

Original Research

Impacts of Ion Adsorption Type Rare Earth Mining Techniques on Topsoil in Mining Area

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Abstract

Rare earth elements (REE) are essential components in various modern technologies. Mining activities, in contrast, severely destabilize the adjacent ecological systems. The soil transformation environmental issue in mining areas is inextricably linked to process techniques. Inconsistencies in harm and serviceability arise from different mining techniques. This study was conducted in Fujian, China, which has abundance of ion adsorption type rare earth resources (IAT-Res). We investigated the soil interaction effects of two mining techniques (heap leaching and *in-situ* leaching). After eight years of restoration, soil destruction and nutrient imbalance remain significant in the heap leaching mining regions. The effects of heap leaching are distinct, whereas pollution caused by *in-situ* leaching is hidden. Although the *in-situ* leaching technique resulted in less soil erosion, its potential environmental risk cannot be ignored. The greater number of $(\text{NH}_4)_2\text{SO}_4$ leachate residues left over after *in-situ* leaching contaminate the surrounding ecosystem as they are easily translocated. Through this study, we demonstrate the ecological impacts of different mining techniques in mining areas. As a result, to obtain accurate protection and contaminant control management. However, additional interests should address the leachate and REE pollution caused by *in-situ* leaching in a larger region.

Keywords: rare earth element, mining techniques, *in-situ* leaching, topsoil, leachate

Introduction

Rare earth elements (REE) are the BIII group on the periodic table, which comprise lanthanide, plus scandium and yttrium [1]. In the last two decades, the global demand for REE increased rapidly from 75,500 tons in 2000 to 170,000 tons in 2020 [2, 3]. Spurred applications of REE in new material, energy conservation, medical equipment [4]. The ion adsorption type rare earth resources (IAT-Res) dormant the world's supply of heavy rare earth element (HREE) production and distribute widely distributed in southern China [5, 6]. High economical profits derived the increasing of small factories and workshops, which are operating at low cost and unregulated [7]. Thus, mining consequence ecological issues are becoming a significant challenge to the ecosystem and habitats in this area.

Environmental impacts by IAT-Res mining are long-term processes and are highly related to mining techniques. The vast leachates that remain in the soil by the mining process change the characteristics of the topsoil in the mining area and cause the natural vegetation difficult to recover [6, 8]. The heap leaching process completely strips the topsoil in the mining area, affects soil fertility, and breaks the ecological balance after mining [8, 9]. Experiments in this area revealed that after leap leaching, the soil erosion was effectively controlled after restoration, but the soil fertility remained poor, such as organic matter, total nitrogen, and available phosphorus [10]. Another example showed that, soil physicochemical properties in the mine tailings did not significantly improve after 10 years of restoration [11]. Additionally, the IAT-Res mines are mainly located on granite hills where the ecosystem is fragile [2, 5, 11]. Mining of REE led to soil desertification, low fertility,

and difficult restoration of vegetation, damaging the surrounding land resources are even more severely. After China limited the REE supply in 2010, the exploration of REE is expanding to other countries, such as the USA, Australia, Myanmar, Madagascar, Brazil, Vietnam, India [3]. Mining consequence negative impacts on the ecosystem have become an international issue.

The special deposits and mining techniques for IAT-Res change the surface environment of the mining area have distinct regional and industrial characteristics [12]. Under the dual effects of natural phenomena (such as rainfall, leaching, wind, etc.) and human activities (such as mining, smelting, farming, etc.), REE are likely to migrate, accumulate, transform and diffuse in the soil [13, 14], which is wasting a large number of IAT-Res and contaminating the ecological environment. Furthermore, REE enter human body through the food chain and other pathways, affecting the physical and mental health of surrounding residents [15]. The effect of different IAT-Res mining technologies on the natural environment of the mining area needs to be studied, thus providing scientific information for conservation and ecological restoration in the mining area.

Experimental

Sampling Site

The sampling sites are located in the southwest Fujian, China, where is one of the REE supplying centers [16]. Changting County ($25^{\circ}18'26^{\circ}02'LN$, $116^{\circ}01'116^{\circ}39'LE$) that covers a district area of 3099.59 km², and Liancheng County ($25^{\circ}13'25^{\circ}56'LN$,

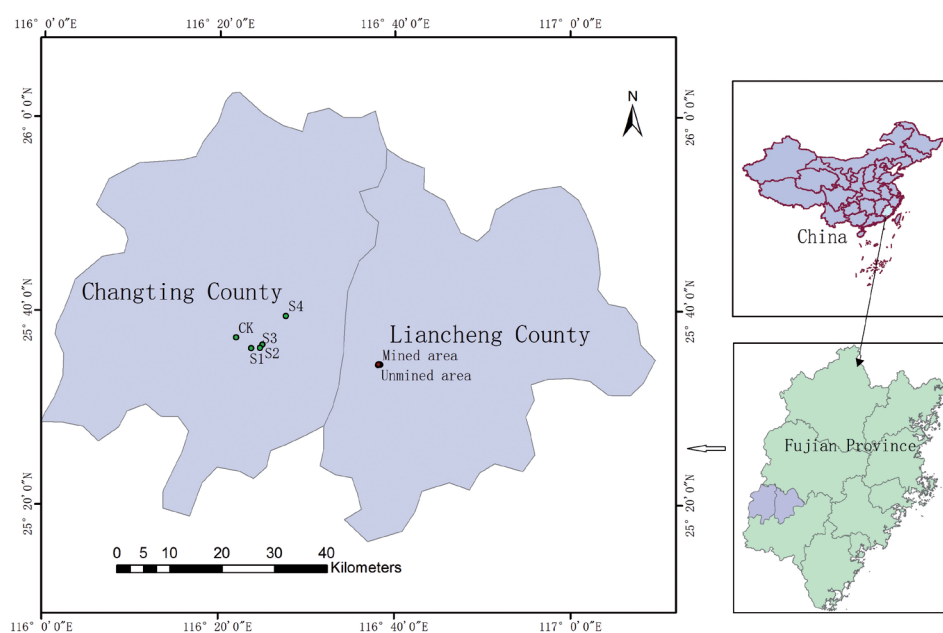


Fig. 1. Location of the sampling site.

116°32'-117°10'LE) where the overall area is around 2578.59 km² (Fig. 1).

Changting County and Liancheng County are located in the mid-subtropical humid monsoon climate zone. The landforms in both counties are hilly areas with a well-developed water system and streams. Soil types in Changting County are mainly red soil and eroded red soil, which developed by the weathering of biotite granite with coarse mineral grains under a long-term of humid and hot climate. The soil is about 10-20 m with poor corrosion resistance, strong acidity, and low water and fertilizer retention capacity [14]. Red soil developed from biotite shells and gneissic porphyritic biotite granite dominates in Liancheng County. Both sampling sites are rich in REE deposits. The zonal vegetation in Changting County and Liancheng County both dominated with subtropical evergreen broad-leaved forest, however anthropogenic activities deconstruct the original forest. Nowadays, mono-structural secondary pine forests replaced most surface vegetation in Changting County, whereas in Liancheng County, secondary monsoon pines forest (*Pinus massoniana*) and fir (*Cunninghamia lanceolata*) forest occupies 82.8% of the total vegetation.

Methods

Sampling from the Fields

Both study area have developed in the REE exploration since the 1970s. The heap leaching is mainly applied in Changting, while *in-situ* leaching technique in Liancheng. In the past two decades, heap leaching has been eliminated in Changting county for REE mining, but tailings wasteland remained [17]. In this study, five sampling sites were chosen to investigate environmental impacts of the heap leaching technique. Four REE mining sites (S1, S2, S3, S4) with different restoration times (8 years, 6 years, 3 years, 0 year) and one unmined control site (CK). We set up 3 soil subsample points in each sampling site and used a diagonal method to collect soil with a depth of 0-10 cm and 10-20 cm in each plot. A total of 30 soil samples were collected from the 5 sampling sites [18].

The sampling site of *in-situ* leaching are in Liancheng County. The mining area is about 1.6 km², an *in-situ* liquid injection technology was used for mining, it had been abandoned 3 years at the sampling time. A total of about 3000 injection holes, 18 cm wide and 0.5-1 m depth, were arranged in 2 m×2 m on the hill ridge and slope sides. The soil and surface vegetation was all removed at locations where injection holes placed. The injection holes remained there at the investigation time, but ground herbaceous had widely recovered. We collected samples along the ride from three slope points (upper slope, middle slope, and lower slope) from the mined hill and an unmined hill as a control. A diagonal approach was used to obtain soil samples from three points in the mined area and the

unmined area, respectively. A total of 18 soil samples were collected from both sites. Each soil sample was carefully placed into a plastic bag and delivered to the laboratory.

Laboratory Measurement

All the soil samples were placed in a cool and ventilated place in the laboratory to air dry naturally. After removing impurities, such as rocks and roots, the soil samples were ground in a mortar, then passed through a 100-mesh (0.149 mm) sieve. The soil physical and chemical properties and REE determination methods are as follows: pH values were measured by water immersion-potential (soil: water = 1:2.5); the mechanical components were evaluated by Malvern particle size analyzer (Masterrizer 2000, UK); soil organic carbon and total nitrogen were investigated by carbon and nitrogen element analyzer (Elementar Vario MAX, Germany); total phosphorus was determined by perchloric acid digestion method and molybdenum antimony colorimetric method; REE were estimated by high-temperature digestion ICP-MS (XSERIES 2, Thermo Scientific, USA) (H. Chen et al., 2019).

Data Analysis

All experimental data were processed under Microsoft Excel and IBM SPSS 19.0 software. One-way analysis of variance (One-Way ANOVA) with the least significant difference (LSD) was used to test the differences of soil carbon, nitrogen and phosphorus nutrients, and the Pearson correlation analysis method was used for correlation analysis.

Mining Techniques

The heap leaching technique has been replaced by the *in-situ* technique in the last two decades. Because the heap leaching requires to remove all vegetation and excavate the whole area, while *in-situ* leaching only removes vegetation in areas where to install injection wells. Alternatively, the *in-situ* leaching needs a larger amount of leachate during processing than the heap leaching.

Results

Physical and Chemical Properties of Soils with Different Restoration Years

The Soil pH and Mechanical Properties

The soil pH in areas processed with heap leaching varied between 4.31-5.22 (Table 1). All of the samples' pH were lower than 5, except 10-20 cm soil at S1, where had the longest restoration time. The order of the pH was S3>S1>S2>CK>S4 and S1>CK>S3>S2>S4

in the soil of 0-10 cm and 10-20 cm respectively. The difference in sand, silt, and clay content between soil layers in the same plot was not significant, except for the sand content in S2 and clay content in the CK. The sand and silt content in mining areas were both significantly higher than that in the CK, while the clay content was opposite. The silt content in restoration plots was significantly higher in CK and lower in S4. The maximum soil clay content from 0-10 cm was found in S4, which was significantly higher than the CK. While in 10-20 cm soil shown in contrast. Both CK and S4 that without restoration were significantly higher than restoration plots [18].

Table 2 showed that the soil pH after the *in-situ* mining process varied between 4.31-4.71. In mined areas, the pH showed an increasing trend downwards with all values lower than 4.5, while the trend was contrasting in the control site and all higher than 4.5. The soil sand content increased vertically downward in both the mining area and the unmined area. In the mined area,

the lower slope was significantly higher than the middle and upper slopes. At the same slope, the upper slope of the mine area was significantly higher than that of the unmined area, while the differences in the middle and lower slope were not significant. The silt content of soil increased first and then decreased in the mining area, whereas the control site shows a decreasing trend from the top to the bottom. On the upper slope, the unmined area was significantly higher than the mine area, but this does not show at the middle and lower slopes. The changing trend of soil clay content was opposite to that of sand content, which decreased downward in both sites. The two plots have significant differences at each slope. At the same slope point, the upper slope and lower slope in the control site were significantly higher than those in the mining area, but not in the middle slope.

Table 1. Soil pH and mechanical composition by heap leaching.

Sampling site	Restoration time /year	Sampling depth /cm	pH	Mechanical Composition /%		
				Sand particle	Silt particle	Clay particle
S1	8	0-10	4.64±0.15	51.44±5.19aA	39.13±3.43aB	9.43±1.99aC
		10-20	5.22±0.17	51.10±12.02aA	39.15±8.31aB	9.75±3.73aB
S2	6	0-10	4.35±0.12	44.97±10.59bB	44.89±8.72aB	10.13±2.03aC
		10-20	4.44±0.32	52.83±3.83aA	38.64±3.59aB	8.53±0.26aB
S3	3	0-10	4.72±0.03	53.61±4.40aA	38.42±3.52aB	8.05±1.24aC
		10-20	4.58±0.15	54.42±5.52aA	37.36±4.92aB	8.23±0.74aB
S4	0 (no restoration)	0-10	4.31±0.01	53.63±2.60aA	27.35±3.74aC	19.02±1.14aA
		10-20	4.42±0.01	54.54±1.29aA	26.78±2.81aC	18.58±4.11aA
CK	0 (unmined)	0-10	4.31±0.14	23.93±7.25aC	61.07±7.45aA	15.01±2.04bB
		10-20	4.60±0.15	20.56±6.42aB	60.11±3.86aA	19.63±2.68aA

Note: S1: Niushitang, S2: Xiakeng, S3: Santongbazhou, S4: Huangnikeng, CK: Longjing. Low case letters indicate significant difference between sampling depths in the same sampling plot, capital letters indicate significant difference between sampling plots at the same depth ($p < 0.05$).

Table 2. Soil pH and mechanical composition by *in-situ* leaching

Sampling site	Slope position	pH	Mechanical Composition /%		
			Sand particle	Silt particle	Clay particle
Mined area	upper slope	4.31±0.01	26.11±1.05bA	51.54±0.28bB	22.35±0.77aB
	middle slope	4.37±0.02	28.77±0.76bA	54.73±0.62aA	16.49±0.14bA
	lower slope	4.40±0.01	38.87±4.87aA	49.29±3.34bA	11.84±1.52aA
Control	upper slope	4.71±0.01	15.06±0.37cB	60.60±0.35aA	24.33±0.22aA
	middle slope	4.58±0.02	27.36±1.59bA	54.19±2.10bA	18.45±0.50bA
	lower slope	4.52±0.02	36.06±1.90aA	49.22±1.23bA	14.72±0.67cA

Note: Different lowercase letters mean significant difference in the different sampling position of the same sample plot, different capital letters indicate significant difference in the same sampling position of the different sample plot ($p < 0.05$).

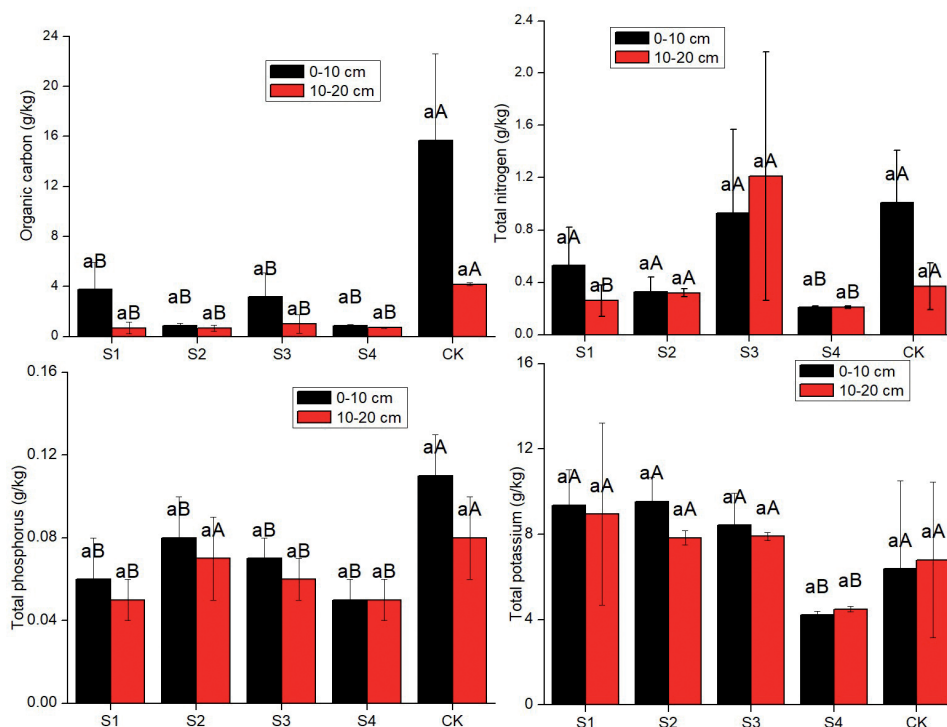


Fig. 2. The soil nutrient contents after heap leaching ($p < 0.05$).

Soil Nutrient Characteristics

Fig. 2 indicates that the soil organic carbon ($0.69\text{--}15.7\text{ g/kg}^{-1}$) was significantly higher in the CK than the four sampling sites at different depths, and there was no significant difference between the different soil layers in each site. The order of organic carbon content of soil from 0-10cm was $CK > S1 > S3 > S4 > S2$, while $CK > S3 > S4 > S1 > S2$ in the 10-20 cm soil. The total nitrogen content ranged from 0.21 to 1.21 g/kg^{-1} , in 10-20 cm soil of S1 and S4 were significantly lower than that of the other two plots and CK. The total nitrogen content in 0-10 cm soil was higher than that in 10-20 cm soil, except for S3. The total phosphorus content of the soil varied from $0.05\text{--}0.11\text{ g/kg}^{-1}$. The content of the CK was significantly higher than that of the sampling sites at different depths, except for the 10-20 cm soil layer of S2. The order of the total phosphorus content of both 0-10 cm and 10-20 cm soils was the same $CK > S2 > S3 > S1 > S4$. The total potassium content of the soil varied from $4.22\text{--}9.37\text{ g/kg}^{-1}$. The S4 at different depths was significantly lower than that of other sampling sites and CK. In the sampling sites with restoration, total potassium content at 0-10 cm was higher than 10-20 cm, and the CK and S4 showed the opposite trend, there was no significant difference between different depths. The trend was $S2 > S1 > S3 > CK > S4$ and $S1 > S3 > S2 > CK > S4$ in 0-10 cm and 10-20 cm soil, respectively.

From Fig. 3, in the mining area by *in-situ* technique, the organic carbon content varied between $5.56\text{--}16.75\text{ g/kg}^{-1}$. In mined area first decreased and then increased vertically downward, while it was opposite

in the unmined area. In the upper slope, the organic carbon content was significantly higher in the mining area than in the unmined area, in the other two slopes showed in contrast. The changing tendencies of total soil nitrogen content in both plots were consistent with organic carbon content. The total phosphorus content ($0.23\text{--}0.65\text{ g/kg}^{-1}$) of the soil in the mining area decreased first, then increased from the upper slope to the lower slope, while increased downwards in the unmined area. The phosphorus content at the same slope was significantly higher in mined area than in the control area, besides at the lower slope. The total potassium content ($4.20\text{--}8.64\text{ g/kg}^{-1}$) showed a decreasing trend in the mining area downwards, and the upper slope was significantly higher than the middle and lower slopes, while at the unmined area showed fluctuate downwards, and the upper slope was significantly lower than the middle and lower slopes. At the same slope position, the mining area was all higher than that in the unmined area, and significant differences were presented at the middle and upper slopes.

Discussion

Soil Physical and Chemical Properties of Different Mining Techniques

The soil pH is one of the most decisive properties, which impacts the availability of soil nutrients and indicates soil environmental characteristics [18]. The main factors that affect soil pH are the natural

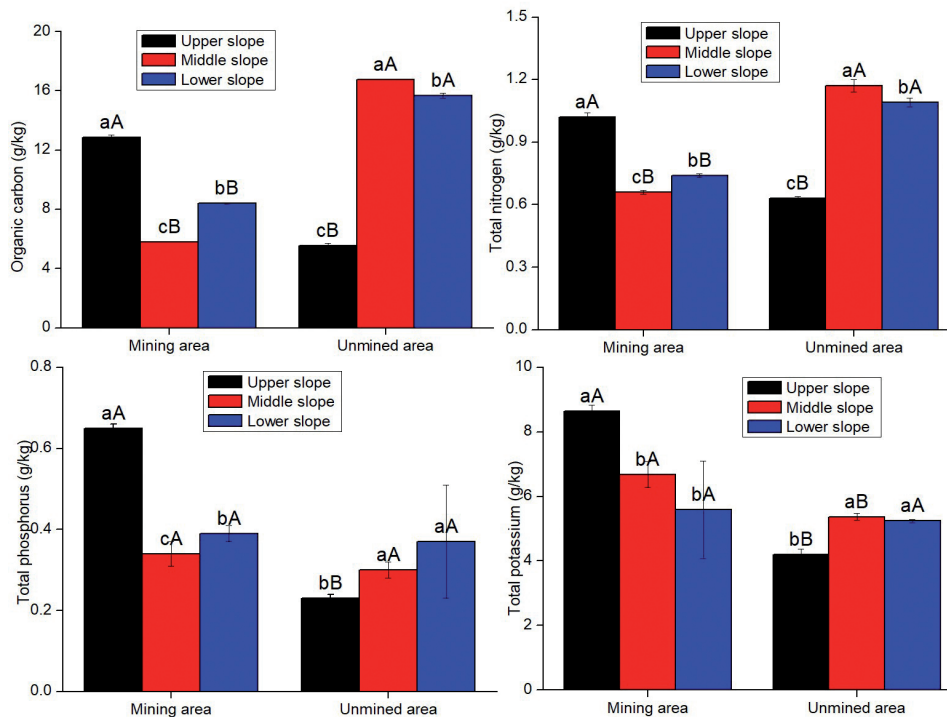


Fig. 3. The soil carbon, nitrogen and phosphorus contents after heap leaching ($p < 0.05$).

soil-forming conditions, followed by farming or resource extraction. For all soil samples from sampling sites after the heap leaching process, the pH were less than 5, besides the the 10-20 cm soil of S1. S1 was under the longest vegetation restoration time of eight years. While at S4 that without restoration, the pH values were less than 4.5 at each soil layer. The soil samples from mined areas were all showed strong acidity and visible piles. The heap leaching process significantly increased soil acidity, which was consistent with the results of most studies [8]. The 0-10 cm soil pH of CK was lower than 4.5, which may be because of the acidity of the subtropical red soil itself and the growth of *Dicranopteris pedata*. As the root system of *Dicranopteris pedata* concentrated in the surface layer and produced organic acid caused the soil pH decreases [19]. After *in-situ* leaching, the soil pH (4.31-4.71) in the mining area were lower than the unmined area, which demonstrated the *in-situ* leaching process also leads to soil acidity. Furthermore, liquid ammonia accelerates soil acidification [20]. Therefore, mining activities by heap leaching and *in-situ* leaching techniques both coursed soil acidity and nutrients decreasing.

The soil mechanical composition is important to either the soil structure characterization or as an index to measure soil quality [21]. The soil structure components varied significantly in the sampling sites after the heap leaching compared to the CK. The biggest difference between sampling sites and the CK was the sand content significantly increased, while silt and clay contents were significantly reduced. With the increase of management years, silt content raised and the clay

content decreased. The significantly increased sand content demonstrates that REE mining has resulted in soil destruction, which has not improved after years of restoration. The increase in silt contents mainly because of the growth of plants that make fine particles more effective. Compared to heap leaching, the impacts of *in-situ* leaching technology on the mechanical composition of the topsoil was lighter because this technique did not excavate the mountain, vegetation was removed only for deploying the injection holes on the slopes. Thus, the proper operation in the *in-situ* leaching process can avoid dramatic damage to the mountain structure, and the impact on the soil's mechanical composition can be small.

The soil organic carbon determines various soil functions and plays an important role in the formation of soil structure, nutrient release, and microbial activities. At the 0-10cm soil of the CK, the organic carbon content was similar to the background value of Fujian Province red soil (22.1 g/kg^{-1}) [22]. In the sampling sites, the organic carbon contents were significantly lower than CK, although they were improved after restoration. The maximum content in the mining area was only 3.76 g/kg^{-1} at the S1 where after 8 years of restoration, this demonstrates that the increase in soil organic carbon content in the mining areas is a slow process. Correspondingly, Zhang's study [23] in these areas also showed that the organic carbon content of 10-20 cm soil was about 5 g/kg^{-1} after 30 years of restoration. The soil organic carbon content fluctuated with the changing of restoration time. At the early restoration stage, in the mining area the organic carbon content increased

because fertilizer was applied to improve planted vegetation growth. However, the plantation dying out under the harsh growth environment of the mining area and soil erosion by rain, the organic carbon content began to decrease. Then the soil organic carbon content increased with the gradual invasion of some native fern species, such as *Dicranopteris pedata*. Compared with the unmined area, the change in soil organic carbon in the *in-situ* leaching mined area showed an opposite trend on different slope positions. The trend in unmined areas was agreed with studies of Seibert [24], the soil organic carbon at the bottom of the slope was higher than that at the upper slope. We also found that the growth of plants on the upper slope in the mining area was better than the middle and lower slope. It is because of the steep slope at the middle and lower slopes caused stronger nutrients loss by cutting off the herbaceous plants.

Soil nitrogen, phosphorus, and potassium were the most important nutrient elements for plant growth. Under the heap leaching mining process, the total nitrogen in the soil was relatively high at the initial stage of restoration, and a large amount of $(\text{NH}_4)_2\text{SO}_4$ remained after the mining area was abandoned. After 3 years of restoration (S3), the total nitrogen content of 10-20 cm soil reached 1.21 g/kg^{-1} , while in the unmined red soil site was only about 0.6 g/kg^{-1} , which demonstrated the residual leachate $(\text{NH}_4)_2\text{SO}_4$ in the early restoration stage increased soil nitrogen content. However, the nitrogen content was similar in S1, S2, and S4 indicates that plants are difficult to effectively uptake residual nitrogen from the soil. A further decrease of nitrogen in those sampling plots was because the residual $(\text{NH}_4)_2\text{SO}_4$ in the soil was easily washed away by precipitation. The nitrogen content after 6 years (S2) of restoration was about 0.3 g/kg^{-1} in both soil layers. The scouring and leaching effect of rainwater resulted in the nitrogen content at 10-20 cm soil layer was higher than that of the 0-10 cm soil layer after 8 years of restoration. The soil total nitrogen after *in-situ* leaching process on

the slope position was similar to the change of organic carbon. The residual nitrogen remained at the top of the slope because of the platform shape at the top of the ore. The leaching effect was the main cause of nitrogen loss in the middle and lower slopes. This means that *in-situ* leaching results in less nitrogen residue in the surface soil, and more nitrogen will stay in the mountain interior or migrate downstream with slope runoff. A dramatically larger amount of leachate is needed in the *in-situ* leaching, however, the nitrogen content in all slopes of the mining area was lower than the S3 after heap leaching, this further proof that the anthropogenic nitrogen did not be used by plants, they translocate and migrate to lower basins by leaching effects or wash off by precipitation. Therefore, the high potential risk of NH_4^+ and SO_4^{2-} pollution after *in-situ* leaching should be emphasized.

By further compared correlation of organic carbon content and total nitrogen after two mining methods, the *in-situ* leaching mined area was consistent with any type of soil, while the correlation in the heap leaching mining area was low, which indicated that the soil destruction led to nutrient imbalance strongly. This consist to the strong correlation between soil organic carbon and total nitrogen, it can reach 0.95 at the significant level of 0.01. Fig. 4 showed the equating relationship between soil organic carbon and total nitrogen, which suggested the lack of organic carbon was a critical factor imbalanced carbon and nitrogen nutrients in heap leaching areas.

The soil phosphorus mainly comes from the parent rock. In southern China, subtropical soils are deficient in phosphorus, and the total phosphorus content of 0-20 cm in the unmined red soil mountain is only 0.15 g/kg^{-1} [22], CK of the heap leaching the total phosphorus content of 0-10 cm soil was similar to that of uneroded red soil, but at 10-20 cm were also low. The total phosphorus content in the mining area was even lower. The lack of phosphorus restricted the growth of soil microorganisms, which made it difficult to improve the soil environment

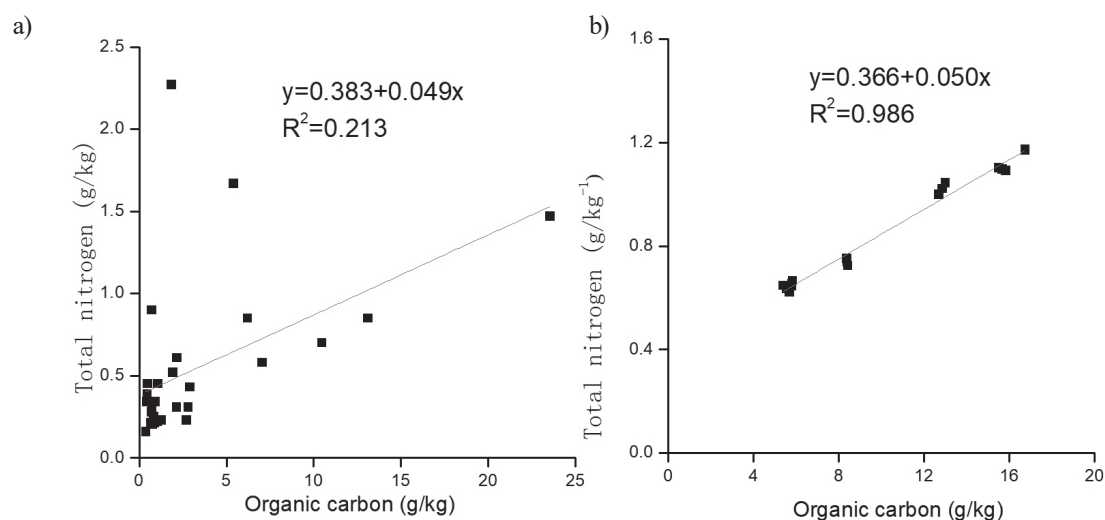


Fig. 4. Relationship between soil organic carbon and total nitrogen: a) heap leaching area, b) *in-situ* leaching area.

in the mining area and restricted plant growth [25]. The changing trend of the total phosphorus content in the four mining areas increased first and then decreased with the extension of the restoration time. Because plants absorbed a certain of phosphorus at the beginning of the restoration, the total phosphorus content in the soil after 3 years of restoration (S3) was relatively low. With the death of plants, phosphorus released into the soil, therefore the total phosphorus content increased after 6 years of restoration (S2). Afterward, new plants invaded and absorbed phosphorus, and the total phosphorus content showed a downward trend. However, the total phosphorus content of the soil in the *in-situ* leaching mined area was higher in the mining area than in the unmined area. The largest difference reflected at the top of the slope, it may due to the absorption and usage of residual ammonia nitrogen in the vegetation at the upper slope after the mining area was abandoned. The growth status was good, and plants absorbed and transformed more phosphorus in the underlying soil and returns it to the topsoil. The phosphorus content difference between the middle and lower slopes was less obvious. It was because less mobility of phosphorus in the soil as there was no erosion happened during *in-situ* mining [25].

The total potassium content in the heap leaching mining area was less than 10 g/kg^{-1} , showing an increasing trend with the increase of management period, and all are higher than the unmined Control area. The lowest content was in the S4, indicated the heap leaching mining method caused potassium leaching. Although the restoration of mining areas used a certain amount of potassium fertilizer, however, potassium was easy to leach downward at the initial stage. Only with the increase of time, the vegetation growth improved the use of potassium fertilizer. So that the potassium content in the top soil rose, but overall the potassium content was low. The total potassium in the *in-situ* leaching area was higher than the unmined area, which can be affected by plant growth, brought potassium from the deep soil to the top soil.

Different Impacts between Heap Leaching and *in-situ* Leaching Techniques

The heap leaching has been applied since the 1960s for IAT-Res. The heap leaching mining caused distinct and long-term ecological hazards, such as deforestation, and soil deconstruction. The rare earth mining in Ganzhou region has left 302 abandoned mines and 191 million tons of tailings and the area of destroyed forests increased from 23 km^2 in 2000 to 153 km^2 in 2010, and in June 2011, the Chinese central government enforced a ban on surface mining, such as tank/heap leaching, *in-situ* leaching was implemented for IAT-Res. The *in-situ* leaching is considered less harmful to the ecosystem. The *in-situ* leaching process does not require stripping large-area of the topsoil and less damage to vegetation. However, to excavate injection wells and

catchment ditches within the ore still generate waste tailings and damages the surface flora [26]. Research on soil erosion in mining areas of Longnan County, Ganzhou, Jiangxi Province showed that although the *in-situ* leaching technology reduced soil erosion, it posed a potential threat of landslides [9]. The *in-situ* leaching technique caused surface soil erosion was lower compared to the heap leaching method. However, the injection wells on hills may collapse as the time gone by can trigger landslides. The study of Sun [27] showed landslides happened in the Longnan mine area after *in-situ* leaching mining. The causes of landslides mainly because of changes in slope stability and the destruction of the ore body by leaching. The problem of landslides and overloaded leachate pollution consequences by *in-situ* leaching has attracted the attention of researchers. Moreover, as the leachates residue generate NH_4^+ and SO_4^{2-} after mining. Those compounds can into the underground water by percolation [28], under the rain and surface runoff contaminate the down string and soil [17]. Ammonium nitrogen promotes vegetative growth and inhibits the reproductive growth of downstream crops, resulting in a substantial reduction in the yield or no harvest. The presence of ammonium nitrogen can also easily cause soil mineral depletion affects the fixation and release of metal ions by changing the ion composition and strength of the soil solution. During the acidification process, ammonia nitrogen invades as an activated ion, which intensifies the acidification process [29]. Ammonia nitrogen is also harmful to aquatic organisms, reducing the number of fish and other aquatic animal species, poisoning, and even death. Therefore, the uncertainty of the time, the location of the landslide, and governance goal are unclear after *in-situ* leaching makes it difficult to conduct targeted governance.

Conclusions

IAT-Res is unique REE resources distribute in southern China, which contribute 80% of middle and heavy REE of the world's production. With the fast development of high technologies, the demand for REE has gradually increased, which consequently intensifies environmental degradation in the mining area. Furthermore, most IAT-Res are weathered layer materials, the geological background in these areas is poor in corrosion resistance and nutrient retention capacity. Mining activities further lead to the structure destruction and nutrient loss, resulting in fragile ecosystem even after years of restoration. The exploration of ion-absorption REE poses chemical environmental problems. The heap leaching significant damages the surrounding plantation and soil structure than *in-situ* leaching technique. Either heap leaching or *in-situ* leaching left over a large amount of $(\text{NH}_4)_2\text{SO}_4$ leachate after mining. Although *in-situ* leaching technique is considered as an eco-friendly method, the larger amount of $(\text{NH}_4)_2\text{SO}_4$ applied during mining can

lead to more severe ecological pollution in a long term period. In conclusion, the heap leaching consequence with evident ecological pollution, but the contamination management can be more purposeful. In contrast, the pollution of *in-situ* leaching technique is concealed. It is not obvious to deconstruct the vegetation and soil erosion, but the larger number of leachate residues can lead to severe ecological problems and potential risks for the surrounding biota. Therefore, further studies should focus on the geochemical behaviors of REE and their ecological effects to the surrounding habitants, which will provide scientific knowledge in the environment conservation and management.

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Conflict of Interest

The authors declare no conflict of interest.

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