou, D., . . . Ok, Y. S. (2020). Soil amendments for immobilization of potentially toxic elements in contaminated soils: a critical review. Environment international, 134, 105046.

Paul, A., Hussain, M., & Ramu, B. (2018). The physicochemical properties and microstructural characteristics of peat and their correlations: reappraisal. International Journal of Geotechnical Engineering, 1-12.

Pruvot, C., Douay, F., Hervé, F., & Waterlot, C. (2006). Heavy metals in soil, crops and grass as a source of human exposure in the former mining areas (6 pp). Journal of soils and sediments, 6(4), 215-220.

Rahgozar, M., & Saberian, M. (2015). Physical and chemical properties of two Iranian peat types. Mires and Peat, 16(07), 1-17.

Rao, Z.-X., Huang, D.-Y., Wu, J.-S., Zhu, Q.-H., Zhu, H.-H., Xu, C., . . . Duan, M.-M. (2018). Distribution and availability of cadmium in profile and aggregates of a paddy soil with 30-year fertilization and its impact on Cd accumulation in rice plant. Environmental Pollution, 239, 198-204.

Riser-Roberts, E. (2020). Remediation of petroleum contaminated soils: biological, physical, and chemical processes: CRC press.

Rothwell, J. J., Evans, M. G., Daniels, S. M., & Allott, T. E. (2008). Peat soils as a source of lead contamination to upland fluvial systems. Environmental Pollution, 153(3), 582-589.

Rothwell, J. J., Evans, M. G., Daniels, S. M., & Allott, T. E. J. E. P. (2008). Peat soils as a source of lead contamination to upland fluvial systems. 153(3), 582-589.

Saikia, B. K., Ward, C. R., Oliveira, M. L., Hower, J. C., Baruah, B. P., Braga, M., & Silva, L. F. (2014). Geochemistry and nano-mineralogy of two medium-sulfur northeast Indian coals. International Journal of Coal Geology, 121, 26-34.

Shakoor, M. B., Niazi, N. K., Bibi, I., Shahid, M., Saqib, Z. A., Nawaz, M. F., . . . Bundschuh, J. (2019). Exploring the arsenic removal potential of various biosorbents from water. Environment international, 123, 567-579.

Smith, A. H., Lingas, E. O., & Rahman, M. (2000). Contamination of drinking-water by arsenic in Bangladesh: a public health emergency. Bulletin of the World Health Organization, 78, 1093-1103.

Smith, K. S., & Huyck, H. L. (1999). An overview of the abundance, relative mobility, bioavailability, and human toxicity of metals. The environmental geochemistry of mineral deposits, 6, 29-70.

Suhaila, J., & Yusop, Z. (2018). Trend analysis and change point detection of annual and seasonal temperature series in Peninsular Malaysia. Meteorology and Atmospheric Physics, 130(5), 565-581.

Sullivan, T. S., McBride, M. B., & Thies, J. E. (2013). Soil bacterial and archaeal community composition reflects high spatial heterogeneity of pH, bioavailable Zn, and Cu in a metalliferous peat soil. Soil Biology and Biochemistry, 66, 102-109.

Sypalov, S., Kozhevnikov, A. Y., Ivanchenko, N., Popova, Y. A., & Sobolev, N. (2020). Assessment of Peat Pollution by Heavy Metals Depending on the Depth of Occurrence. Solid Fuel Chemistry, 54(1), 32-36.

Tan, M. L., Juneng, L., Tangang, F. T., Chung, J. X., & Radin Firdaus, R. Changes in Temperature Extremes and Their Relationship with ENSO in Malaysia from 1985 to 2018. International Journal of Climatology.

Tangang, F. T., Juneng, L., Salimun, E., Sei, K., & Halimatun, M. (2012). Climate change and variability over Malaysia: gaps in science and research information. Sains Malaysiana, 41(11), 1355-1366.

Thiele, D. J. W. (1995). Metal detoxification in eukaryotic cells. Crisp

Data Base of National Institute of Health.

Umeh, C., Asegbeloyin, J. N., Akpomie, K. G., Oyeka, E. E., & Ochonogor, A. E. (2020). Adsorption properties of tropical soils from Awka north Anambra Nigeria for lead and cadmium ions from aqueous media. Chemistry Africa, 3(1), 199-210.

Wang, L., Chen, L., Tsang, D. C., Li, J.-S., Baek, K., Hou, D., . . . Poon, C.-S. (2018). Recycling dredged sediment into fill materials, partition blocks, and paving blocks: Technical and economic assessment. Journal of Cleaner Production, 199, 69-76.

Wuana, R. A., Okieimen, F. E., & Vesuwe, R. N. (2014). Mixed contaminant interactions in soil: Implications for bioavailability, risk assessment and remediation. African Journal of Environmental Science and Technology, 8(12), 691-706.

Xu, J., Morris, P. J., Liu, J., & Holden, J. J. C. (2018). PEATMAP: Refining estimates of global peatland distribution based on a meta-analysis. 160, 134-140.

Zainorabidin, A., & Bakar, I. (2003). Engineering properties of in-situ and modified hemic peat soil in Western Johor. Paper presented at the Proceedings of 2nd International Conference on Advances in Soft Soil Engineering and Technology.

Zainorabidin, A., & Mohamad, H. M. (2017). Engineering properties of integrated tropical peat soil in Malaysia. Electronic Journal of Geotechnical Engineering, 22(02), 457-466.

Zhou, T., Wu, L., Luo, Y., & Christie, P. (2018). Effects of organic matter fraction and compositional changes on distribution of cadmium and zinc in long-term polluted paddy soils. Environmental Pollution, 232, 514-522.

Wahab, A., Embong, Z., Naseem, A. A., Madun, A., Zainorabidin, A., & Kumar, V. (2018). The Effect of Electrokinetic Stabilization (EKS) on Peat Soil Properties at Parit Botak area, Batu Pahat, Johor, Malaysia. Indian Journal of Science and Technology, 11(44), 1-12.