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Research Article

INVESTIGATING THE IMPACT OF LITHIUM MINING ON SOIL QUALITY, AND PLANT GROWTH IN ANGWA-KEDE COMMUNITY, KOKONA LGA, NASARAWA STATE, NIGERIA

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ABSTRACT

Transition to green energy has made lithium mining one of the biggest venture in the world but this comes with its implications. This research was conducted to check the level of lithium mining contamination on soil quality and on plant in Angwa-Kede community due to observed poor agricultural yield. A systematic sampling method was conducted on both plant and soil samples from mining site and host community of Angwa-Kede to check the effects of lithium mining activity. The obtained plant and soil samples were analyzed using X-ray flourescence analysis (XRF) analysis to check elemental composition and the nutrient dynamics of both plant and soil. The XRF result revealed that soil samples from host community displayed higher level of Aluminum (Al) concentration in soil ranging from 20.48 to 31.18% Al indicating high contamination. Flame test results of plant samples from lithium mining site contains 0.466–0.477 ppm Li while those from host community has lithium concentration ranging from 0.0139 to 0.194 ppm Li which is above the accumulated level of lithium concentration in the blood (0.01374–0.02748 ppm Li) an indication of toxicity to human health. Soil samples of the mining site having risk factor (R_f) of 139.76, 168.49, and 350.26 while the soil samples from the host community has R_f of 7,194.24, 10,810.81, and 14,388.48, respectively. In conclusion, the obtained result shows high level of soil and plant lithium contamination in Angwa-Kede community which is caused by uncontrolled lithium mining method and poor waste disposal system.

Keywords: Soil contamination, Plant contamination, Soil nutrient dynamics, X-ray flourescence analysis.

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INTRODUCTION

Plant growth is intricately influenced by various factors, encompassing weather conditions, genetic traits, topography, and soil fertility. While several elements play pivotal roles in plant growth, their effects depend on their concentrations within both the plant and its environment. (Anjum *et al*., 2016). However, an elevated concentration of certain elements can become detrimental, impeding plant growth and yield (Anjum *et al*., 2016). The potential toxic effects of lithium on higher plants remain a topic of ongoing investigation. Existing evidence suggests that Lithium, particularly in the form of Li-salts, can induce a significant reduction in plant growth, often leading to the formation of necrotic regions. Nevertheless, different plant species exhibit plasticity in their sensitivity and tolerance to Lithium toxicity. The overview of lithium's effects on plants is presented in Table 1 below.

Plant responses to lithium

According to Shahzad *et al*. (2016), plants are categorized into four groups based on their reactions to the presence of Lithium (Li). Lithium Accumulators are plants in the first group exhibit elevated Lithium accumulation under various conditions, thriving in soils with high Lithium content. Examples include certain plants from the *Ranunculaceae*, *Solanaceae*, and *Cirsium vulgare* from the *Asteraceae* family. Conditional accumulators are plants in the second group accumulate Lithium only when it exceeds optimal levels in the soil. Examples include *Mentha longifolia*, *Phlomis thapsoides*, and *Gossypium hirsutum*. Non-Lithium demanders are the third group and they comprise of plants with minimal Lithium requirements, avoiding soils with elevated Lithium content. Examples include plants from the *Brassicaceae*, *Caprifoliaceae*, *Liliaceae*, and *Poaceae* families while the Lithium-tolerant non-demanders are plants in the fourth group and they do not have high Lithium requirements but can tolerate soils with elevated Lithium content. Examples include *Tamaricaceae*, *Zygophyllaceae*, and *Alhagi crichisorum* from the *Fabaceae* family. The responses of different species of plants to lithium concentration are presented in Table 2 below.

Li concentration in plants

Research conducted by Kabata-Pendias (2010) sheds light on Lithium (Li) concentration in various plant families, revealing diverse levels of accumulation. In parts per million dry weight (ppm DW), the highest Lithium (Li) concentrations were observed in *Rosaceae* (2.9), *Ranunculaceae* (2.0), and *Solanaceae* (1.9). Contrasting this, *Urticaceae* (0.24) and *Poaceae* (0.24) exhibited lower concentrations, while *Polygonaceae* displayed the lowest (0.10). It's important to note that species within a family may exhibit significant differences in Lithium concentration.

Franzaring (2016) expanded this understanding by analyzing Lithium (Li) concentration in thirteen plant species collected from the field. *Ranunculus sardous* Crantz (2.16) and *Plantago lanceolata* L. (0.42) demonstrated the highest concentrations (ppm), whereas *Vitis vinifera* L. (0.05) and *Hypericum perforatum* L. (0.05) exhibited the lowest.

Kishi *et al*. (2021) reported varying Lithium (Li) concentrations in specific plant species in karst areas, with *Lolium* spp. averaging 4.30 mg Li/kg DW, *Mentha* spp. at 1.70, and *Urtica* spp. at 0.66 mg Li/kg DW. Notably, *Cirsium arvense* and *Solanum dulcamara* were identified as accumulators, displaying 3–6 times higher Lithium (Li) accumulation than other plants.

Examining Lithium (Li) concentration in edible plants, Shahzad *et al*. (2016) reported values for lettuce (0.3–0.6 mg/kg), cabbage (1.2 mg/kg), green onion (1.8 mg/kg), and spinach (4.6 mg/kg). Kavanagh *et al*. (2018) highlighted plant species with elevated Lithium (Li) accumulation, with *Brassica carinata* standing out with an impressive 8000 mg Li/kg. It's worth noting that Lithium (Li) concentration tends to be higher in young plants compared to older ones.

Studies by Antonkiewicz *et al.* (2017) suggested the potential use of maize for rhizo-filtration of contaminated water or soil remediation through phyto-extraction. Fungi, such as *Aspergillus* and arbuscular mycorrhizal fungi, were identified as contributors to Lithium (Li)

Table 1: Overview of the beneficial effects of Lithium on higher plants

Lithium (Li) application	Plant species	Effect
Seed immersion in 1% solution of LiCl	Wheat, Barley, Peas, Clover	Growth simulation
0.1g $LiNO_3$/kg soil	Barley, Pea	Growth simulation
Hydroponic solution 12 ppm Li	Cucumber	Increased fruit yield
10 lbs Li/Ac (Li_2SO_4)	Spinach, mustard	In reduced light increased plant fresh weight
Murashig and Skoong medium		Stimulated root length
30 mMLi	*Brassica carinata*	Stimulated root length and fresh weight
Nutrient solution 5 mg Li/L	Maize	Increased shoot fresh biomass
Hydroponic culture 2.5 mgLi/L (LiOH), 2.5 and 20 mg Li	Lettuce	Increased root fresh biomass
Hydroponic conditions 1–32 mg/Li/L (Li as LiCl)	Maize	Stimulating effect on the yield

Source: Babar Shahzad and Mohsin Tanveer (2016)

Table 2: Responses of different species of plant to lithium concentration

Family	Plant species	Toxicity level	Effects
Apocynaceae	*Apocynum venetum*	Low (50 mg/kg)	No reduction in *A. venetum* shoot and root dry weight, chlorophyll contents, and leaf gas exchange
		High (200 and 400 mg/kg)	Significant reduction in shoot and root dry weight, chlorophyll contents, and leaf gas exchange
Asteraceae	*H. annuus*	Low (20 and 40 mM)	No reduction in hypocotyl length and circumnutation
		High (60 and 80 mM)	Hypocotyl length was reduced by 34 and 55%, respectively, and circumnutation was reduced by 30 and 70%, respectively
Asteraceae	*Lactuca saliva* var. Capitata (Lettuce)	Low (2.5 mg dm^{-3})	Significant increase in the root system
		High (50 or 100 dm^{-3})	Considerable reduction in the root system
Poaceae	*Z. mays* (Maize)	Low (5 mg dm^{-3})	Shoot biomass was increased by 15%
		High (50 mg dm^{-3})	Shoot biomass was increased by 32%
Asteraceae	*Helianthus annuus* (Sunflower)	Low (5 mg dm^{-3})	Shoot biomass was increased by 10%
		High (50 mg dm^{-3})	Shoot biomass was increased by 27%

Source: Babar Shahzad & Mohsin Tanveer (2016). *A. venetum: Apocynum venetum*, *H. annuus*: *Helianthus annuus*, *Z. mays*: Zea mays, L. saliva: *Lactuca saliva*

remediation in soils. Lithium concentration in different food crops and their daily intake is seen in Table 3 below.

Table 3: Lithium concentration in different food crops and daily intake

Crop plant	Lithium concentration kg^{-1}	Estimated daily intake (mgLi/day)
Lettuce	0.3–0.6 (FW)	0.09–0.18
Cabbage	1.2 (FW)	0.12–0.48
Green onion	1.8 (FW)	0.18
Spinach	4.6 (FW)	1.15–1.38
Forage plant species	0.2–200 (FW)	-
Fodder beat	0.3–11.7 (FW)	-
Celery	6.6 (DM)	-
Chard	6.2 (DM)	-

Source: Shahzad *et al.* (2016)

MATERIALS AND METHODS

Materials

(a) Sample bag (b) global positioning system (c) Note book.

Methods

Obtained soil and plant samples from the host community and mining areas were crushed and pulverized. Using a benchtop oven, the pulverized samples were dried to remove moisture and a representative sample of 100 g each was taken to the Laboratory for X-ray flourescence analysis (XRF) and flame test analysis. The coordinate of the study area are N8°47'11.3928", E7°57'1.0332" and N8°49'40.74", E7°58'52.28", respectively. The various coordinate for the area where both the soil and plant samples were obtained is seen in Table 4 below and the digitized map is seen in Fig. 1 below.

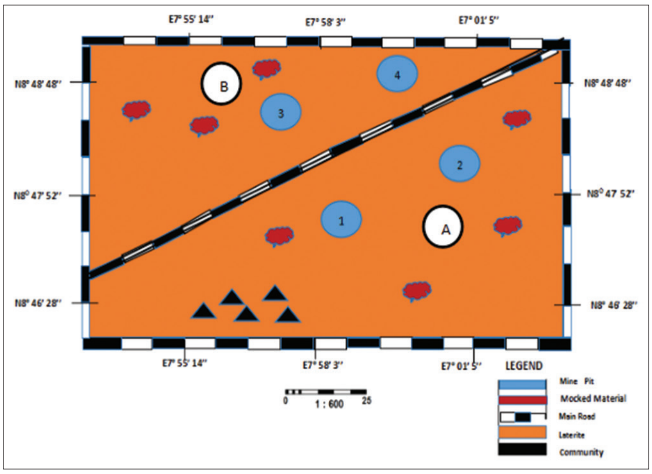

Fig. 1: (a) digitized map showing various visited mine pits within the study area (site a and b)

RESULTS AND DISCUSSION

The various obtained results are seen in Tables 5-13 below.

Table 5 above shows the XRF result for soil sample obtained from the Lithium mining sites and the host community at point 1. The presence of the various elements in the soil of the mining host community indicates the nutrient dynamics of the soil sample sourced at point 1. It can be observed that soil sample at point 1 of the mining site, has 55.61% Si while that of the host community has 55.31% Si; Aluminum: Mining site: 23.24% Al, host community: 23.64% Al; Potassium: Mining site: 8.58% K, host community: 2.00% K; Sodium: Mining site: 4.39% Na, host community: 4.14% Na; Iron: Mining site: 1.07%Fe, host community: 5.58% Fe; Magnesium: Mining site: 2.42% Mg, host community: 3.12% Mg; Phosphorus: Mining site: 1.65% P, host community: 1.52% P; Calcium: Mining site: 1.03% Ca, host community: 0.41% Ca; Chlorine: Mining site: 0.90% Cl, host community: 0.95% Cl; Sulfur: Mining site: 0.90% S, host community: 1.32% S; Titanium:

Table 4: Soil and plant samples coordinates

Angwa kede mine site points A and B					
Mining site			Host community		
Serial number	Latitude (X)	Longitude (Y)	Serial number	Latitude	Longitude
1	N8° 47'11.3928"	E7° 57' 1.0332"	1	8.777268°	7.958065°
2	N8° 4758065332"'	E7° 575806	2	8.777165°	7.957997°
3	N8° 4757997	E7° 575799	3	8.777137°	7.958087°
4	N8° 4958087332	E7° 5858087332	4	8.777130°	7.958080°

Table 5: Soil sample analysis from lithium mine site and host community at point 1

Lithium mining site				Host community			
Element Name	Symbol	Atomic Conc.	Weight Conc.	Element name	Symbol	Atomic Conc.	Weight Conc.
Silicon	Si	55.61	53.73	Silicon	Si	56.31	53.28
Aluminum	Al	23.24	21.57	Aluminum	Al	23.64	21.48
Potassium	K	8.58	11.54	Potassium	K	2.00	2.63
Sodium	Na	4.39	3.47	Sodium	Na	4.14	3.21
Iron	Fe	1.07	2.05	Iron	Fe	5.58	10.50
Magnesium	Mg	2.42	2.02	Magnesium	Mg	3.12	2.55
Phosphorus	P	1.65	1.76	Phosphorus	P	1.52	1.58
Calcium	Ca	1.03	1.41	Calcium	Ca	0.41	0.55
Chlorine	Cl	0.90	1.09	Chlorine	Cl	0.95	1.13
Sulfur	S	0.90	1.00	Sulfur	S	1.32	1.42
Titanium	Ti	0.21	0.34	Titanium	Ti	1.02	1.65

Table 6: Soil sample analysis from the lithium mining site and Host Community at Point 2

Lithium mining site				Host community			
Element Name	Symbol	Atomic Conc.	Weight Conc.	Element name	Symbol	Atomic Conc.	Weight Conc.
Silicon	Si	50.41	43.46	Silicon	Si	60.62	57.61
Aluminum	Al	31.08	28.71	Aluminum	Al	22.73	20.76
Potassium	K	5.11	6.84	Potassium	K	2.56	3.39
Sodium	Na	3.55	2.79	Sodium	Na	2.80	2.18
Iron	Fe	3.03	5.79	Iron	Fe	5.14	9.71
Magnesium	Mg	3.00	2.49	Magnesium	Mg	2.78	2.29
Phosphorus	P	1.65	1.76	Phosphorus	P	0.88	0.92
Calcium	Ca	1.07	1.13	Calcium	Ca	0.00	0.00
Chlorine	Cl	0.52	0.54	Chlorine	Cl	0.90	1.08
Sulfur	S	0.73	0.80	Sulfur	S	0.91	0.99
Titanium	Ti	1.06	1.73	Titanium	Ti	0.66	1.07

Table 7: Soil sample analysis from lithium mining site and host community at point 3

Lithium mining site				Host community			
Element Name	Symbol	Atomic Conc.	Weight Conc.	Element name	Symbol	Atomic Conc.	Weight Conc.
Silicon	Si	45.85	42.91	Silicon	Si	55.15	51.74
Aluminum	Al	31.18	28.04	Aluminum	Al	26.69	24.05
Potassium	K	4.35	5.67	Potassium	K	2.71	3.54
Sodium	Na	3.76	2.88	Sodium	Na	2.47	1.89
Iron	Fe	6.46	12.02	Iron	Fe	6.70	12.51
Magnesium	Mg	4.80	3.89	Magnesium	Mg	2.97	2.41
Phosphorus	P	0.76	0.78	Phosphorus	P	1.12	1.15
Calcium	Ca	0.78	1.04	Calcium	Ca	0.37	0.50
Chlorine	Cl	0.45	0.53	Chlorine	Cl	0.70	0.83
Sulfur	S	0.63	0.67	Sulfur	S	0.79	0.85
Titanium	Ti	0.98	1.57	Titanium	Ti	0.33	0.53

Mining site: 0.21% Ti, host community: 1.02% Ti. Comparing the results of the elemental distribution in the soil samples from both the mining site and the host community, it can be said that all the elements that are found in the soil sample of the mining site are also traceable to that of the host community. The reason for the trend could be attributed to the uncontrolled mining activities that is taking place within the lithium mining site and this may have resulted to accelerated weathering and leaching of the associated mineral elements into the vicinity of the mining host community. However, the soil samples of both host community and lithium mining site appear to have 0.95% Cl and 0.90% Cl, respectively, which are far above 0.3% Cl required by plants and animals. The presence of high chlorine in soil leads to formation of chlorine ions, which acidifies the soil and thus affects the roots of the plant leading to stunted growth.

Table 8: Soil sample analysis from lithium mining site and host community at point 4

Lithium mining site				Host community			
Element name	**Symbol**	**Atomic Conc.**	**Weight Conc.**	**Element name**	**Symbol**	**Atomic Conc.**	**Weight Conc.**
Silicon	Si	44.29	41.94	Silicon	Si	62.71	59.19
Aluminum	Al	30.91	28.12	Aluminum	Al	20.48	18.57
Potassium	K	3.19	4.20	Potassium	K	3.38	4.44
Sodium	Na	6.45	5.00	Sodium	Na	2.22	1.72
Iron	Fe	5.91	11.14	Iron	Fe	5.51	10.34
Magnesium	Mg	4.30	3.52	Magnesium	Mg	2.66	2.17
Phosphorus	P	1.42	1.49	Phosphorus	P	1.01	1.05
Calcium	Ca	0.90	1.21	Calcium	Ca	0.00	0.00
Chlorine	Cl	0.75	0.89	Chlorine	Cl	0.55	0.66
Sulfur	S	1.04	1.12	Sulfur	S	1.00	1.08
Titanium	Ti	0.84	1.36	Titanium	Ti	0.49	079

Table 9: Plant sample analysis from lithium mining site and host community at point 1

Lithium mining site (Shrub)			Host community (Shrub)		
Element name	**Symbol**	**Conc. (%)**	**Element name**	**Symbol**	**Conc. (%)**
Oxygen	O	42.645	Oxygen	O	42.214
Magnesium	Mg	0.000	Magnesium	Mg	0.000
Aluminum	Al	9.186	Aluminum	Al	2.776
Silicon	Si	22.198	Silicon	Si	26.789
Phosphorus	P	0.232	Phosphorus	P	0.382
Sulfur	S	0.452	Sulfur	S	1.120
Chlorine	Cl	2.322	Chlorine	Cl	4.973
Potassium	K	7.164	Potassium	K	8.306
Calcium	Ca	4.271	Calcium	Ca	9.038
Titanium	Ti	1.129	Titanium	Ti	0.375
Vanadium	V	0.060	Vanadium	V	0.022
Chromium	Cr	0.058	Chromium	Cr	0.007
Manganese	Mn	0.235	Manganese	Mn	1.394
Iron	Fe	9.260	Iron	Fe	2.329
Cobalt	Co	0.048	Cobalt	Co	0.012
Nickel	Ni	0.003	Nickel	Ni	0.004
Copper	Cu	0.187	Copper	Cu	0.142
Zinc	Zn	0.066	Zinc	Zn	0.027
Rubidium	Rb	0.290	Rubidium	Rb	0.020
Zirconium	Zr	0.110	Zirconium	Zr	0.027
Niobium	Nb	0.022	Niobium	Nb	0.013
Molybdenum	Mo	0.005	Molybdenum	Mo	0.004
Silver	Ag	0.042	Silver	Ag	0.006
Tin	Sn	0.000	Tin	Sn	0.000
Barium	Ba	0.000	Barium	Ba	0.000
Tantalite	Ta	0.014	Tantalite	Ta	0.015
Tungsten	W	0.002	Tungsten	W	0.004

Furthermore, the concentration of Aluminum (Al) seems to be high in both samples of the host community 23.64% Al and 23.24% Al for the mining site. High concentration of aluminum in soil is also toxic to plants and aluminum toxicity is a significant concern in acidic soils where aluminum becomes more soluble and available to plants. In such conditions, aluminum ions can inhibit root growth, impair nutrient uptake and interfere with various physiological processes in plants ultimately leading to reduced crop yields and plant health. The presence of Aluminum and other associated elements in the lithium ore can also be traced in the soil as a result of weathering and leaching processes of the aluminum-bearing minerals, such as spodumene ($LiAlSi_2O_6$), lepidolite ($K(Li,Al)_3Al,Si,Rb)_4O_{10}(F,OH)_{2)}$, and Albite Na ($AlSi_3O_8$)) found in the matric of the ore samples.

Table 6 shows the XRF result of soil samples obtained from point 2, respectively. It reveals that the mining site has 50.41% Si while the host community has 60.62% Si; Aluminum: Mining site: 31.08% Al, host community: 22.73% Al; Potassium: Mining site: 5.11% K, host community: 2.56% K; Sodium: Mining site: 3.55% Na, host community: 2.80% Na; Iron: Mining site: 3.03% Fe, host community: 5.14% Fe; Magnesium: Mining site: 3.00% Mg, host community: 2.78% Mg; Phosphorus: Mining site: 1.65% P, host community: 0.88% P; Calcium: Mining site: 1.07% Ca, host community: 0.00% Ca; Chlorine: Mining site: 0.52% Cl, host community: 0.90% Cl; Sulfur: Mining site: 0.73% S, host community: 0.91% S; Titanium: Mining site: 1.06% Ti, host community: 0.66% Ti. However, it can be observed from Table 6 that almost all the mineral elements found in the soil sample of the mining site can be traced in the sample of the host community though Calcium is not present in the soil sample of point 2 of the host community. The reason for this trend could be attributed to the geochemical and mineralization of the soil sample of the host community that may have not favored formation of calcium during the mineralization process. Furthermore, the weathering process could be responsible for the leaching of the calcium in the soil sample of the host community. However, the lack of calcium in the soil sample of the host community presents a treat to the nutrient dynamics of the soil and can also affect plant growth. Furthermore, the soil in both host community and lithium mining site appears to have high concentration of Aluminum of 31.08% Al in mining site and 22.73% Al in host community. The high concentrations of Aluminum in soil are toxic to plant and inhibit their growth. However, the high concentration of Aluminum in the soil could also be due to the weathering process of Aluminum bearing minerals.

Table 10: Plant sample analysis from lithium mining site and host community at point 2

Lithium mining site (Shrub)			Host community (Shrub)		
Element name	**Symbol**	**Conc.(%)**	**Element name**	**Symbol**	**Conc. (%)**
Oxygen	O	42.437	Oxygen	O	41.365
Magnesium	Mg	0.000	Magnesium	Mg	0.000
Aluminum	Al	9.208	Aluminum	Al	6.851
Silicon	Si	21.791	Silicon	Si	21.984
Phosphorus	P	0.477	Phosphorus	P	0.182
Sulfur	S	0.570	Sulfur	S	0.938
Chlorine	Cl	2.899	Chlorine	Cl	3.653
Potassium	K	7.485	Potassium	K	9.150
Calcium	Ca	3.854	Calcium	Ca	6.360
Titanium	Ti	1.232	Titanium	Ti	1.316
Vanadium	V	0.054	Vanadium	V	0.066
Chromium	Cr	0.020	Chromium	Cr	0.029
Manganese	Mn	0.325	Manganese	Mn	1.144
Iron	Fe	8.578	Iron	Fe	6.395
Cobalt	Co	0.051	Cobalt	Co	0.016
Nickel	Ni	0.003	Nickel	Ni	0.014
Copper	Cu	0.200	Copper	Cu	0.250
Zinc	Zn	0.087	Zinc	Zn	0.102
Rubidium	Rb	0.276	Rubidium	Rb	0.000
Zirconium	Zr	0.113	Zirconium	Zr	0.074
Niobium	Nb	0.035	Niobium	Nb	0.022
Molybdenum	Mo	0.013	Molybdenum	Mo	0.010
Silver	Ag	0.024	Silver	Ag	0.016
Tin	Sn	0.000	Tin	Sn	0.000
Barium	Ba	0.000	Barium	Ba	0.000
Tantalite	Ta	0.074	Tantalite	Ta	0.060
Tungsten	W	0.001	Tungsten	W	0.003
Strontium	Sr	0.193	Strontium	Sr	N/D

Table 11: Plant Sample analysis from the lithium mining site and host community at point 3

Lithium mining site			Host community		
Element Name	**Symbol**	**Conc. (%)**	**Element Name**	**Symbol**	**Conc. (%)**
Oxygen	O	36.181	Oxygen	O	37.030
Magnesium	Mg	0.000	Magnesium	Mg	0.000
Aluminum	Al	5.175	Aluminum	Al	4.615
Silicon	Si	15.013	Silicon	Si	17.105
Phosphorus	P	0.712	Phosphorus	P	0.242
Sulfur	S	1.791	Sulfur	S	1.005
Chlorine	Cl	6.000	Chlorine	Cl	3.931
Potassium	K	16.764	Potassium	K	15.245
Calcium	Ca	10.991	Calcium	Ca	13.390
Titanium	Ti	0.836	Titanium	Ti	1.260
Vanadium	V	0.048	Vanadium	V	0.057
Chromium	Cr	0.041	Chromium	Cr	0.056
Manganese	Mn	0.680	Manganese	Mn	0.547
Iron	Fe	4.650	Iron	Fe	4.175
Cobalt	Co	0.010	Cobalt	Co	0.028
Nickel	Ni	0.005	Nickel	Ni	0.013
Copper	Cu	0.216	Copper	Cu	0.438
Zinc	Zn	0.117	Zinc	Zn	0.142
Rubidium	Rb	0.206	Rubidium	Rb	0.082
Zirconium	Zr	0.050	Zirconium	Zr	0.089
Niobium	Nb	0.017	Niobium	Nb	0.068
Molybdenum	Mo	0.006	Molybdenum	Mo	0.021
Silver	Ag	0.018	Silver	Ag	0.070
Tin	Sn	0.313	Tin	Sn	0.000
Barium	Ba	0.045	Barium	Ba	0.193
Tantalite	Ta	0.040	Tantalite	Ta	0.018
Tungsten	W	0.000	Tungsten	W	0.026
Strontium	Sr	0.074	Strontium	Sr	0.156

Table 7 presents the result of the soil samples of the mining site and the host community at point 3. The result reveals that soil sample of the mining site has 45.85% Si in host community, 55.15% Si in mining site, 31.18% Al in mining site, 26.69% Al in host community; 4.35% K in mining site, 2.71 K% in host community; 3.76% Na in mining site, 2.47% Na in host community; 6.46% Fe in mining site, 6.70% Fe in host community; 4.80% Mg in mining site, 2.97% Mg in host community; 0.76% P in mining site, 1.12% P in host community; 0.78% Ca in mining

Table 12: Result of lithium flame test analysis of soil samples/mining risk factor

Serial number	Mining site				Host community			
	Soil samples	Li content (ppm)	Mining risk factor Mining (*Rf=Ci/Cn*)	Remark of risk (0–1: Low; 1–10: Moderate; >10: High)	Soil samples	Li content (ppm)	Mining risk factor (*Rf=Ci/Cn*)	Remark of risk (0–1: Low; 1–10: Moderate; >10: High)
1	Soil Sample 1	1.431	139.76	High	Soil Sample 1	0.0278	7194.24	High
2	Soil Sample 2	1.187	168.49	High	Soil Sample 2	0.0185	10,810.81	High
3	Soil Sample 3	0.571	350.26	High	Soil Sample 3	0.0139	14,388.48	High

Table 13: Result of lithium flame test analysis of plant samples/mining risk factor

Serial number	Mining site				Host community			
	Plant samples	Li content (ppm)	Risk factor of mining (*Rf=Ci/Cn*)	Remark of risk (0–1: Low; 1–10: moderate; >10: High)	Shrub samples	Li Content (ppm)	Risk factor of mining (*Rf=Ci/Cn*)	Remark of risk (0–1: Low; 1–10: Moderate; >10: High)
1	Plant Sample 1	0.477	10.482	High	Plant Sample 1	0.0185	270.27	High
2	Plant Sample 2	0.562	8.896	Moderate	Plant Sample 2	0.194	25.773	High
3	Plant Sample 3	0.466	10.729	High	Plant Sample 3	0.0139	359.71	High

site, 0.37% Ca in host community; 0.45% C in mining site, 0.70%C in host community; 0.63% S in mining site, 0.79% S in host community; and 0.98% Ti in mining site, 0.33% Ti in host community. Based on the result obtained, it can be observed that all the mineral elements found in the soil sample of the mining site are also found in the soil sample of the host community at point 3. Table 4 as provided above, revealed that the soil in both host community and lithium mining site appears to have high concentration of Aluminum (Al). The Aluminum (Al) concentration is found to be 31.18% in mining site and 26.69% in host community. Furthermore, Calcium (Ca) concentration is low in host community with 0.37% compared to lithium mining site of 0.78%, Potassium (K) is also low with 2.71% compared to lithium mining site of 4.35%. Based on soil nutrient dynamics, the high concentration of Aluminum (Al) in host community also shows soil toxicity in point 3.

Table 8 presents the distribution of the various mineral elements in the soil samples of the mining site and the host community. It results revealed that mining site soil sample contains 44.29% Si, host community: 62.71% Si; Aluminum: Mining site: 30.91% Al, host community: 20.48%, Al; Potassium: Mining site: 3.19% K, host community: 3.38% K; Sodium: Mining site: 6.45% Na, host community: 2.22% Na; Iron: Mining site: 5.91% Fe, host community: 5.51% Fe; Magnesium: Mining site: 4.30% Mg, host community: 2.66% Mg; Phosphorus: Mining site: 1.42%, host community: 1.01% P; Calcium: Mining site: 0.90% Ca, Host community: 0.00% Ca; Chlorine: Mining site: 0.75% Cl, host community: 0.55% Cl; Sulfur: Mining site: 1.04% S, host community: 1.00% S; Titanium: Mining site: 0.84% Ti, host community: 0.49%Ti.

Furthermore, it can observed that the soil sample in both the host community and mining site appears to have a high concentration of Aluminum 30.91% Al for the mining site and 20.48% Al in the host community. In point 4, the host community does not have calcium present compared to the lithium mining site of 0.90% Ca. Based on soil nutrient dynamics, the high concentration of Aluminum (Al) in the host community also shows soil toxicity at point 4.

The result in Table 9 shows that the concentration of Aluminum (Al) is higher in the plant sample of the lithium mining site (9.186% Al) compared to that of the host community (2.776% Al). This trend can be attributed to potential contamination caused by Aluminum enrichment of the soil due to weathering at the mining site triggered by the uncontrolled mining activity at the mining site thus enhancing the absorption and assimilation of aluminum ion by the plant at the mining site. This is due to the aluminum presence in the lithium-bearing mineral (Spodumene-$Li_2OAl_2O_3$ $4SiO_2$), Petalite-$LiAlSi_4O_{10}$ and Lepidolite- $KLi_2Al(Al,Si)_3O_{10}$ $(F,OH)_2$)). Furthermore, Silicon (Si) concentration is higher in the host community shrub (26.789%) compared to the mining site plant (22.198%). This may indicate differences in soil composition due to land use patterns between the two locations. Other elements such as Potassium (K), Calcium (Ca) and Iron (Fe) concentrations are relatively similar between the mining site and the host community, although there are slight variations. Phosphorus (P), Sulfur (S), and Chlorine (Cl) concentrations also show some differences between the two locations, with higher concentrations observed in the host community for P, S, and higher concentrations observed in the mining site for Cl. The indication of the presence of P, S, and Cl in high concentrations in both plant samples of the host community and the mining site reveals the potential risk of the shrubs to suffer stunted growth due to toxicity caused by the high concentration of the elements.

From Table 10, the concentration of Aluminum (Al) in the plant sample from the lithium mining site (Al) is higher (9.208%) compared to the host community (6.851%) though the host community is also favorably high with a competitive concentration of 6.851% though, they are both higher when compared to 0.01% Al needed by plant. This suggests a higher presence of Aluminum both in the plant sample at the mining site and in the host community. The trend could be attributed to weathering processes of lithium minerals within the host community since the lithium-bearing minerals are also Aluminum-based minerals (e.g., spodumene, lepidolite, albite, etc.). This suggests a higher presence of Aluminum both in the plant sample at the mining site and in the host community. The trend could be attributed to the weathering processes of lithium minerals within the host community since the lithium-bearing minerals are also Aluminum-based minerals (e.g., spodumene, lepidolite, albite, etc.).

Table 11 shows that the concentration of Aluminum in the plant at the lithium mining site is slightly higher (5.175% Al) compared to the plant sample at the host community (4.615% Al) though the competitive concentration of Aluminum in both sites suggests potential contamination or enrichment of Aluminum in the soil from which there was Aluminum intake into the plant. This high Aluminum concentration also poses great health concerns to man's health since some of the plants are sources of food for both man and animals. Chlorine concentration is higher in the mining site (6.000%) compared to the host community (3.931%). The percentage of Chlorine and Iron obtained in the plants for both the host community and the mining site are above the specified limits of 0.002–0.02% Cl and 1–3% for plants, respectively.

CONCLUSION

From Tables 12 and 13 above, the mining risk factor (R_f) values for lithium mining activities as seen in the soil samples at the mining site and the host community was found to be extremely high. The soil samples of the mining site have R_f of 139.76, 168.49, and 350.26 while the soil samples from the host community have R_f of 7,194.24, 10,810.81, and 14,388.48, respectively. More so, the mining R_f values for plant samples from the mining site was found to be significantly high above the standard specified value of ≤10. R_f values for plant samples at the mining site was found to be 10.482, 8.896, and 10.729 while R_f values for the host community was found to be 270.27, 25.773, and 359.71, respectively. The mining R_f values for plant and soil samples all point to be extremely detrimental to both plant and human health hence the need for certain mitigations to reduce the effect posed by lithium mining activity in the community.

Recommendations/mitigations

i. Implement measures to mitigate soil and plant contamination resulting from lithium mining activities, such as proper waste management systems and remediation techniques
ii. Soil treatment should be carried out (either biological or physical) to reduce the level of soil toxicity
iii. Conduct regular monitoring of soil quality in the community to assess potential health risks and environmental impacts
iv. Foster stakeholder collaboration between mining companies, local authorities, and community members to address health concerns and promote sustainable development in the community
v. The agricultural soil of the host mining community should be treated to enhance balanced nutrient dynamics for the crops and plants.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

As approved by the Department of Metallurgical and Materials Engineering; Ahmadu Bello University, Nigeria for the purpose of "Academic Research" and "Addition to Knowledge."

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AUTHOR'S CONTRIBUTION

EEC was involved in the fieldwork, site visitation, collection of data, writing, and typing of the research while RAM and DT were research supervisors. All authors have read and approved the final manuscript.

CONSENT FOR PUBLICATION

Not applicable.

AVAILABILITY OF DATA AND MATERIALS

Not applicable.

COMPETING INTEREST

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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