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Impact of Bauxite Mining on Heavy Metal Levels in Kara Kara Blue Lake and Associated Active Tailing Pond

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Authors' contributions

This work was carried out in collaboration among all authors. Author MA did the data curation, formal analysis, investigation, writing- original draft. Author JKM did the conceptualization, supervision, review & editing. Author KH did the formal analysis, supervision, investigation. All authors read and approved the final manuscript.

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ABSTRACT

Bauxite exploration and production have significant negative impacts on ecological systems, primarily due to the high distribution of heavy metals in the environment. Post-bauxite mining reclamation efforts are most times inadequate. As a result, some abandoned pit mines have turned into lakes, now used for recreational activities. This study examines the heavy metal distribution in two locations affected by bauxite mining: the recreational Kara-Kara Blue Lake (BL) and the active Tailing Pond (TP). Using X-ray fluorescence, ten sediment samples from these sites were analysed for metals such as Al, Co, Cd, Cr, Cu, Fe, Mg, Mo, Ni, Pb, Ti, and Zn. Data analysis was conducted

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using Microsoft Excel, SPSS, and JASP software. The heavy metals in the Tailing Pond demonstrated a decreasing sequence of Fe > Ti > Al > Mn > Ni > Cd > Co > Cr > Zn > Pb > Mo > Cu, while in Blue Lake, the order was Ti > Fe > Mn > Co > Cr > Cd > Ni > Mo > Zn > Pb > Cu > Al. The study employed the Contamination Factor (CF) and Pollution Load Index (PLI) to evaluate pollution levels, revealing higher contaminant levels in the tailings pond than in Blue Lake, with PLI values of 1.06 and 0.83, respectively. Although Blue Lake appears relatively unpolluted and suitable for recreation, both lakes' elevated Ni, Cd, and Cr levels necessitate continuous monitoring to mitigate long-term exposure risks.

Keywords: Bauxite; heavy metal; Kara-kara Blue Lake; Tailing Pond; Contamination Factor (CF); Pollution Load Index (PLI).

ABBREVIATIONS

CF : Contamination Factor
PLI : Pollution Load Index
BL : Blue Lake
TP : Tailing Pond
DSP : Digital Signal Processor
XRP : X-Ray Fluorescence
ppm : Parts per Million

1. INTRODUCTION

Throughout the years, the mining industry in South America, particularly in Guyana, has undergone significant developments, playing a pivotal role in the local economy by providing numerous jobs and generating substantial profits, primarily due to its success in bauxite production [1,2]. However, this growth has been marred by environmental concerns, as insufficient monitoring and management of mining operations have led to considerable ecological damage, altering the environment's physical, chemical, and biological integrity. Bauxite, a rock rich in aluminum hydroxide minerals such as gibbsite and boehmite, is at the heart of this industry [3,4].

The history of bauxite mining in Guyana dates back to 1917, with the industry booming post-World War I as global aluminum demand soared. By World War II, Guyana's production escalated from 4,200 tons to 29,000 tons, driven by continued demand and subsequent advancements in mining technology and infrastructure [5]. The detailed exploration history and contributions of entities like Scotia exploration underscore the pivotal role of this sector in Guyana’s economy [6]. However, the emergence of Jamaica as a significant player in the bauxite market introduced competition.

Between 1990 and 2000, Guyana experienced state ownership of the bauxite industry, a period of economic significance, albeit with challenges. The bauxite mining sector is acknowledged for contributing substantially to the country's economic stability and employment landscape. Environmental issues have become prominent, particularly in transforming mined-out areas into lakes and waste disposal sites, which are now part of the local community's recreational landscape. These pit lakes, often characterized by their blue color, do not directly impact residents through water consumption but present indirect health risks due to potential toxic metal exposure from prolonged contact.

Bauxite mines are formed in countries that are in the Sub tropic and tropical regions of the world that experience heavy rainfall, the most important geological process that must occur is extensive weathering. These are referred to as the residual deposits. The three main processes that aided in the distribution of these metals are erosion, chemical weathering, and deposition. Erosion allows the material to be transported from one location to another where it can be deposited. In both study areas, there is active erosion at a slow rate, which enables the movement of these heavy metals at different locations. This geological process is not as dominant as chemical weathering, but it causes the surface to be more prone to chemical weathering. Chemical weathering is the chemical breakdown of rocks, changing the composition of the rocks through hydrolysis, oxidation, hydration, and carbonation [7]. The geomicrobiological aspects of bauxite deposits are crucial for understanding the ecological dynamics of mined areas. Microbial activities can significantly influence the geochemical properties and reclamation potentials of bauxite residues. Studies, such as those by [8], have shown that microbial populations in bauxite deposits play a role in the biogeochemical cycles that affect the stability and contamination risks of these mining environments.

This research intends to comprehensively evaluate the environmental and health impacts of bauxite mining by focusing on analyzing heavy metals in two specific regions. The aim is to assess the level of metal contamination and its potential health ramifications, thereby offering insight into the broader ecological changes induced by mining activities and their implications for the local ecosystem.

2. GEOLOGY

The Guiana Shield lies between the Orinoco and Amazon Rivers, covering an area of 1.6 million km2, extending to Suriname, French Guiana, Venezuela, Brazil, and Colombia [9]. Belonging to the Quaternary period, the bauxite deposits in Guyana span approximately 300 km in a north-to-southeast direction [10]. It has a width ranging from 25 to 40 km and is situated 96 km away from the coast. The Bauxite Belt (Kwakwani–Linden) has seven main groups and comprises of six formations. The main tectonic processes responsible for the stratigraphy of the Bauxite Belt are uplift and subsidence. The formation of the Guyana Bauxite Belt from (base to top) is as follows: The Mombaka Formation is a clay and sandy clay composition overlain by the Akyma Formation. This formation is primarily made up of kaolin, which is overlain by the Montogomery formation. The Montogomery Formation comprises of sands, sandy clay, kaolinitic clay, and lignite bands. It is overlain by a succession of white sand, clay, and sandy clay known as the Mackenzie Formation. The Coropina Formation, composed of red loam and marked by fluvial deposits, overlays the Mackenzie Formation at the base area, which is reworked kaolinitic clay. The Demerara formation is the youngest succession overlying the Mackenzie formation and is predominantly grey silt and clay, with a lacustrine and fluvial depositional environment. The bauxite belt is a succession of meta-sediments and migmatite [11]. The seven main groups of the Bauxite Belt are Pomeroon, Essequibo or Bartica, Demerara or Mackenzie, Ituni, Berbice or Kwakwani, Canje and Tarakuli-Orealla.

"The bauxite deposits in Suriname and Demerara, as documented by [12], provide a historical context to the extensive bauxite mining activities in the region. These deposits have been a significant part of the local economies since the early 20th century, reflecting similar geological formations and mining developments as those in Guyana.

2.1 Location of Study Area

Linden is the second largest town in Guyana, located in the tenth administrative region (Upper Demerara – Upper Berbice), about 101 kilometers (63 miles) from the capital, Georgetown (Figs. 1 and 2). The town is divided into shores by the Demerara River – the Mackenzie and Wismar shores [13]. Study area 1 is the tailings pond located in the Industrial Area, Mackenzie. Study area 2 is the NE Kara Kara Blue Lake in Kara Kara Mackenzie.

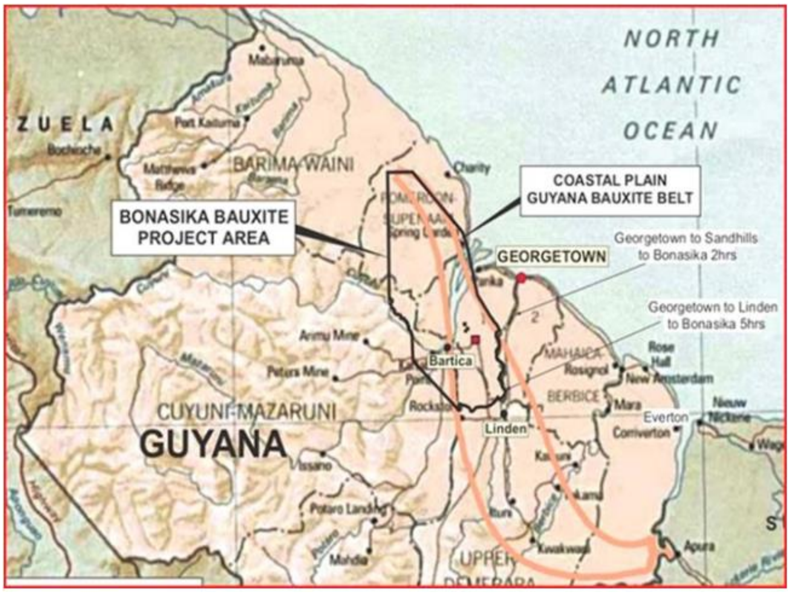

Fig. 1. Location map of the Bauxite Belt extension in the North of Guyana [11]

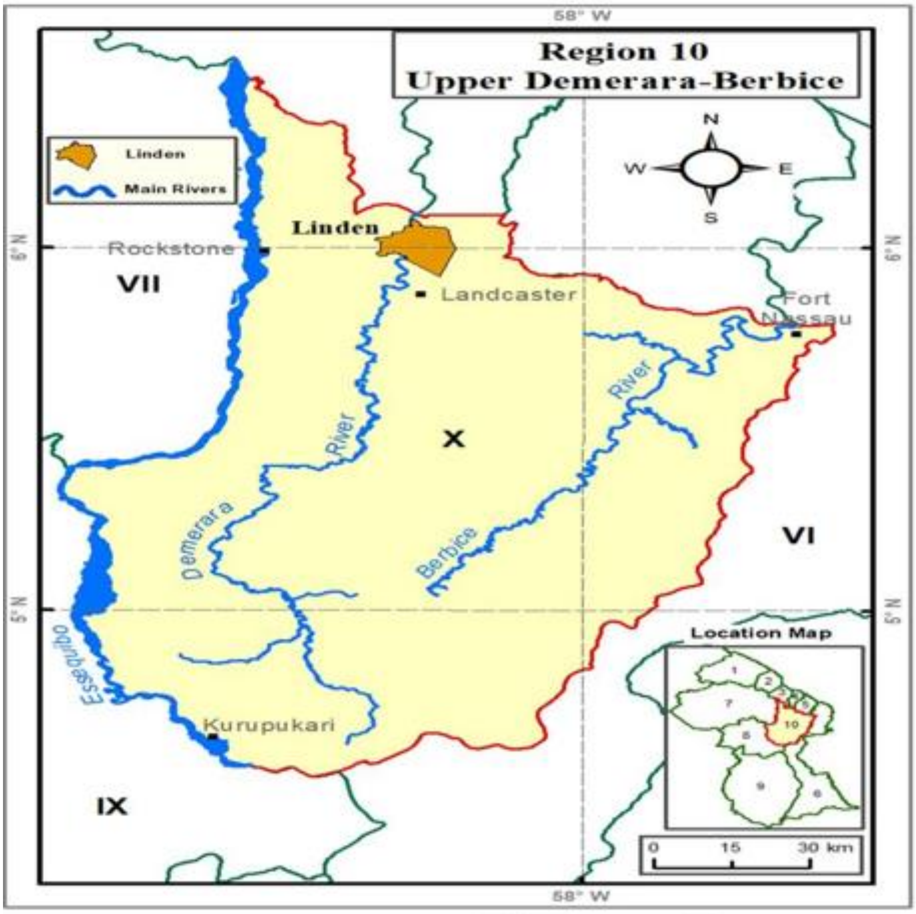

Fig. 2. Map of Upper Demerara Upper Berbice showing the location of Linden [14]

The two locations resulting from bauxite mining in the Linden region were subject to geochemical sampling. The first sample area, situated at coordinates 5059'58.52 N58017'42.14" W, covers an estimated area of 190,000m^2. The second sample area, located at 6000'10.49" N 58016'21.32" W, encompasses an estimated area of about 450,000 m^2, as seen in Fig. 3. The active tailing pond, characterized by a brownish hue, consists of fine sand and clay. Conversely, the NE KaraKara mined-out region predominantly comprises sand ranging from fine to coarse grains.

3. METHOD OF STUDY

3.1 Sample Collection

Location 1: Samples were collected from shallower areas of the tailings pond at Location 1. Five (5) random sample areas were chosen. These samples were placed into tightly sealed and labeled ziplock bags.

Location 2: To access the NE Kara Kara Mined out area, also known as Linden Blue Lake, boat transportation was necessary due to its significant size (over 25 meters) and depth (exceeding 14 meters). An Acoustic Doppler Current Profiler was used to study the lake. This device measured water velocity throughout the water column and was attached to the boat using a 2-meter rope to prevent any interference with the engine. The profiler was connected to a laptop to record various data like lake depth, distance, speed, and time. A Van Veen Grab Sampler was utilized to sample the lakebed. The sampler was suspended from the boat with a 15- meter rope and lowered into the lake. Once it reached the lake bottom, the sampler's mouth stayed open as the locking mechanism secured sediment samples. The sampler was then retrieved by pulling the rope and collecting the samples. A total of five ziplock bags were labeled and stored, each representing a specific location like Blue Lake or S1.

Fig. 3. Aerial view of study area & sample locations: Active Tailings Pond & Blue Lake

3.2 X-ray Fluorescent Analysis

The X-ray fluorescence analysis was conducted at the Guyana Geology and Mines Commission Pet lab. The analysis utilizes drying ovens, crushers, XRF nitrogen analyzers, and a computer system. The process begins with fluorescent X-rays entering the detector, generating electronic pulses. The preamp amplifies these pulses and transmits them to the Digital Signal Processor (DSP). The DSP collects and digitizes the X-ray events, sending spectral data to the Computer System, which conducts the analysis and generates results [15].
Preparation:

- Transfer samples from ziplock bags to pans and place them in the Drying oven at 100°C to remove moisture.
- Crush dried samples that are more significant than 3 cm in the crusher to a size of 2 mm or less.
- Homogenize and split crushed particles with sizes of 2 mm or less to obtain aliquots of 30 grams.
- Pulverize aliquots weighing 30 grams and send them for XRF analysis.

XRF Procedure:

- Calibrate the XRF Niton Analyzer following guidelines for XRF analysis.
- Set each sample relative to the XRF machine for analysis.
- Input resultant data into the computer system.

4. DATA ANALYSIS

This study used Descriptive Statistical Analysis and Multivariate Analysis to explore the distribution and relationships of heavy metals under investigation. Descriptive analyses were employed to effectively illustrate and summarize data, aiding in identifying patterns and trends, as well as assessing different data conditions—an essential aspect of Statistical Analysis. Critical components of descriptive analysis include distribution (examining data frequencies visually), central tendency (calculating the mean, mode, and median), and variation (evaluating data dispersion). Analysis for normality was conducted to determine whether the dataset originated from a population with a standard or non-normal distribution, with descriptive statistics serving to confirm distribution normality. The statistical software utilized for these analyses was the JASP version (0.17.1.0).

Multivariate Statistical methods were used to understand the relationships among more than two variables while considering their interconnections. Pearson Correlation Analysis was employed in this study to measure the linear

Table 1. XRF analysis results for heavy metals

Sample Identity	Sample Type	Mo PPM	Pb PPM	Zn PPM	Cu PPM	Ni PPM	Co PPM	Fe PPM	Mn PPM	Cr PPM	Ti PPM	Cd PPM	Al PPM
KH SO-1	Slurry	35.31	13.34	47.31	52.5	367.15	187.48	4290.82	1087.88	6.04	914.04	180	0
KH SO-2	Slurry	12.37	16.66	18.29	14.48	0	0	15126.7	134.65	124.2	12300.82	22.59	4010.55
KH SO-4	Slurry	11.75	34.3	18.26	0	98.4	159.41	3963.97	321.57	0	1608.95	63.64	0
KH SO-5	Slurry	6.89	26.28	13.05	22.36	50.71	0	18789.33	110.48	212.91	15495.92	0	5068.14
KH SO-6	Slurry	27.31	10.46	18.01	0	90.21	107.19	573.42	400.28	0	4.88	190.91	0
KH BL-1	Slurry	23.12	10.35	36.31	33.1	52.15	98.75	4035.82	972.88	19.4	414.04	96.3	0
KH BL-2	Slurry	16.8	6.66	7.29	12.9	35	75.98	2259	19.65	114	11800.82	74.2	0
KH BL-3	Slurry	14.5	24.3	7.26	0	63.4	87.86	3708.97	206.57	74.15	1108.95	55.2	0
KH BL-4	Slurry	6.9	16.28	2.05	0	15.71	100.32	1738.86	15.48	138.12	14995.92	49.53	0
KH BL-5	Slurry	2.9	0.46	7.01	7.8	55.21	77.19	318.42	285.28	87.5	495	84.9	0

Table 2. Statistical parameters results from the Tailings Pond

Descriptive Statistics Tailings Pond	PPM	Mo	Pb	Zn	Cu	Ni	Co	Fe	Mn	Cr	Ti	Cd	Al
Mean	PPM	18.7	20.2	23.0	17.9	121.3	90.8	8548.2	411.0	68.6	6064.9	91.3	1815.7
Mode	PPM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Median	PPM	12.4	16.7	18.3	14.5	90.2	107.2	4290.8	321.6	6.0	1609.0	63.6	0.0
Min	PPM	6.9	10.5	13.1	0.0	0.0	0.0	573.4	110.5	0.0	4.9	0.0	0.0
Max	PPM	35.3	34.3	47.3	52.5	367.2	187.5	18786.3	1087.9	212.9	15495.9	190.3	5068.1
Standard Deviation	PPM	12.0	9.9	13.8	21.6	142.9	87.8	7918.9	397.8	96.5	7261.9	88.7	2514.3
Skewness	PPM	0.7	0.7	2.1	1.2	1.8	-0.2	0.6	1.7	1.1	0.7	0.3	0.7
Percentile 25%	PPM	11.8	13.3	18.0	0.0	50.7	0.0	3964.0	134.7	0.0	914.0	22.6	0.0
Percentile 75%	PPM	27.3	26.3	18.3	22.4	98.4	159.4	15126.7	400.3	124.2	12300.8	180.0	4010.6
Percentile 90%	PPM	32.1	31.1	35.7	40.4	259.7	176.3	17322.5	812.8	177.4	14217.9	186.2	4645.1
Percentile 95%	PPM	33.7	32.7	41.5	46.5	313.4	181.9	18054.4	950.4	195.2	14856.9	188.2	4856.6
Percentile 99%	PPM	35.0	34.0	46.1	51.3	356.4	186.4	18639.9	1060.4	209.4	15368.1	189.9	5025.8

Table 3. Statistical parameters result from NE Kara Kara Blue Lake

Descriptive Statistics Blue Lake	PPM	Mo	Pb	Zn	Cu	Ni	Co	Fe	Mn	Cr	Ti	Cd	Al
Mean	PPM	12.8	11.6	12.0	10.8	44.3	88.0	2412.2	300.0	86.6	5762.9	72.0	0.0
Mode	PPM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Median	PPM	14.5	10.4	7.3	7.8	52.2	87.9	2259.0	206.6	87.5	1109.0	74.2	0.0
Min	PPM	2.9	0.5	2.1	0.0	15.7	76.0	318.4	15.5	19.4	414.0	49.5	0.0
Max	PPM	23.1	24.3	36.3	33.1	63.4	100.3	4035.8	972.9	138.1	14995.9	96.3	0.0
Standard Deviation	PPM	8.0	9.1	13.8	13.6	19.0	11.5	1514.8	394.1	44.9	7066.2	19.7	0.0
Skewness	PPM	0.0	0.3	2.1	1.4	-0.9	0.0	-0.4	1.8	-0.7	0.7	0.0	0.0
Percentile 25%	PPM	6.9	6.7	7.0	0.0	35.0	77.2	1738.9	19.7	74.2	495.0	55.2	0.0
Percentile 75%	PPM	16.8	16.3	7.3	12.9	55.2	98.8	3709.0	285.3	114.0	11800.8	84.9	0.0
Percentile 90%	PPM	20.6	21.1	24.7	25.0	60.1	99.7	3905.1	697.8	128.5	13717.9	91.7	0.0
Percentile 95%	PPM	21.9	22.7	30.5	29.1	61.8	100.0	3970.5	835.4	133.3	14356.9	94.0	0.0
Percentile 99%	PPM	22.9	24.0	35.1	32.3	63.1	100.3	4022.7	945.4	137.2	14868.1	95.8	0.0

relationship between variables, a technique introduced by Karl Pearson based on an idea by Francis Galton [16]. This method, commonly used for numerical variables, assigns a value between 0 and 1, with 0 representing no correlation, 1 indicating complete positive correlation, and -1 denoting total negative correlation. For example, a correlation coefficient of 0.7 between two variables indicates a solid and positive relationship between them. In cases of positive correlation, an increase in variable A corresponds to an increase in variable B, and vice versa for negative correlation. IBM SPSS Version l was used for Pearson Correlation analysis, while JASP version (0.17.1.0) was used for additional statistical tests.

The Table 1 depicts the results of the X-ray analysis for the retrieved samples. Ten (10) samples were retrieved, and all were analyzed for the same group of heavy metals to determine the concentration levels further. Each sample depicted a range of metal distribution at the various locations; iron and titanium showed high concentration levels in samples extracted from the Blue Lake and Tailings Pond.

Tables 2 and 3 show the results achieved using descriptive statistical parameters to assess and determine the distribution of the heavy metals for the samples. The following values were identified: mean, mode, median, minimum, maximum, standard deviation, skewness, and percentile. Most values obtained from the Tailings Pond were higher than those obtained from Blue Lake. The mean concentration level of Al in the Tailings Pond was 1815.74 ppm versus 0.00 ppm achieved at Blue Lake. The mean concentration level of iron was 8548 ppm and 2412.21 ppm for the Tailings Pond and the Blue Lake, respectively.

5. RESULTS AND DISCUSSION

5.1 Concentration Level of Heavy Metals in the Study Areas

The earth's crust is dominated by aluminum, the most plentiful metallic element, usually found as oxide fixed in rocks, mostly igneous rocks, within the earth's crust. However, aluminum levels in the study areas are generally lower than their average presence in the crust, as indicated in Tables 2 and 3. For instance, the mean concentration in sample TP was 1815.74 ppm, while sample BL showed no detectable Aluminum which is lower than the average presence in the earth’s crust [8]. Molybdenum is widespread in the environment due to natural processes like oxidation and human activities such as industrial and agricultural processes. Research shows that Molybdenum makes up roughly 1.5 ppm of the earth's crust. In the study areas, the mean concentrations of Mo were 18.73 ppm in sample TP and 12.84 ppm in sample BL, surpassing the crustal distribution.

Cobalt exists in the earth's crust only as a chemical compound, constituting about 30 ppm of the crust. Nevertheless, oxygen and chlorine in the atmosphere limit its free formation. Co concentration results in the Tailings Pond and Blue Lake exceeded 50% of the mean crustal abundance, with mean levels of 90.82 ppm and 88.02 ppm, respectively. Nickel, another transition element, is typically found in the environment at low levels, often alongside other minerals like iron and cobalt. Nickel distribution in soils and sediments can range from 0.2 ppm to 450 ppm, with a crustal abundance of 22 ppm. In the study areas, mean levels of Nickel were measured at 121.29 ppm and 44.29 ppm, surpassing the crustal concentration. Notably, the mean level in the Active Tailings Pond exceeded that of Blue Lake by over 70%.

Lead is considered toxic and non-essential, mainly originating from human activities. Though naturally occurring in the earth's crust at 14 ppm, the mean concentration values in the study areas were 20.21 ppm in TP and 12.84 ppm in BL. Manganese makes up 1000 ppm of the earth's crust. Human activities can increase its environmental presence. However, concentrations of Mn in the study areas were lower than their crustal distribution at mean levels of 410.97 ppm in TP and 299.97 ppm in BL.

Zinc, ranked as the 24th most abundant element in the earth's crust, comprises 75 ppm of its composition. Zinc is commonly found in ores alongside other base metals like copper and lead. Mean concentrations of Zn in the study areas were below the earth's crust average, measuring 22.98 ppm in TP and 11.98 ppm in BL. Chromium, a hard steel-gray metal with an atomic number of 24 and an atomic weight of 51.99, comprises nearly 100 ppm of the earth's crust. It enters the environment through erosion of chromium-bearing rocks and volcanic eruptions, with human activities sometimes enhancing its levels. Concentrations of Cr in the study areas were below the average crustal value.

The average concentration of heavy metals in the Tailings Pond significantly exceeded that in Blue Lake. The Tailings Pond, designed to store waste from bauxite mining activities by Bosai Mineral Group, exhibited lower Cr levels than Blue Lake, possibly due to increased human activity at the lake for recreational purposes. Sediment metal concentrations in the Tailings Pond followed the order Fe > Ti > Al > Mn > Ni > Cd > Co > Cr > Zn > Pb > Mo > Cu, while in Blue Lake, they were Ti > Fe > Mn > Co > Cr > Cd > Ni > Mo > Zn > Pb > Cu > Al. This variation indicates differences in the chemical composition due to the history and development of the NE Kara Kara mine.

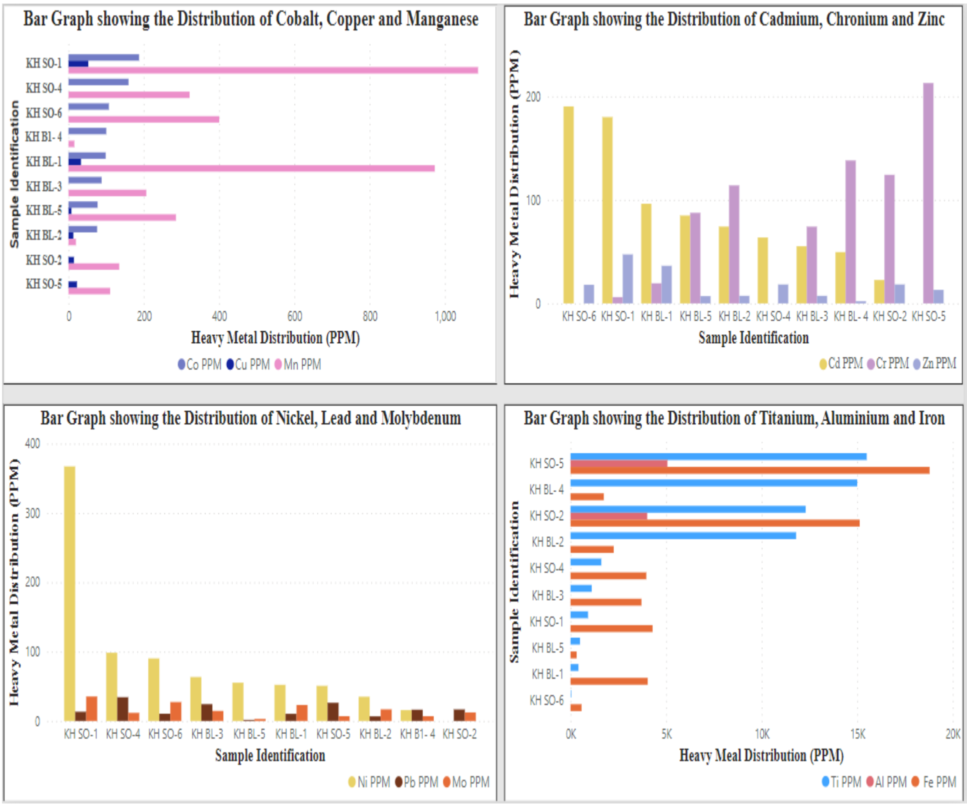

Fig. 4. Graphs showing the mean distribution of each heavy metal at the sample locations for the Study Areas. Samples retrieved from the Tailings Pond show higher values compared to samples retrieved from Blue Lake

Table 4. Correlation between the elements at the sampling location of the study areas

Element	Al	Cd	Co	Cr	Cu	Fe	Mn	Mo	Ni	Pb	Ti	Zn
Al												
Cd			0.69					0.81				
Co									0.71			
Cr	0.71										0.87	
Cu												0.85
Fe	0.97			0.63								
Mn		0.65						0.76				
Mo												
Ni		0.67					0.73	0.72				
Pb												
Ti	0.63											
Zn								0.78				

Pearson's correlation analysis revealed a significant correlation coefficient (r-value = 0.71) between Ni and Co, metals typically associated with lateritic environments and derived from ultramafic rocks. Ni-Co laterites manifest as residual products in various silicate rock types, including oxide, clay-silicate, hydrous-silicate, and distinctive, redeposited clay-oxide ores [17]. Moreover, near-surface deposits of iron, manganese, and bauxite exist, with aluminum and iron demonstrating a direct geological linkage [17]. Consequently, the Pearson correlation analysis yielded a robust r-value of 0.97. Chemical weathering of silicate-rich rocks of igneous origin and aluminosilicate rocks of sedimentary nature contributes to producing aluminum, iron, and other heavy metals [18].

Box-Whisker Plots

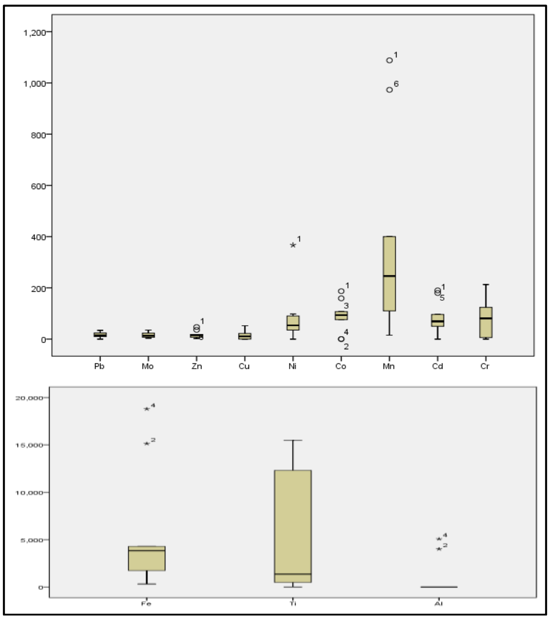

Fig. 5. Box-whisker plots showing the heavy metal concentration range in the lake sediments of the study areas (rhomboid-shaped points indicate outliers)

Frequency Distribution-Histogram

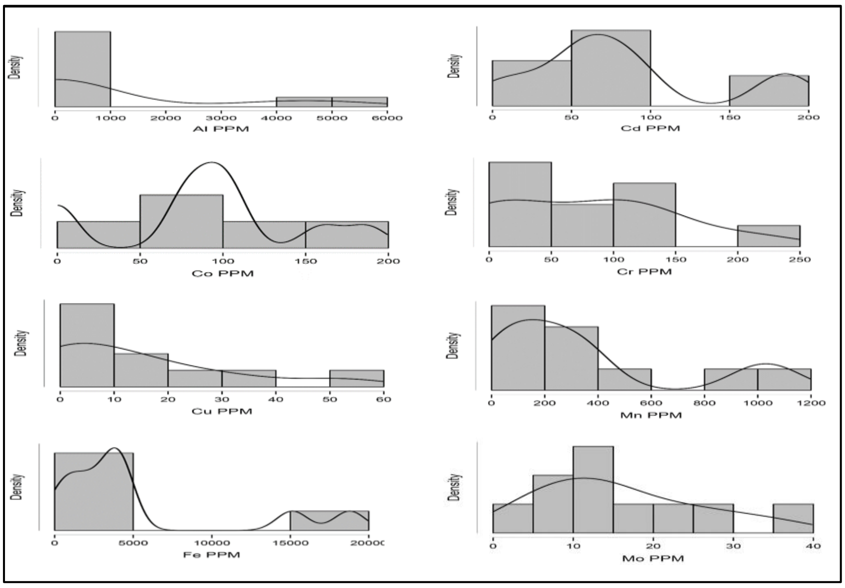

Fig. 6. Histograms showing the frequency distribution of identified heavy metals

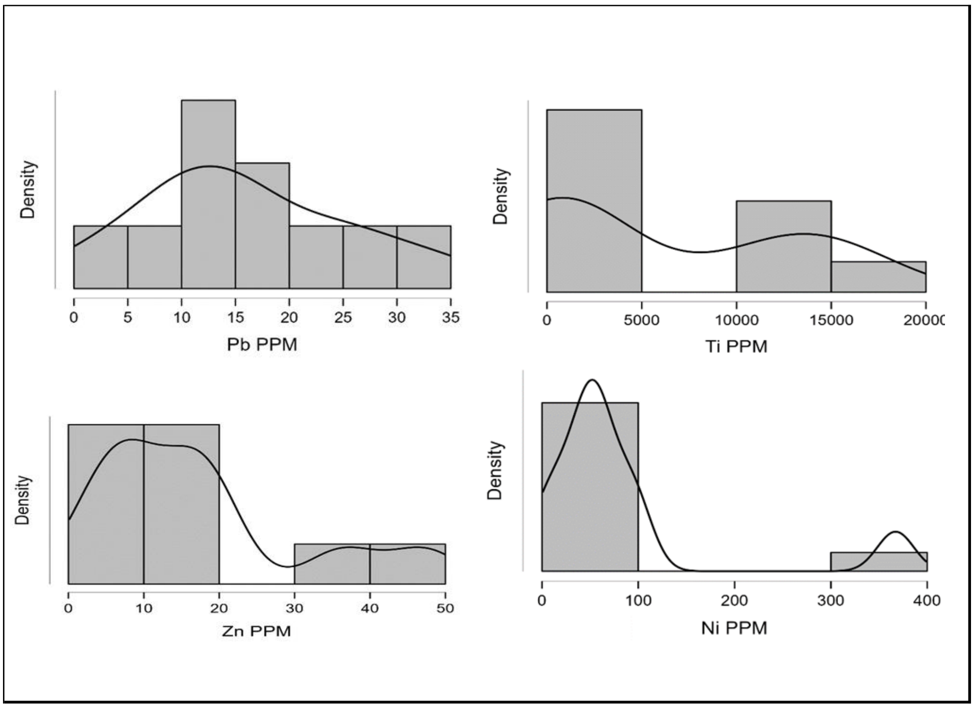

Fig. 7. Histograms showing the frequency distribution of identified heavy metals

Figs. 6 and 7 above demonstrate the frequency distribution of each heavy metal assessed using the Histogram. The Histograms of the heavy metals are skewed right and have outliers, which means the data is non-normally distributed [13]. Exploration of geochemical data seldom demonstrates normal distribution; however, careful analysis of statistics and graphics helps to determine geochemical data structure and behavior.

The five-number summary (minimum number, the lower quantile, the median, the upper quantile, and the maximum number), as seen in Fig. 5, is expressed using the Box & Whisker Plot. These plots are used to detect data skewness and outliers in a data set.

5.2 Environmental Pollution Indices

The environmental pollution parameters selected for this research were the Contamination Factor and Pollution Load Index [19].

Contamination Factor (CF)

This is an indicator to assess the level of contamination of heavy metal present in soil or sediment; this is obtained by dividing the concentration of the element in the sample taken by the concentration of the same element in the background [20,21]

CF = C sample / C background
C sample- is the concentration of the element in the sample
C background- is the concentration of the element in a global shale

The ratio of the measured concentration can be classified using these four grades.

$CF < 1$ = Low Degree
$1 \leq CF < 3$ = Moderate Degree $3 \leq CF < 6$ = High degree
$CF \geq 6$ = Very High Degree [19] Pollution Load Index (PLI)

This index is used to evaluate the amount or degree of pollution present in the soil or sediment; it can be defined as the nth root of the multiplications of the contamination factor of the metals (CF).

PLI = (CF1 X CF1 X CF1 X CFn)1/n

The estimated values derived from the PLI show the degree of pollution based on the potential contribution of all elements in a particular location [20,21].

Table 5. Concentration factor and pollution factor index of each metal at the sample locations

Sample Identification	Mo CF	Pb CF	Zn CF	Cu CF	Ni CF	Co CF	Fe CF	Mn CF	Cr CF	Ti CF	Cd CF	Al Cf	PLI
KH SO-1	13.58	0.67	0.50	1.17	5.40	9.87	0.09	1.28	0.07	0.20	600.00	0.00	1.66
KH SO-2	4.76	0.83	0.19	0.32	0.00	0.00	0.32	0.16	1.38	2.67	75.30	0.05	0.84
KH SO-4	4.52	1.72	0.19	0.00	1.45	8.39	0.08	0.38	0.00	0.35	212.13	0.00	1.52
KH SO-5	2.65	1.31	0.14	0.50	0.75	0.00	0.40	0.13	2.37	3.37	0.00	0.06	0.58
KH SO-6	10.50	0.52	0.19	0.00	1.33	5.64	0.01	0.47	0.00	0.00	634.37	0.00	0.68
KH BL-1	8.89	0.52	0.38	0.74	0.77	5.20	0.09	1.14	0.22	0.09	321.00	0.00	1.11
KH BL-2	6.46	0.33	0.08	0.29	0.51	4.00	0.05	0.02	1.27	2.57	247.33	0.00	0.80
KH BL-3	5.58	1.22	0.08	0.00	93.00	4.62	0.08	0.24	0.82	0.24	184.00	0.00	1.05
KH BL-4	2.65	0.81	0.02	0.00	0.23	5.28	0.04	0.02	1.53	3.26	165.00	0.00	0.75
KH BL-5	1.12	0.02	0.07	0.17	0.81	4.06	0.01	0.34	0.97	0.11	283.00	0.00	0.42

Table 6. Heavy metal concentrations in the study areas and maximum permitted concentration level

Elements		Mo	Pb	Zn	Cu	Ni	Co	Fe	Mn	Cr	Ti	Cd	Al
Study Areas	TP	18.73	20.21	22.98	17.87	121.29	90.82	8548.25	410.97	68.63	6064.69	91.31	1815.74
	BL	12.84	11.61	11.98	10.76	44.29	88.02	2412.21	299.97	86.63	5762.95	78.03	0.00
Permissible Limits	EPA (mg/kg) [20]		<40.00		<25.00	<20.00			<300.00	<25.00		<6.00	
	Dutch Ecologist (mg/kg) [22]	253	55	16	3.5	2.6	24			3.8		0.76	

The above analysis for computing CF values shows that the world shale average concentrations have been taken as background values. The CF values of Mo, Co, and Cd indicate high contamination for the tailing pond and blue lake. CF values Cu, Ni, Mn, Pb, Cr, and Ti showed a moderate to low degree of contamination, while the CF values of Zn, Fe, and Al showed no contamination at the tailing pond. The CF value for Pb, Zn, Cu, Ni, Fe, Mn, Zn, Ti, and Al shows a low to no degree of contamination at the Blue Lake. The results showed that the average PLI value for the study areas for TP and BL varied from 1.06 to 0.83, respectively. The pollution status for the Tailings Pond was >1, indicating that the pond is with heavy metals, and the pollution status of Blue Lake was < 1, hence less pollution from Heavy Metal.

5.3 Environmental Assessment and Potential Health Risk of Heavy Metals Contaminations

The concentration of Pb and Cu for both TL and BL are below the EPA permissible limit, as seen above. Mn for TP is moderately polluted, while the value of Mn in BL is below the EPA permissible limit. Ni, Cr, and Cd values are above the EPA permissible limit for both TP and BL and are said to be heavily polluted, according to [20]. Heavy metals pose a significant threat to human health and the ecological environment, as they can enter the body through various pathways, including the gastrointestinal tract, skin, and inhalation. The level of contamination in the environment determines the potential health risks associated with these metals. Nickel, for instance, exhibits a dual nature as both an essential element and a toxic substance for human health. Exposure to nickel can occur through ingesting foods containing nickel, drinking water with nickel content, direct skin contact, and breathing polluted air. Allergy is a common harmful effect of nickel, particularly in individuals susceptible to the metal, and even minimal exposure can trigger reactions.

Furthermore, chronic bronchitis, nasal sinus issues, reduced lung function, and cancer are among the more severe health effects associated with nickel exposure [23,24]. Studies conducted by entities such as the U.S. Department of Health and Human Services, the International Agency for Research on Cancer, and the U.S. Environmental Protection Agency have confirmed nickel's carcinogenicity in humans. Despite its essential role in enzymatic function, anthropogenic activities significantly influence environmental nickel levels, and prolonged exposure in contaminated areas can have severe health implications.

Similarly, cadmium, lead, chromium, and arsenic are identified as some of the most toxic metals to humans, even in small amounts. Cadmium poses significant risks, with inhalation and ingestion being common routes of exposure. Prolonged exposure to cadmium can lead to lung cancer, kidney failure, bone damage, and even death [25]. Chromium can transform soil and water while not persistent in the air. Exposure to elevated levels of chromium can adversely affect various organs and systems in the body, including the respiratory tract, stomach, small intestine, and male reproductive system, and has been linked to cancer. In assessing the level of heavy metal contamination and its potential health ramifications, this study compares the observed concentrations to established standards for soil content, as detailed by [26], thereby offering insight into the broader ecological changes induced by mining activities [27-30].

6. CONCLUSION

Heavy metal contamination poses a significant challenge for countries with extensive mining activities aimed at boosting economic growth. Prolonged exposure to these metals can adversely affect human health and the environment, as they can infiltrate the air, water, and soil. A study was conducted to compare the distribution of heavy metals in an active tailings pond, and Kara-Kara Blue Lake formed after bauxite mining. The analysis revealed that except for Chromium, the active tailings pond had higher average concentrations of all the evaluated elements. The concentrations of various metals in the active tailings pond were recorded as follows: Fe (8548.25 ppm), Ti (6064.92 ppm), Al (1815.74 ppm), Mn (410.97 ppm), Ni (121.29 ppm), Cd (91.31 ppm), Co (90.82 ppm), Cr (68.63 ppm), Zn (22.98 ppm), Pb (20.21 ppm), Mo (18.73 ppm), and Cu (17.87 ppm). On the other hand, the concentrations in Blue Lake were Ti (5762.95 ppm), Fe (2412.21 ppm), Mn (299.97 ppm), Co (88.02 ppm), Cr (86.63 ppm), Cd (72.03 ppm), Ni (44.29 ppm), Mo (12.84 ppm), Zn (11.98 ppm), Pb (11.61 ppm), Cu (10.76 ppm), and Al (0.00 ppm). The higher levels of cadmium in Blue Lake are believed to be linked to increased human activities. Pearson's Correlation analysis supported the connection between the geological composition of the bauxite mines and the release of certain metals during the mining process. Environmental Indices, including the Contamination Factor and Pollution Load Index, were used to assess metal distribution in the study areas comprehensively. The results indicated higher values for the Active Tailings Pond than Blue Lake, reflecting the area's nature and respective functions. The Pollution Load index for Blue Lake was below 1, suggesting a lower risk compared to the Active Tailings Pond. The analysis of samples revealed that the average concentrations of nickel, chromium, and cadmium in the active tailings pond exceeded the established EPA permissible limits, with readings of 121.29 ppm, 68.63 ppm, and 91.31 ppm, respectively. Sediment samples from Blue Lake also showed elevated levels of cadmium and chromium. While Blue Lake currently poses no immediate threat to human health, caution is advised to prevent prolonged exposure to heavy metals that could lead to health issues. Addressing this risk is crucial, particularly for the residents of Linden, the second-largest city in Guyana, which experiences the impacts of bauxite mining more intensely than other areas.

DATA AVAILABILITY STATEMENT

The data supporting the outcome of this research work has been reported in this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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