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GEOCHEMICAL ASSESSMENT OF TRACE ELEMENTS AND MINING-RELATED POLLUTION IN STREAM SEDIMENTS OF THE A-TYPE GRANITE COMPLEX, OF SHIRA AREA, NORTHEASTERN NIGERIA

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ABSTRACT
This study investigates the occurrence and distribution of elements in rocks and stream sediments from the Shira area, Bauchi State, Nigeria, to assess metal inputs into the surrounding environment. Primary data were obtained through systematic sampling and laboratory analysis using Inductively Coupled Plasma–Mass Spectrometry (ICP-MS) following HF–HNO_3 digestion. Twenty-three sampling sites covering approximately 120 km² were investigated. Results show that Li, Cs, Co, Cu, Ga, Ge, Ni, Pb, Th, U, and Zn are the most prominent trace elements in the study area. Thorium and uranium concentrations are significantly higher in rock samples than in stream sediments, with mean values of 3.89 ppm (Th) and 21.92 ppm (U) in rocks compared to 0.38 ppm and 2.7 ppm, respectively, in stream sediments. Lead exhibits a high mean concentration of 186.68 ppm in rocks but only 4.05 ppm in stream sediments. Copper, nickel, and zinc show notably elevated concentrations in rocks (296.23 ppm, 35.29 ppm, and 97.67 ppm, respectively) relative to stream sediments. The analysed elements include As, Zn, Pb, Cu, Co, Cs, Ga, Nb, Ni, Mo, Sn, Th, and U. Comparison with global average crustal and rock-type geochemical background values indicates enrichment in As, V, Ni, Cr, and Pb. Enrichment factor analysis, based on regional geological background values, demonstrates that elevated elemental concentrations in stream sediments are primarily controlled by geological sources rather than industrial contamination.

Keywords: A-type granites, anthropogenic sediments, mining, geogenic, trace elements.

INTRODUCTION

The Shira complex, which is part of the anorogenic granitic provinces of Niger and Nigeria, can be divided into three centres. The Shira quartz syenite dominates centre 1, and this has been intruded by a large cone sheet of Birji granite and by microgranite dykes. Birji granite has two facies of the arfvedsonite. The Shira quartz syenite consists of microperthite, quartz, ferrorichterite, arfvedsonite and aenigmatite. These peralkaline syenites and granites are believed to represent successive intrusions from a progressively differentiating magma chamber. The habit facies distinguishes them by exhibiting layering. The Birji granite contains microperthite, quartz, arfvedsonite and a little aegirine, and the dykes related to it have a similar mineralogy but are more mafic-rich (Bennett, 1981).

Rocks and minerals contain most of the naturally occurring chemical elements essential to plant, animal, and human health in small doses. Major, minor, and trace elements reflect the geology of the area. On the other hand, rocks weather or break down to form the soils on which crops and animals are raised.

The anthropogenic sources of heavy metals in the environment include mining and industrial and agricultural activities in the study area, which release heavy metals during the mining and extraction of different elements from their respective ores (Lee & Yao, 1970). Heavy metals released to the atmosphere during mining, smelting, and other industrial processes return to the land through dry and wet deposition. Discharge of wastewaters, such as industrial effluents and domestic sewage, adds heavy metals to the area. Then, the application of chemical fertilisers and the combustion of fossil fuels also contribute to anthropogenic inputs of heavy metals into the environment. Regarding the contents of heavy metals in commercial chemical fertilisers, phosphate fertilisers are vital. In general, phosphate fertilisers are produced from phosphate rock by acidulation. In the acidulation of single superphosphate, sulfuric acid is used. While in the acidulation of triple superphosphate, phosphoric acid is used (Dissanayake & Chandrajith, 2009). The final product contains all of the heavy metals present as constituents in the phosphate rock (Mortvedt, 1996; Martin & Bowden, 1981). Heavy metals added to agricultural soils through inorganic fertilisers may leach into groundwater, contaminating it.

Phosphate rock⟶fertiliser,⟶soil/water⟶ plant⟶food⟶, human body

Contamination of sediments with heavy metals is an environmentally important issue with consequences for aquatic organisms and human health. Sediments act as the main pool of metals in the aquatic environment. Their quality can indicate the status of water pollution (Zahra et al., 2014; Garette, 2000). Sediments serve as both sinks and sources of heavy metals, releasing them into the water column. Continuing deposition of heavy metals in sediments can also lead to contamination of groundwater with these pollutants.

Contamination of soil with toxic metals poses serious risks for biota and human health (Forstner, 1995). At low concentrations, some Potential Toxic Metals (PTMs), such as copper, chromium, molybdenum, nickel, selenium, and zinc, are essential for the healthy functioning and reproduction of microorganisms, plants, and animals (including man) (Alloway, 1995). However, at high concentrations, these same essential elements may cause direct toxicity or reproductive effects. Some elements are also non-essential (e.g., arsenic, lead, and mercury), and even low environmental concentrations can cause toxicity in both plants and animals (Alloway, 1995). Volcanic eruptions redistribute many harmful elements such as arsenic, beryllium, cadmium, mercury, lead, radon, and uranium. Many other redistributed elements have undetermined biological effects (Adekoya, 1995).

MATERIALS AND METHODS

Study Area

The study area lies between latitude 10º00′ and 10º08′ N and longitude 11º23′ and 11º29′ E with an aerial extent of about 120 km^2 (Figure 1). Shira and environs lie in the Sahel Savannah (semi-desert vegetation) with characteristic isolated stands of thorny shrubsThe study area generally has low relief and is almost flat, with a peak elevation of 2075 m. The drainage system of Shira and environs has a dendritic pattern, with the primary stream flowing radially to form a watershed in the southern part.

Geology of the Area

The study area belongs to the anorogenic province of Niger and Nigeria, dominated by peralkaline syenites and granites and has an estimated area of 120km^2. Shira and environs encompass three belts of different lithology of peralkaline granite and syenite. The surrounding stream has been influenced by quarrying and other activities. As a result, extensive mining activity has changed the overall character and morphology of the landscape. The western part of Bauchi State underlies crystalline rocks. The rest is Cretaceous to Recent sediments. Migmatites and gneisses are intruded by Older Granite Suite rocks (comprising foliated porphyritic granites and bauchites), younger granite suite rocks (mainly medium-grained magmatic granites) and acid volcanic rocks. A central belt of unfolded Tertiary continental sediments overlie both crystalline and Cretaceous rocks. In the north, the Quaternary lacustrine sediments overlie crystalline and Tertiary rocks.

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Following prolonged erosion, the sandstones and kaolinites of the Kerri-Kerri Formation, which are dated as Palaeozoic, were deposited—the lateralized Kerri-lacustrine beds of the Chad margin partly covered the Kerri surface. Most recently, the last desert incursion left fossil dunes in the northern part of the Bauchi area (Table 1). Crystalline rocks of the Younger Granite underlie the northern portion of the study area, while Tertiary to Recent sediment overlies the crystalline rock outcrops in the remaining area (Thompson, 1985). Bowden *et al. (1981) reported that the Younger Granite ring complex of Shira is composed of three varieties:* the synite, peralkaline granite and biotite granite. Bennett (1981) and Martin and Bowden (1985) further distinguished the peralkaline granite of the Shira ring complex into quartz syenite, the biotite granite and microgranite (Figure 1).

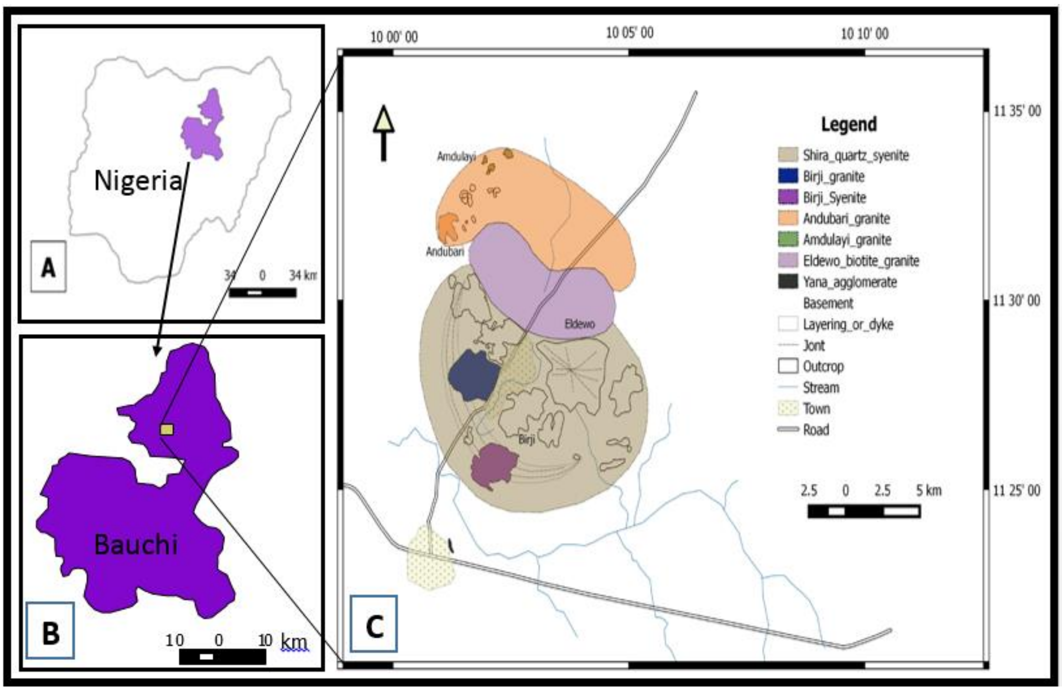

Figure 1: Map Showing (a) the location of Bauchi State, (b) the study area and (c) the geological map of the study area (Modified after Bennett, 1981).

Data Collection and Laboratory Analyses

The research methods and procedures primarily involve field operations and laboratory techniques for sample collection, preparation, and data analysis in the study area (Muhammad, 2016). During the study, eleven (11) stream sediments and twelve (12) rock samples were collected. The stream and soil samples were collected at a depth of 20-25 cm using a hand trowel. Sieve analysis was used to separate coarse-grained from fine-grained sediments, which were then packed and labelled for onward transmission to the laboratory. Fresh rock samples were collected using a geologic hammer.

The wet samples were sun-dried and carefully pulverised in the laboratory with an agate mortar and pestle. Ethanol was used to rinse the mortar before and after each pulverisation to prevent contamination of the samples. Two grams (2g) of each pulverised sample were weighed and sent for analysis at Activation Laboratories Ltd., Ancaster, Ontario, Canada. In the Laboratory, each sample was processed using aqua regia digestion and analysed using an ICP-MS method. This

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technique uses a combination of concentrated hydrochloric and nitric acid to leach sulphides, some oxides and some silicates from the samples.

RESULTS AND DISCUSSION

Results of the geochemical analysis of 23 trace elements determined in the analysed rocks and stream sediment samples are shown in Figure 2 and Table 1.

The distribution of dominant trace elements in the study area shows that Li, Cs, Co, and Cu are present. Ga, Ge, Ni, Pb, Th, U and Zn are more pronounced in the samples (Figures 3 and 4). Th and U have higher values in rocks than in stream sediment and soil samples. In rock samples, Th and U have average values of 3.89 ppm and 21.92 ppm, while in stream sediment, the average values were 0.38 ppm and 2.7 ppm, respectively. On the other hand, Pb has a mean value of 186.68 ppm in rock samples, whereas in stream sediment it has a mean value of 4.05 ppm. Cu, Ni, and Zn contents were extremely high compared with other trace elements, with average values of 296.23 ppm, 35.29 ppm, and 97.67 ppm in rock samples and 2.57 ppm, 1.95 ppm, and 8.45 ppm in stream sediment, respectively (Figures 3 and 4).

The results of the geochemical analysis of the samples Li, Ge, and Th indicate that these elements are associated with uranium in the study area. They also show remarkably high content when compared with other trace elements from the same area. Figures 3 and 4 show the variation in mean concentrations of some trace elements in the samples. The mean value for U in stream sediments and soil is recorded as 0.38ppm, while in rocks, peralkaline granite - 2.32ppm, biotite granite – 6.41 ppm, and granitic dyke – 1.49 ppm, respectively. The Th/U ratio in rocks ranges between 2.53 and 24.49, with the granitic dyke having lower values, whereas in stream sediment it ranges between 1.59 and 14.29. The mean compositions of stream sediments and soils are comparatively deficient in all trace elements, though slightly enriched in Ge, Li, Co, Th, and Zn relative to the rock samples. The samples from the Northwestern area show a distinctive increase in trace element contents, especially Th.

The paucity of base cations (Ca, Mg) is a typical result of intense tropical weathering in Northeastern Nigeria, which leaches more mobile elements from the source rocks into the hydrological system.

The trace element concentrations in Table 2 provide evidence of both mineralisation and environmental degradation.

Immobile Element Enrichment: High concentrations of Zirconium (Zr) and Niobium (Nb) are indicative of the zircon and niobium mineralisation typical in the Younger Granite Province. These are generally geogenic and linked to the primary mineralogy of the Shira ring complex.

Toxic Trace Metals (Pb, Cd, Zn): Elevated levels of Lead (Pb), Cadmium (Cd), and Zinc (Zn) often surpass Upper Continental Crust (UCC) values, suggesting an anthropogenic input. In the Shira area, these results are likely tied to the mechanical weathering and chemical processing associated with mining activities.

Values for Pb and Cd that fall into Class 2 or 3 (1.0 – 3.0) indicate "moderate to strong" pollution. These anomalies are typically localised near mining sites where tailings or runoff enter the stream system.

Enrichment Factor (EF): EF values greater than 3 for elements such as Pb or Zn suggest "moderate to severe" enrichment that cannot be explained by natural weathering alone. An EF > 10 for specific sites would classify them as having "severe" anthropogenic contamination.

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Pollution Load Index (PLI): A PLI greater than 1 indicates that the site is generally polluted—sites near mining clusters in the Shira complex likely exhibit higher PLI values than upstream background locations.

The combination of high and EF for toxic metals such as lead poses a potential health risk to the local community. While high concentrations of Nb and Zr indicate economic mineralisation potential, the presence of Pb and Cd in mobile stream sediments warrants urgent environmental monitoring to protect local water sources.

The present data correlate with the other uranium-bearing rocks reported by Bennetti (1981) and Bowden *et al* (1981; Table 2).

According to Kinnaird (1984), Kinnaird et al. (1985), and Bowden (1985), the alteration processes of younger granite are characterised by changes in alkali element ratios, accompanied by enrichment in specific trace elements. Normative variations in Q-Or and Ab can also distinguish each process. The early fluids responsible for soda metasomatism, in addition to Na, also contained Fe combined with Nb, Y, U, Th, Zr, and REE relative to unaltered granite. An increase in K2O, Rb, Li, and Zn, a loss of Na2O, and trace-element depletion characterise potash metasomatism. The chondrite-normalised rare-earth spectrum shows an enrichment in light rare-earth elements, a slight enrichment in Eu, and increasing Yb and Lu. The silicification process shows a noticeable increase in Si, balanced by decreases in all other major elements except Fe in some cases. There is an increase in Li, Cs, Co, and Cu. Ga, Ge, Ni, Pb, Th, U and Zn.

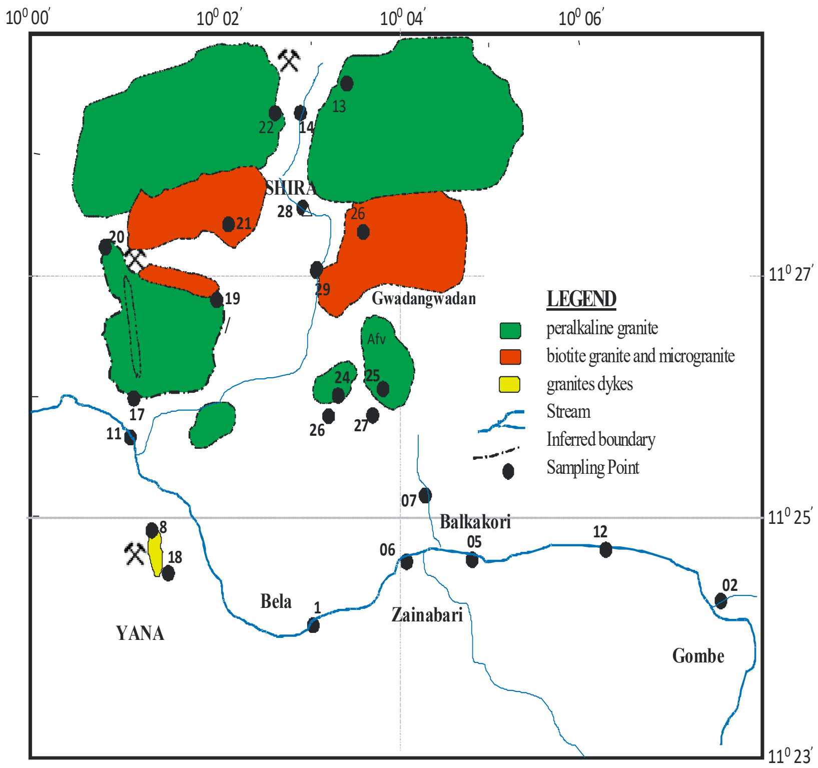

Figure 2: Geological map of the study area.

Table 1. Comparison of mean, median, mode and standard deviation of some dominant trace elements (ppm) in stream sediments and rock samples of the study area

	STREAM SEDIMENTS					ROCKS				
ELEMENT	**NO. SAMLES**	**MEAN**	**MEDIAN**	**ODE**	**STD. DEV**	**NO. SAMLES**	**MEAN**	**MEDIAN**	**MODE**	**STD. DEV.**
Co	11	1.01	0.9	0.9	0.61	12	0.61	0.4	0.3	0.43
Cs	11	0.2	0.16	#N/A	0.12	12	0.46	0.36	0.412	0.42
Cu	11	2.57	2.1	2.1	1.07	12	296.23	260.5	#N/A	248.74
Ga	11	2.1	1.8	2.4	0.76	12	2.09	1.65	1.3	1.23
Ge	11	0.28	0.26	0.26	0.05	12	0.81	0.61	#N/A	0.74
Li	11	1.45	1.2	1	0.65	12	3.83	2.55	3.2	3.89
Ni	11	1.95	1.7	1.5	0.74	12	35.39	26.9	2.3	28.11
Pb	11	4.05	3.9	2.1	1.8	12	183.68	22.25	28.1	565.76
Th	11	2.7	3	3	1.16	12	21.92	14	15	24.44
Tl	11	0.026	0.02	< 0.01	0.02	12	0.15	0.1	0.03	0.22
U	11	0.38	0.29	0.28	0.31	12	3.89	2.46	#N/A	4.99
Zn	11	8.45	8	10	3.8	12	97.67	65.5	#N/A	123.48

Source: Muhammad, 2016.

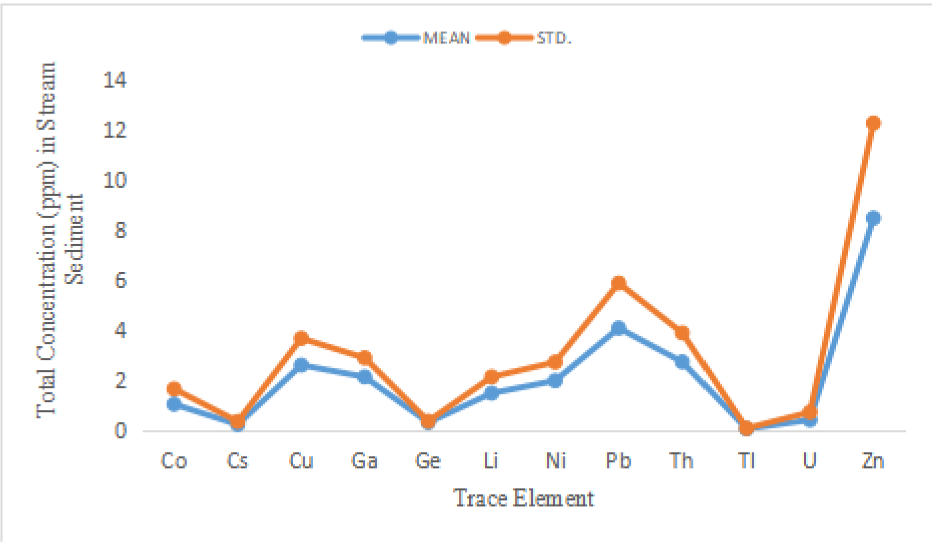

Figure 3: Cobalt, Caesium, copper, Gallium, germanium, lithium, Lithium, Nickel, Lead, Thorium, Thallium, Uranium and zinc contents (ppm) of the stream sediments

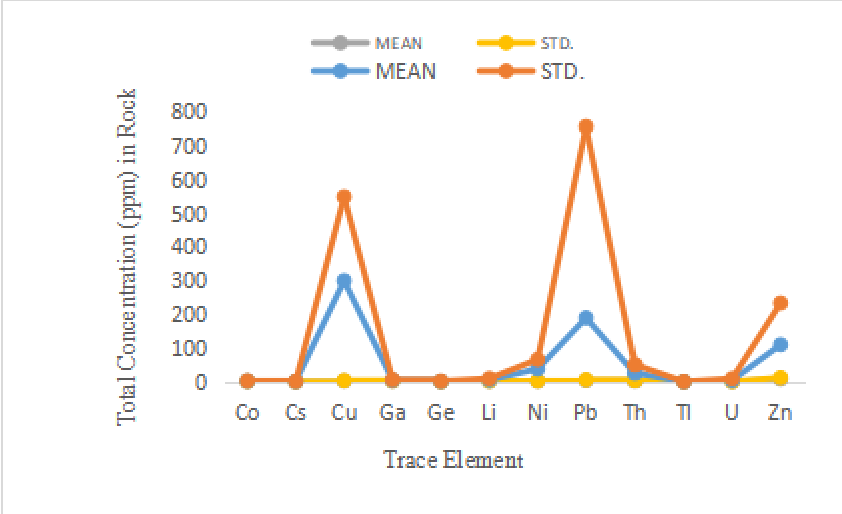

Figure 4. Cobalt, Caesium, copper, Gallium, germanium, lithium, Lithium, Nickel, Lead, Thorium, Thallium, Uranium and zinc contents (ppm) in rocks.

Table 2: Compilation of Average Geochemical Background Data for the Earth's Crust and Selected Rock Types

	Hg (mgkg-¹)	*Pb (mg kg-¹)*	*Cd (mg kg-¹)*	*Cr (mg kg-¹)*	*Ni (mg kg-¹)*	*As (mg kg-¹)*	*Cu (mg kg-¹)*	*Zn (mg kg-¹)*	*Ref.*
Earth's crust									
	80	13	0.2	100	75	2	55	70	Taylor, 1964
	90	12	0.2	110	89	2	63	94	Lee & Yao, 1970
Upper continental crust									
		20	0.1	35	20	1.5	25	71	McLennan, 1992
	80	13	0.2	77	61	1.7	50	81	Lee & Yao, 1970
Igneous rocks									
Ultramafic	4	1	0.1	1600	2000	1	10	50	Turekian & Wedepohl, 1961
Mafic	13	6	0.2	170	130	2	87	105	Turekian & Wedepohl, 1961
Intermediate	21	15	0.1	22	15	2	30	60	Turekian & Wedepohl, 1961
		10		55	30		60		McLennan, 1992
Felsic (4)	39	19	0.1	4	5	1	10	39	Turekian & Wedepohl,1961
Sedimentary rocks									
Sandstone		57	14	0.02	120	3	1	15	16 Faust & Aly, 1981
Limestone		46	16	0.05	7	13	2	4	16 Faust & Aly, 1981
Shale	270	80	0.2	423	29	9	45	130	Faust & Aly, 1981
Black shale		15	4.0	18	68	22	50	189	Dunn, 1990
		100		700	300		200	1500	Vine & Tourtelot, 1970

Source: Garrett (2000).

CONCLUSION AND RECOMMENDATIONS

The geochemical assessment of stream sediments in the Shira Area provides critical insights into the interplay between the natural mineralogical framework of the A-type Granite Complex and the environmental impact of local mining activities. The results confirm that the sediments retain the primary geochemical signature of the Younger Granite Province, characterised by high silica and alkali contents, alongside significant geogenic enrichment of high-field-strength elements such as Niobium (Nb) and Zirconium (Zr). However, the elevation of toxic trace metals—specifically Lead (Pb), Cadmium (Cd), and Zinc (Zn)—above both the Upper Continental Crust (UCC) and local background values indicates a clear anthropogenic footprint.

Amongst the elements, Li, Pb, Cu, and Zn are commonly enriched in average biotite granite, but typically low in peralkaline granite and granitic dykes. A plot of the determined values (i.e., the average of all samples from the study area) shows that uranium-bearing rocks are relatively enriched in Li, Ga, Th, and Pb.

To minimise the adverse effects of mineral mining and processing, both the government and mining and processing companies must take specific precautionary measures. The government's role is to provide the legislation required to make it mandatory for companies to take all necessary precautions in their operations to prevent or minimise environmental damage. There is a need to strengthen the new law with the following suggestions:

(i) Mining companies should submit environmental restoration plans together with their application for either prospecting or mining lease of an area;

(ii) Processing companies must install appropriate equipment, where necessary, for preventing or minimising pollution;

(iii) All large mining and processing companies are to prepare a prognosis of the possible environmental impact of their operations, as well as the technique for monitoring the impact, for approval of the Mines Department before the companies can commence operation.

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