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Heavy Metals in Soil of the Tropical Climate Bauxite Mining Area in Malaysia

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ABSTRACT: *Deposited soil around the stockpile and bauxite mining area in Kuantan, Pahang, Malaysia was measured for heavy metal contents with X-ray fluorescence (XRF) technique and 36 elements were detected. The concentrations of non-carcinogenic elements in descending order are: iron (Fe) > silicon (Si) > titanium (Ti) > calcium (Ca) > manganese (Mn) > barium (Ba) > molybdenum (Mo) > zinc (Zn) > mercury (Hg). Carcinogenic elements were chromium (Cr) > nickel (Ni) > lead (Pb) > arsenic (As) > cadmium (Cd) > selenium (Se). Other traces elements with prominent value were praseodymium (Pr) > vanadium (V) > cerium (Ce) > neodymium (Nd) > hafnium (Hf) > and yttrium (Y). These elements were mainly derived from the crustal mineral, mine waste or residues as well as dust and aerosol emission from the extraction, transportation and deposited of soil particles in the mining area.*

Keywords: Bauxite, heavy metals, mining, soil, XRF, carcinogenic elements

1. INTRODUCTION

Bauxite is a reddish clay with a pisolitic structure, earthy lustre and a low specific gravity.[1] It is an ore form leached of other soluble materials from severely weathered rocks in a wet tropical and sub-tropical climate.[2] In tropical regions, lateritic bauxite or silicate bauxites ores are largely formed by the weathering process of silicate rocks and these ores contain the highest concentration of aluminium.[1] The continuing demand for mineral supply has spurred the mining industry in Malaysia, with bauxite mining one of those in the metallic mineral sector.[3] The 18,000 ha area in Kuantan, Pahang is heavily mined for bauxite (found 1 m or 2 m below the soil layer) and this area is occupied with basalt composed of Al_2O_3 (12%–13%), Fe_2O_3 (3%–6%), FeO (7%–8%), TiO_2 (1%–2%), Cr_2O_3 (0.02%) and NiO (0.01%).[4–6] The soil of Kuantan Series contains gibbsite, i.e., $Al(OH)_3$ mixed with goethite (FeOOH), kaolin and hematite (Fe_2O_3) that produce the red colour in the soil.[7,8] Detrimental environmental impacts from mining activities varied depending on mining technique, meteorological and geological conditions.[9,10] Recent environmental degradation and the potential impact to public health have triggered this study to measure the heavy metal contents in the soil samples from the mining area as the basis to validate the health risk concern.

2. EXPERIMENTAL

This study was performed in Kuantan, Pahang (latitude 3° 45' 0" N and longitude 102° 30' 0" E), a growing hub for trade and commerce in Malaysia (Figure 1). Bauxite mining has started in this area since 2014.[11] Soil sampling was done at 40 sampling stations in the mining area (Bukit Goh) and the stockpile area (Kuantan Port, KP) where the ore deposits are stored before being exported to China. The sampling was done during the temporary cessation period from December 2015 to February 2016. Heavy metal contents were measured using high definition X-ray fluorescence (HDXRF) HD Rocksand XOS's (Model 800701-01). A reference material representative of samples analysed, the National Institute of Standards and Technology (NIST) is used for establishing and monitoring the stability and precision of an analytical measurement system. The percentage of recoveries for the metals studied ranged between 80% and 120%. A duplicate analysis of a sample was performed periodically to ensure precision of the sample analysis.[12,13] Data were analysed with SPSS Statistics software.

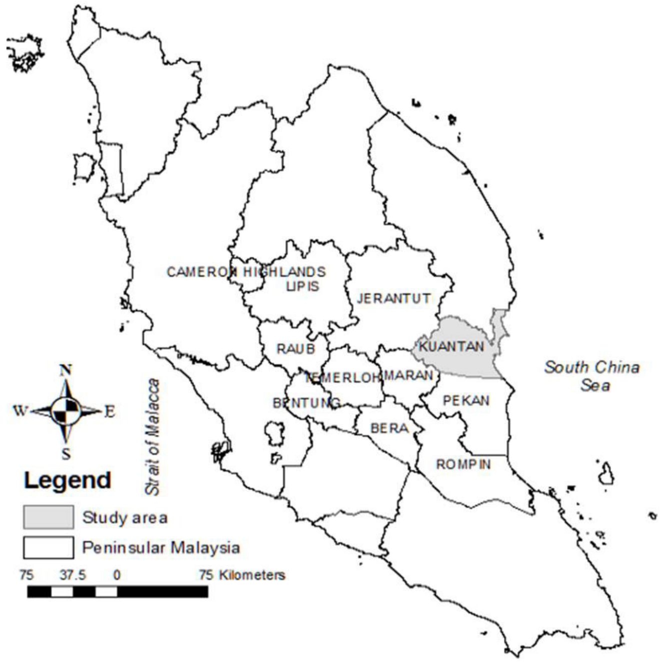

Figure 1: Map showing the location of the study area, a bauxite mining area in Kuantan, Pahang, located at the central of Peninsular Malaysia.

3. RESULTS AND DISCUSSION

Table 1 presents the concentration of elements detected in the soil samples. Elements detected were divided into three categories, namely: (1) elements that can cause cancer or carcinogenic health effects; (2) elements that cause non-carcinogenic health effects such as irritation, respiratory problems, kidney problem, etc.; and (3) elements that have not been reported of their concern to human health or tracers. Most of the elements were higher in the stockpile area compared with the mining site. Elements that can cause carcinogenic health effects were detected in the soil samples as follow: chromium (Cr) > lead (Pb) > nickel (Ni) > arsenic (As) > cadmium (Cd) > selenium (Se). Most prominent elements that can cause non-carcinogenic health effects detected were iron (Fe) > calcium (Ca) > manganese (Mn) > barium (Ba) > molybdenum (Mo) > zinc (Zn) > mercury (Hg). Other traces elements highly detected in the samples were silicon (Si) > titanium (Ti) > praseodymium (Pr) > vanadium (V) > cerium (Ce) > neodymium (Nd). The heavy metal concentrations in this study exceed the Dutch soil standards and higher than reported in most of the previous studies.

Past studies have reported that heavy metals in the soil dust and aerosol emission resulted from the mining operations.[11,14] Metal dust transportation from the mine wastes, along with the prevailing wind direction cause particle grain deposited and segregated in the soil which produce contamination in the study area.[14–17] Wind erosion and heavy rainfalls have greater impact in the dispersion of metals in soils and cause the dispersion of materials from tailing impoundments into their surroundings of the stockpile area.[17] Finer particle size fraction produced during mining travels at greater distance in the environment.[18,19] Previous studies also reported that the crustal minerals contribute 33% to the total trace metals concentration into the atmosphere, followed by the suspended mine waste dust (32%) and mixture of industrial or fuel-oil combustion and secondary inorganic compounds from the regional ore (25%).[14]

Elements Bi, As, Cu, Pb, Cd, Zn and Sb detected in this study were derived from pyrite-bearing materials and mine soils.[20] Mn and Nd were the silicate mineral related to bauxite mining while Cr, V, Ti and Fe were derived from Kuantan basalt. Fe is attributed to the iron oxides minerals soil of the Kuantan series that contains gibbsite ($Al(OH)_3$) mixed of goethite (FeOOH), hematite (Fe_2O_3) and kaolin.[5–8] Ti, V, Fe K, Zr, Zn and Ca are derived from the parent rocks in the upper continental crust, the elements of the silicate particles minerals resulting from the process of soil extraction in bauxite Kuantan mining area.[14] Zn was also reported extremely high in soil around mining areas and smelters in Austria (8900 mg kg^{-1}), Greece (10,547 mg kg^{-1}) and Poland (1062 mg kg^{-1}).[21,22] Ca presence in sedimentary rocks in the minerals include calcite, dolomite ($CaMg(CO_3)_2$) and gypsum ($CaSO_4$ H_2O). It is greatly dispersed and has a major influence on the pH of soils. Mo, Ce and Rb are mainly regarded as crustal minerals from the mining process. Mo also is a primary ore deposit and a by-product of copper mines.[21] Cerium (Ce) is a lanthaniides (LA), a rare earth element (REE) which occurs naturally in the earth's crust and incorporated in relatively common minerals such as monazite, bastnaside, cheralite and xenotime, and is also often associated with phosphatic rocks resulted in elevated Ce in phosphorus fertilisers. Meanwhile, Rubidium (Rb) is considered to be a dispersed element from the mining process.[23] Agriculture activity and palm oil plantation in the study area also may contribute to the enrichment of these metals in soil from the use of fertilisers.[11,19]

Physicochemical factors also contribute to high metal enrichment in the soil. For example, soil pH plays an important role in metal mobility such as Pb, low mobility in neutral or alkaline soils due to the formation of insoluble salts, while As, Cu and Zn, have greater mobility, due to the relative solubility of the complexes formed in neutral or alkaline soils.[20]

Table 1: Concentration of elements that can cause carcinogenic health risk (ppm) in soil samples (N = 40).

Elements	Bukit Goh (*n* = 20)				Kuantan Port (*n* = 20)			
	No. of samples detected	Mean	Std. dev	Range	No. of samples detected	Mean	Std. dev	Range
Elements with carcinogenic health risk effect								
Cr	20	480.30	61.47	357–634	20	465.35	144.37	176–703
Ni	20	87.30	52.88	50–238	20	65.94	18.29	30–115
Pb	19	44.76	22.63	9–114	20	108.06	78.88	28–336
As	13	10.52	6.84	4–30	18	25.17	37.49	2–143
Cd	3	3.63	0.49	3–4	12	4.61	0.78	4–6
Se	13	1.87	0.28	1–2	5	2.04	0.21	2–2
Elements with non-carcinogenic health risk effect								
Fe	20	164,771.65	23,987.08	120,072–225,986	20	194,912.75	30,229.31	103,813–246,323
Mn	20	641.10	129.77	431–1022	20	1,551.65	954.83	524–4582
Mo	20	597.95	82.05	445–757	20	546.40	79.08	370–650
Sr	20	34.83	10.77	13.50–53.70	20	43.00	26.24	25.50–141.00
Sn	11	33.72	17.71	14.60–69.60	14	66.26	58.02	15.80–205.00
Tl	15	3.60	0.56	2.40–4.50	17	4.76	1.17	3.20–7.30
Ca	20	4,672.35	4,042.28	367–16,949	20	2,564.55	1,953.92	409–7,347
Ba	13	695.08	164.68	408–886	16	1,260.88	1,523.29	510–6903
Cu	20	90.86	25.00	66.5–154	20	100.09	32.79	57.70–206.00
Hg	3	1.97	0.21	1.8–2.2	3	2.63	0.40	2.20–3.00
Zn	20	171.80	63.17	105–354	20	212.90	97.76	93.90–503.00
Ag	3	5.50	0.52	5.20–6.10	4	5.58	0.35	5.20–6.00

(*continued on next page*)

Table 1: (*Continued*).

Elements	Bukit Goh ($n = 20$)				Kuantan Port ($n = 20$)			
	No. of samples detected	Mean	Std. dev	Range	No. of samples detected	Mean	Std. dev	Range
Elements considered as tracers								
Si	6	160,170.50	41,784.34	86,031–197,889	12	159,239.25	49,229.02	86,127–285,259
Ti	20	26,740.40	3,485.32	20,976–32,780	20	21,827.75	8,062.05	7,670–36,259
K	17	3,841.82	2,325.47	158–7,688	20	3,528.95	2,746.68	445–12,076
V	20	524.35	71.00	372–640	20	442.30	153.79	168–741
Pr	20	457.70	82.69	321–619	17	534.29	37.77	468–605
Zr	20	412.35	109.98	280–637	20	392.30	123.03	251–721
Ce	20	165.60	38.78	101–256	20	222.95	70.70	128–364
Nd	15	127.03	34.13	80.80–209	16	202.94	79.88	101–411
Hf	20	80.32	13.89.917	66.60–119	20	91.24	18.78	33.90–130
Ga	20	44.12	6.98	35.50–60.60	20	46.22	9.42	29.30–66.90
Rb	16	38.18	20.24	7.50–72.30	16	24.09	23.41	4.10–98.80
W	20	31.30	6.80	14.10–38.10	19	39.75	12.26	9.40–64.40
Y	20	22.91	11.87	9.60–45.60	20	31.16	14.84	9.20–52.50
Br	19	8.52	2.71	4.20–15.40	16	8.66	1.93	5.40–14.10
Rh	5	6.12	1.29	4.80–7.80	7	5.21	0.891	4.10–6.60
Bi	9	5.19	1.54	3.70–8.80	15	12.15	12.35	5.20–55.30
Pd	12	5.19	0.93	4–6	15	5.69	0.86	4.20–6.90
Ge	15	2.01	0.58	1.20–3.50	15	1.95	0.640	1.10–3.20

Note: BDL = below detection limit

4. CONCLUSION

The analysis has detected 36 elements in the soil samples from the bauxite mining area where most of the elements were highly detected in the stockpile area. The elements were derived from the crustal mineral, mine waste or residues as well as dust and aerosol emission from the extraction, transportation and deposited of soil particles in the mining area. Further assessment is needed to determine the contribution of these elements to human health.

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