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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

EBIKEMEFA EBIMOBOWEI CLINTON, RAMALAN ALIYU MOHAMMED, DUNGKA THOMAS

Department of Metallurgical and Materials Engineering, Ahmadu Bello University, Zaria, Nigeria. E-mail: clintonebiks@gmail.com

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ABSTRACT

Transition to green energy has made lithium mining one of the biggest ventures 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 plants in the Angwa-Kede community due to observed poor agricultural yield. A systematic sampling method was conducted on both plant and soil samples from the 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 fluorescence analysis (XRF) analysis to check elemental composition and the nutrient dynamics of both plant and soil. The XRF result revealed that soil samples from the 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 the lithium mining site contain 0.466–0.477 ppm Li while those from the host community has lithium concentrations 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 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. In conclusion, the obtained result shows a high level of soil and plant contamination in the Angwa-Kede community, which is caused by uncontrolled mining method and a poor waste disposal system.

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

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BACKGROUND

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.

However, an elevated concentration of certain elements can become detrimental, impeding plant growth and yield (Anjum, 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 effects on plants is presented in Table 1 below.

PLANT RESPONSES TO LITHIUM PRESENCE

Babar and Tanveer (2016) have categorized plants into four groups based on their reactions to the presence of Lithium (Li):

(i) Lithium accumulators: 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.
(ii) Conditional accumulators: 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.
(iii) Non-lithium demanders: The third group comprises plants with minimal Lithium requirements, avoiding soils with elevated Lithium content. Examples include plants from the Brassicaceae, Caprifoliaceae, Liliaceae, and Poaceae families.
(iv) Lithium-tolerant non-demanders: Plants in the fourth group 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.

While these categorizations provide insights into plant reactions to Lithium, the nuanced responses across different plant species underscore the complexity of Lithium-plant interactions. Further research is imperative to unravel the molecular mechanisms underpinning these varied responses and to develop strategies for harnessing the potential benefits of Lithium without compromising plant health and productivity. The responses of different species of plants to lithium concentration are presented in Table 2 below.

Lithium in the environment: Soil and plant interaction

Naturally, Lithium concentrations in soil typically range between 2 and 200 mg/kg. Various soil types, such as light sandy soils in humid climates, contain lower Lithium content, whereas heavy loamy soils possess higher concentrations. On average, light organic soils contain about 1.3 mg/kg, and limestone soils contain 56 mg/kg. Arid and saline soils tend to have relatively higher Lithium concentrations.

In arid conditions, Lithium migrates upward with the soil solution and accumulates in the upper layers as easily soluble salts, such as borates, sulfates, and chlorides. Similar to Sodium (Na), Lithium (Li) is found on the surface of soil colloids in an easily exchangeable form. A positive correlation between clay content and exchangeable Lithium in the soil has been observed. The clay fraction contains higher Lithium concentrations than the organic soil fraction, with reported Lithium content ranging from 7 to 200 mg/kg.

In soil, Lithium exists as Lithium oxide (Li_2O), Lithium chloride (LiCl), and Lithium carbonate (Li_2CO_3) primarily in the clay fraction and to a lesser extent in the organic soil fraction. Lithium content in typical mineral deposits varies widely from 0.5 to 2%, influenced by deposit location and Lithium mineral type (Babar and Tanveer, 2016).

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
10lbs Li/Ac ($Li2_SO_4$)	Spinach, mustard	In reduced light increased plant fresh weight
Murashige and Skoog 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 and 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^{-1})	No reduction in A. venetum shoot and root dry weight, chlorophyll contents, and leaf gas exchange
		High (200 and 400 mg kg^{-1})	Significant reduction in shoot and root dry weight, chlorophyll contents, and leaf gas exchange
Asteraceae	*Helianthus annuus*	Low (20 and 40 mM)	No reduction in hypocotyl length and in 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.	Low (2.5 mg dm^{-3})	Significant increase in the root system
	Capitata (Lettuce)	High (50 or 100 dm^{-3})	Considerable reduction in the root system
Poaceae	Zea 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 and Tanveer (2016)

Lithium accumulation in plants

Research conducted by Kabata-Pendias (2010) sheds light on Lithium (Li) concentrations 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), Ranunculacea (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 *et al.,* (2016) expanded this understanding by analyzing Lithium (Li) concentration in thirteen plant species collected from the field. Ranunculus sardous Crantz (2.16) and Plantago laceolata L. (0.42) demonstrated the highest concentrations (ppm), whereas Vitis vinifera L. (0.05) and Hypericum perforatum L. (0.05) exhibited the lowest.

Taro Kishi *et al*., (2021) reported varying Lithium (Li) concentrations in specific plant species in karst areas, with Lolium sp. averaging 4.30 mg Li/kg DW, Mentha sp. at 1.70, and Urtica sp. at 0.66 mg Li/kg DW. Notably, Cirsium arvense and Solanum dulcamera 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) remediation in soils. Lithium concentration is seen in Table 3 below.

METHODS

Obtained soil and plant samples from the host community and mining areas as represented in the map shown in Fig. 1 were crushed and pulverized. Using a benchtop oven, the pulverized samples were dried to remove moisture and a representative sample of 100g each was taken to the Laboratory for X-ray fluorescence analysis (XRF) and Flame Test analysis. The coordinates 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.

RESULTS

The various obtained results are seen in Table 5-13 below

DISCUSSION

Table 5 above shows the XRF result for the 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 (Al): 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: 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 the host community and lithium mining site appear to have 0.95% Cl and 0.90% Cl, respectively, which are far above the 0.3% Cl required by plants and animals. The presence of high chlorine in the soil leads to formation of chlorine ions, which acidifies the soil and thus affects the roots of the Plants leading to stunted growth.

Furthermore, the concentration of 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 Al 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; Al: 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, which may have not favored the

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 beet	0.3–11.7 (FW)	-
Celery	6.6 (DM)	-
Chard	6.2 (DM)	-

Source: Babar and Tanveer (2016)

Table 4: Soil and plant samples coordinates

Angwa kede mine site points A and B					
Mining site			Host community		
S/N	Latitude (X)	Longitude (Y)	S/N	Latitude	Longitude
1	N8° 47'11.3928"	E7° 57' 1.0332"	1	8.777268°	7.958065°
2	N8° 47' 11.3928"	E7° 57' 0"	2	8.777165°	7.957997°
3	N8° 47' 10"	E7° 57' 1"	3	8.777137°	7.958087°
4	N8° 49' 40.74"	E7° 58' 52.28"	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 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

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 the 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

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 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

formation of calcium during the mineralization process. Furthermore, the weathering process could be responsible for the leaching of 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 the host community and lithium mining site appears to have a high concentration of Al of 31.08% Al in the mining site and 22.73% Al in the host community. The high concentrations of aluminum in soil are toxic to plants and inhibit their growth. However, the high concentration of Al in the soil could also be due to the weathering process of Al bearing minerals.

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 the Mining Site, 2.71K% in the 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 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; 0.98% Ti in Mining Site; and 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 the host community and lithium mining site appears to have a high concentration of Al. The 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 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; Al: 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 Al 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 Al in host community also shows soil toxicity at Point 4.

The result in Table 9 shows that the concentration of 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 Al 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 Al ion by the plant at the mining site. This is due to the Al presence in the lithium-bearing mineral (Spodumene-$Li_2O\mathbf{Al}_2O_3$ $4SiO_2$), Petalite-$Li\mathbf{Al}Si_4O_{10}$ and Lepidolite- $KLi_2\mathbf{Al}(\mathbf{Al},Si)_3O_{10}(F,OH)_2$)). 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, and 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 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 Al 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 Al based minerals (E.g. Spodumene, Lepidolite, Albite etc.). This suggests a higher presence of Al 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 Al based minerals (E.g. Spodumene, Lepidolite, Albite etc.).

Table 11 shows that the concentration of Al 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 Al in both sites suggests potential contamination or enrichment of Al in the soil from which there was Al intake into the plant. This high Al 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

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

S/N	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

S/N	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

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 were found to be extremely high. The Soil samples of the mining site had R_f of 139.76, 168.49, 350.26 while the Soil samples from the host community had 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 were found to be significantly high above the standard specified value of ≤10. R_f values for Plant samples at the mining site were found to be 10.482, 8.896, and 10.729 while R_f values for the host community were 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 AND 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."

CONSENT FOR PUBLICATION

Not applicable

AVAILABILITY OF DATA AND MATERIALS

Not applicable

COMPETING INTERESTS

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

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AUTHORS CONTRIBUTIONS

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.

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