Element Contents and Distribution in Surface Soils on the Northern Slope of Changbai Mountain Nature Reserve

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Date: 2024-08-12T00:00:00+00:00

Abstract

To investigate the distribution of various elements in the surface soil of the northern slope of the Changbai Mountain Nature Reserve, this study employed a portable X-ray fluorescence spectrometer for in-situ determination of element contents, characterized element distribution patterns, and compared differences in soil element contents across various locations. The results indicated that: 1) Among the 38 elements detectable by the instrument, 16 elements were detected on the northern slope, with K, Fe, and Ca contents all exceeding 5000 mg/Kg, followed by S, Ti, Mn, and Cl, which exceeded 400 mg/Kg; 2) Among different forest types, the low-altitude dark coniferous forest exhibited the highest contents of K, Fe, Ca, and other elements; 3) In the comparison between the protected area and the planned management area, the contents of most elements in the protected area soils were lower than those in the surrounding planned management area; 4) At different distances from the main highway, no obvious trend was observed for Pb in soil, while Zn content exhibited a decreasing trend with increasing distance from the highway; 5) At different locations along the main river, anthropogenic activities resulted in enrichment of K, Cl, and Zn elements in downstream sediments.

Full Text

Element Content and Distribution in Surface Soil on the North Slope of Changbai Mountain Nature Reserve

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Abstract

To investigate the distribution of elements in surface soils on the north slope of Changbai Mountain Nature Reserve, this study employed portable X-ray fluorescence spectrometry (PXRF) for in-situ determination of various element contents, characterized their distribution patterns, and compared elemental content differences across different locations. The results showed that: (1) Among the 38 elements detectable by the instrument, 16 were detected on the north slope, with K, Fe, and Ca contents exceeding 5000 mg/kg, followed by S, Ti, Mn, and Cl exceeding 400 mg/kg; (2) Among different forest types, low-elevation dark coniferous forests exhibited the highest contents of K, Fe, Ca, and other elements; (3) In the comparison between the protected area and the planning management zone, most element contents in protected area soils were lower than those in the surrounding planning management zone; (4) At different distances from the main highway, the variation trend of Pb in soil was not significant, while Zn content showed a decreasing trend with increasing distance from the road; (5) At different locations along the main river, human activities led to enrichment of K, Cl, and Zn elements in downstream sediments.

Keywords: Changbai Mountain Nature Reserve; Soil; Element; Portable X-ray fluorescence spectrometry

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The Changbai Mountain forest ecosystem represents the best-preserved and largest primary forest area at its latitude worldwide, forming a crucial component of the ecological barrier zone in northeastern China [1]. As early as April 1960, the Changbai Mountain National Nature Reserve was established in the core area of this forest ecosystem, marking one of China’ s first nature reserves. Soil constitutes a fundamental element of forest ecosystems, influenced by multiple factors including parent material, climate, and biota, while simultaneously exchanging matter and energy with forest flora and fauna to facilitate ecosystem evolution. The contents of major elements such as carbon, nitrogen, and phosphorus in forest soils are critical to ecosystem productivity and nutrient cycling, which has drawn extensive research attention. As products of rock weathering, soils exhibit substantial compositional differences across regions. Conventional methods for determining soil elements include chemical analysis and photoelectric colorimetry, which typically require digestion processes that are time-consuming and potentially hazardous. Portable X-ray fluorescence spectrometry (PXRF) circumvents these issues while enabling rapid determination of multiple elements in soil samples. This technique has been widely applied in heavy metal detection [2-4] and has demonstrated good correlation with conventional laboratory methods [5].

Soil plays a vital role in sustaining life on Earth, providing essential nutrients for plant growth and influencing plant productivity and species composition [6]. Understanding soil element contents and distribution facilitates better utilization of ecosystem services. This study employed PXRF to conduct in-situ measurements of various elements in surface soils on the north slope of Changbai Mountain Nature Reserve, analyzing and comparing spatial distribution patterns and underlying causes. The research provides a reference for in-situ soil element determination and soil survey methodologies.

1.1 Study Area Overview

Changbai Mountain Nature Reserve is located in southeastern Jilin Province, with terrain that is higher in the southeast and lower in the northwest, averaging 1312 m in elevation [7]. Due to unique geological structures, vegetation shows distinct vertical distribution zones along elevation gradients: broadleaf-Korean pine forest, dark coniferous forest, subalpine Betula ermanii forest, and alpine tundra [8]. The reserve features high forest coverage and abundant water resources, serving as the source of the Songhua, Yalu, and Tumen Rivers. The Erdao Baihe River on the north slope of Changbai Mountain is one source of the Songhua River and the only river flowing from Tianchi (Heavenly Lake). Changbai Mountain Tianchi is a dormant volcano, with its most recent major eruption occurring approximately 1000 years ago, representing the largest Holocene eruption in terms of distribution range [9].

1.2 Sampling Point Layout

Sampling points were established on the north slope of Changbai Mountain Nature Reserve and surrounding areas, covering roads, forests, and rivers [Figure 1: see original paper]. For road sampling, five points were selected on each side of the 331 National Highway along the north slope (the highway largely coincides with the eastern boundary of the reserve, with protected forest on the west side and planning management zone forest on the east side), with sampling locations at 0 m, 50 m, 100 m, 150 m, and 200 m perpendicular to the highway. For forest sampling, five plots were selected from the Jilin Changbai Mountain Forest Ecosystem National Observation and Research Station (hereinafter referred to as Changbai Mountain Station). For river sampling, four points were established along the Erdao Baihe River: at the source below Changbai Mountain Tianchi Waterfall, before the river reaches Erdao Baihe Town after flowing through forest, within Erdao Baihe Town, and downstream of the town, to determine element contents in riverbank sediments. For each sampling point (2$×5×$5 + 5 + 4 = 59 total), three replicates were collected within a 1 m radius, with three measurements taken per replicate using the instrument. Latitude and longitude information for each sampling point is provided in .

1.3 Data Processing and Analysis

Among the 38 elements detectable by the PXRF instrument, 22 were found to be below detection limits or below 10 mg/kg during our measurements. The remaining 16 detected elements were classified into four categories: elements related to vehicle emissions, plant macronutrients, plant micronutrients, and volcano-related elements [Figure 2: see original paper]. Zinc, a plant micronutrient also associated with vehicle emissions, was classified in the former category based on actual detection results. Sulfur, both volcano-related and a plant macronutrient, was classified in the latter category.

Different elements were selected for comparison based on sampling point attributes. For the survey of element contents in protected area soils, all 16 detected elements were considered. For comparisons among different forest types, given elevation differences and varying distances from the Changbai Mountain Tianchi crater, eight plant nutrient elements and seven volcano-related elements were examined. For the comparison between protected and planning management zones, all 16 detected elements were included. For soil element contents at different distances from highways, Zn and Pb were selected based on relevant research [10] and measurement results. For soil element contents at different river locations, three elements related to human activities (K, Cl, Zn) and seven volcano-related elements (including S, totaling eight) were considered, given that the river flows through human activity zones and varies in distance from the crater.

The study primarily calculated and compared means and standard deviations for different sampling points based on their attributes.

2 Results

2.1 Overall Element Levels in Regional Soils

A total of 16 elements were detected in soils across the north slope of the reserve. Among these, K, Fe, and Ca contents exceeded 5000 mg/kg, followed by S, Ti, Mn, and Cl exceeding 400 mg/kg. The descending order of the 16 elements in soil was: K > Fe > Ca > S > Ti > Mn > Cl > Ba > Zr > Zn > Sr > P > Rb > Nb > Pb > Y [Figure 3: see original paper].

2.2 Element Contents and Distribution in Different Forest Types

The five plots at Changbai Mountain Station encompassed four vegetation types: broadleaf-Korean pine forest, dark coniferous forest, subalpine Betula ermanii forest, and alpine tundra. Overall, the descending order of eight plant nutrient elements was: K > Fe > Ca > S > Mn > Cl > Zn > P [Figure 4: see original paper]. Low-elevation dark coniferous forests exhibited the highest contents of K, Fe, Ca, and other elements. Element contents varied significantly among different forest types, while similar vegetation types (dark coniferous forests at different elevations) showed comparable contents of K, Fe, and S. Contents of S and P tended to increase with plot elevation. Among volcano-related elements, the seven elements showed no distinct patterns.

2.3 Element Contents and Distribution in Protected vs. Planning Management Zones

The study compared element contents between protected and planning management zone soils. Most element contents were lower in the protected area. Among the 16 elements, Ca and S showed similar contents, while Mn was higher in the protected area [Figure 5: see original paper].

2.4 Element Contents and Distribution at Different Distances from Highway

National Highway 331 is the main route from the north slope of Changbai Mountain to Tianchi. The study considered Pb and Zn as elements related to vehicle emissions. The variation trend of Pb in soil was not significant, while Zn content showed a decreasing trend with increasing distance from the highway [Figure 6: see original paper].

2.5 Element Contents and Distribution in River Sediments at Different Locations

In comparing element contents in river sediments at different locations, the study found that elements related to human activities (K, Cl, Zn) gradually decreased before flowing through human activity zones, then increased after passing through these areas. Among volcano-related elements, the eight elements showed no significant changes [Figure 7: see original paper].

3 Discussion

In-situ PXRF enables rapid determination of soil element contents, providing an alternative solution for large-scale soil surveys and spatial mapping. Studies have used kriging interpolation to generate high-resolution soil heavy metal pollution maps from PXRF-measured large-sample data, offering precise characterization of contaminants [11]. Additionally, PXRF analysis of plant micronutrients warrants considerable attention [12, 13].

This study systematically compared differences in soil elements among different forest types, at varying distances from highways, and at different river locations. Previous related research within the protected area has only addressed heavy metal elements in coniferous forest soils [14]. For the same vegetation type in surface soils, that study' s ranges for Mn, Zn, and Pb contents were consistent with our results, partially validating our data reliability. Plant element contents differed substantially among forest types, possibly due to varying elemental uptake preferences among plant species. Heavy metal pollutants from traffic typically concentrate within 0.3 m of roads [15], and our study also showed a decreasing trend in soil Zn content with increasing distance from highways. In the comparison between protected and planning management zones, most element contents were lower in the protected area, possibly because forest management in the planning management zone leads to more litter input and human activity contributions. In the river location survey, contents of K, Cl, and Zn increased in sediments after flowing through human activity zones, indicating that human activities caused enrichment of these three elements downstream of inhabited areas.

Soil moisture content typically leads to underestimation in PXRF detection results [16, 17]. To minimize moisture effects, our survey was conducted during the less rainy month of September in the reserve, with all measurements completed within one week. Consideration of moisture effects remains essential for future surveys.

4 Conclusion

PXRF is a suitable method for rapid in-situ detection and quantitative analysis of soil elemental composition. Baseline data for element contents in Changbai Mountain Nature Reserve soils are currently lacking. Based on this, we investigated the distribution of various elements in surface soils on the north slope of the reserve. The results indicate that the overall north slope surface soil experiences low levels of human disturbance. This study contributes to understanding elemental distribution in Changbai Mountain soils.

References

[1] Zheng Xingbo, Yu Dapao, Wang Anzhi, et al. Long-term monitoring and field control experiments reveal the structure, function, and evolution of typical temperate forests [J]. Bulletin of Chinese Academy of Sciences, 2019, 34(08): 948-61.

[2] Yang Guilan, Shang Zhaocong, Li Liangjun, et al. Application of portable X-ray fluorescence spectrometry in rapid detection of heavy metals in soil [J]. Applied Chemical Industry, 2016, 45(08): 1586-91.

[3] Wang Bao, Yu Jianxin, Huang Biao, et al. Rapid monitoring of heavy metal soil environmental quality using portable X-ray fluorescence spectrometer (in English) [J]. Spectroscopy and Spectral Analysis, 2015, 35(06): 1735-40.

[4] Silva E A, Weindorf D C, Silva S H G, et al. Advances in Tropical Soil Characterization via Portable X-Ray Fluorescence Spectrometry [J]. Pedosphere, 2019, 29(4): 468-82.

[5] Wan Mengxue, Hu Wenyou, Huang Biao, et al. Application of portable X-ray fluorescence spectrometry (PXRF) in rapid detection of heavy metals in fertilizers [J]. Soils, 2019, 51(06): 1137-43.

[6] Schoonover J E, Crim J F. An Introduction to Soil Concepts and the Role of Soils in Watershed Management [J]. Journal of Contemporary Water Research & Education, 2015, 154(1): 21-47.

[7] Zhang Yuan, Yuan Fenghui, Wang Anzhi, et al. Variation characteristics of NDVI during growing season and its response to climate change in Changbai Mountain Nature Reserve from 2001 to 2018 [J]. Chinese Journal of Applied Ecology, 2020, 31(04): 1213-22.

[8] Yu Dapao, Tang Lina, Wang Shaoxian, et al. Quantitative determination of ecotones in vegetation vertical zones on the north slope of Changbai Mountain [J]. Chinese Journal of Applied Ecology, 2004, (10): 1760-4.

[9] Cui Zhongxie, Zhang Sanhuan, Tian Jing. Study on volcanic eruption activities and forest fires in Changbai Mountain since the Holocene [J]. Geographical Research, 1997, (01): 92-7.

[10] Zhou Yi, Wu Qiumei, Fan Yanan, et al. Distribution characteristics and influencing factors of soil heavy metals along typical highways in Jiangsu Province [J]. Chinese Journal of Soil Science, 2023, 54(01): 161-70.

[11] Zhao Manying, Zhao Yuxin, Shen Tiezhi, et al. Co-kriging interpolation and high-resolution mapping of soil manganese and zinc pollution distribution based on in-situ PXRF data [J]. Research of Environmental Sciences, 2023, 36(03): 599-609.

[12] Kang Shixiu, Shen Xiansheng, Yao Kun, et al. Application of synchrotron radiation X-ray fluorescence analysis in plant trace element analysis [J]. Progress in Natural Science, 2001, (10): 44-8.

[13] Zhou S, Weindorf D C, Cheng Q, et al. Elemental assessment of vegetation via portable X-ray fluorescence: Sample preparation and methodological considerations [J]. Spectrochimica Acta Part B-Atomic Spectroscopy, 2020, 174.

[14] Wang Xu, Zhang Shen. Study on distribution and speciation of heavy metal elements in coniferous forest soils of Changbai Mountain [J]. Environmental Pollution & Control, 1987, (04): 22-5+38+46.

[15] Wang H, Nie L, Xu Y, et al. The Effect of Highway on Heavy Metal Accumulation in Soil in Turfy Swamps, Northeastern China [J]. Water Air and Soil Pollution, 2017, 228(8).

[16] Zhao Xia, Zheng Jingming, Si Liqing, et al. Effect of moisture on determination of element contents in soil by portable X-ray fluorescence spectrometer [J]. Metallurgical Analysis, 2018, 38(07): 20-6.

[17] Zhu Mengjie. Application of portable XRF analyzer in soil detection and its influencing factors [J]. Environmental Monitoring in China, 2019, 35(06): 129-37.

Note: Figure translations are in progress. See original paper for figures.