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Hazards, Sources and Control Measures of Heavy Metal Pollution of Forest Soil: Taking Jin-Jing-Ji Region of China as an Example

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ABSTRACT

Forest is a complex system of woods, plants, animals, and other environmental components. However, owing to unsustainable population growth and rapid economic development, large quantities of poisonous heavy metal elements are directly or indirectly released into forests by human activities, which has damaged the soil quality. This study took Jin-Jing-Ji region of China as an example to analyze the hazards and sources of heavy metals in forest soil. Related literature on heavy metal pollution of forest soil was analyzed. Subsequently, control measures were proposed to overturn the current polluted state of the above region's forest. Results show that the effect strength, urbanization, and industrialization level of human activities are closely related to the degree of heavy metal pollution of forest soil. The hazards of heavy metals pollution to forest soil manifest in four aspects: plants, soil animals, soil enzymes, and people dwelling around the forest. Meanwhile, the main sources of heavy metal pollution are atmospheric dry and wet deposition, industrial activities and transportation, fertilization of man-made forest, and mining activities. The current state can be improved by employing control measures such as economic and industrial structural adjustments, strengthening the environmental awareness of individuals, strict control of pollution sources through prevention management, and strict control of atmospheric deposition and forest pollution. The findings of this study can serve as a significant reference for relevant regions when analyzing the state of heavy metal pollution to their respective forest soils and when conducting environmental diagnosis and forest protection activities.

INTRODUCTION

The forest ecosystem is composed of woods, plants, animals, and other environmental components. Forests are considered an important territory, given their natural resource functions, such as water and soil conservation, biological diversity protection, climate regulation, and sustainable development of ecosystems. In other words, forests play a significant role in safeguarding regional and national ecological safety.

However, continued population growth and rapid economic development have caused unprecedented interference of human activities that seriously affect forest ecosystems. Large quantities of poisonous heavy metal elements that are directly or indirectly released by human activities have seriously altered the composition and biogeochemical circulation of terrestrial and aquatic ecosystems. Moreover, accelerated urbanization and industrialization have caused forest ecosystem imbalance. Heavy metals have caused environmental pollution, and the resultant heavy metal pollution of forest soil has seriously endangered the safety of forest ecosystems.

Regarded as the "capital circle" of China, the Jing-Jin-Ji region has undergone rapid economic and industrial development, as shown by its year-by-year GDP growth in Fig. 1. However, forest pollution caused by perennial industrial and agricultural production cannot be neglected, because the physicochemical properties and nutrient status of forest soil are closely related to the quality of wood growth, forest products (i.e., quality safety), ecosystem, and human health.

A comprehensive study of forest soil status is conducted to accurately evaluate the degree of heavy metal pollution in the Jing-Jin-Ji region. The level of productive forces of forest ecosystems can be improved to maintain ecosystem balance, and protection measures can be adjusted to adapt to local conditions. For instance, certain species are matched with specific sites through scientific management and sustainable development. Simultaneously, forest productivity and sustainable forest management are improved, thereby ensuring product quality and ecological safety.

Soil is an important constituent of forest ecosystems, and the quality of soil directly affects the forest composition. Several studies have been conducted on heavy metal pollution of forest soil, although foreign initiatives are more advanced than domestic (Chinese) research.

Oliver reported that heavy metals in the atmosphere and water bodies continuously accumulate in soil and consequently harm the health of animals and plants after contact, ingestion, and absorption (Oliver 1997). Cogliastro et al. conducted a two-month study on the input quantity of heavy metals within the six-kilometer range of Olkusz Forest (South Poland), which is surrounded by a zinc smelting plant. Findings showed that heavy metal contents (Cd, Pb, Cu, Zn and Fe) in the litter layer of Olkusz Forest were higher by several magnitudes compared with those in other regions (Cogliastro et al. 2001). Hernandez et al. analysed the contents of heavy metals (Cr, Zn, Pb, Ni, and Cu) in forest soil in France (Hernandez et al. 2003). Sawicka-Kapusta et al. studied the urbanization and industrialization of Cracow City and the effect of pollution on ground cover plants in urban forests. Results showed that human activities were significantly associated with heavy metal content (Sawicka-Kapusta et al. 2003). De Vries et al. proposed to standardize the parameters of air pollution impact in the European region to fully understand the environmental and other factors affecting forest ecosystems (De et al. 2003). Menon et al. analyzed the water regime of heavy metals in polluted soil in forest vegetation and studied the influences of heavy metal contents (Zn, Cu, and Cd) on topsoil pollution (Menon et al. 2005). Itoh et al. studied the current deposition status of Pb and Cd in the atmosphere over the forests of Kanto region in Japan (Itoh et al. 2006). Helmisaari et al. analyzed the possibility of using regenerated organic matters and woody plants in native soil to recover forest soil from heavy metal pollution (Helmisaari et al. 2007). Mertens et al. suggested that tree growth alters soil property and forests avert heavy metal circulation and distribution (Mertens et al. 2007). Xin-Ling et al. employed a high-resolution sampling method to study the vertical distribution of Cu, Zn, Pb, and Cd migration in forest soil (Xin-Ling et al. 2008). Ilany et al. suggested that soil influences phytocoenosis, and thus, a method to measure heavy metal accumulation in soil is necessary (Ilany et al. 2010). Micu et al. reported that the degree of mineralization of heavy metals in forest leaves was much higher than those in fruits; however, the heavily polluted leaves gradually affect the fruit quality and consumer metabolism after slow accumulation (Micu et al. 2016). Li et al. analyzed the contents of heavy metals in the overlying water body, deposit sediments, rhizospheric sediments, and mangrove plant seedlings in Futian City in China. Results showed that cadmium posed ecological risk to mangrove forest soil (Li et al. 2016). Napa et al. analyzed the biological pollution of coniferous forest as a result of heavy metal pollution in Estonia (Napa et al. 2017). Mazurek et al. used a pollution index to evaluate the heavy metal pollution of Roztocze National Park (Poland), and results showed that the distribution of heavy metals is related to human activities and soil properties (Mazurek et al. 2017).

Domestic and international research mainly focused on the distribution, sources, and evaluation of heavy metal pollution of forest soil. A number of these studies proved the relationship between heavy metal pollution and human activity; that is, the longer the history of city construction (i.e., high levels of urbanization and industrialization), the higher the degree of pollution. This relationship serves as the foundation of subsequent research on the sources and hazards of heavy metals in forest soil. In this study, the hazards, sources, and degree of heavy metal pollution of forest soil in the Jing-Jin-Ji region is analyzed. Then, the current status of heavy metal pollution of forest soil in the context of Jing-Jin-Ji coordinated development is explored. Finally, a reference for environmental diagnosis and forest soil protection is offered on the basis of the study findings.

HAZARDOUS EFFECTS OF HEAVY METAL POLLUTION ON FOREST SOIL

Impact on plants: Heavy metals in forest soil exert a toxic effect on plants. Physiological features, such as height, main root length, and leaf area, are altered when plants absorb heavy metals. Subsequently, plant bodies generate toxic substances (e.g., H_2O_2 and C_2H_2) that adversely affect plant enzymes and metabolism. Stress from heavy metal pollution causes nutrient shortage and enzymatic effectiveness degradation. Moreover, high concentrations of heavy metals inhibit the absorption and transportation of beneficial minerals such as Ca and Mg in plant bodies. In wheat seedlings affected by Cd contents, leaf and root growth is inhibited due to the decrease of Fe, Mg, Ca, and K nutrients. Stress from heavy metal pollution also cause physiological metabolic disorder and inhibited growth; that is, the absorbing capability of plant roots is weakened, which then results in nutrient deficiency in plant bodies.

Impact on soil animals: An increase in all kinds of heavy metal elements can seriously threaten the survival and proliferation of soil animals. Heavy metal pollution negatively affects soil zoocenosis and diversity, and heavy metals pose hazards to soil animals in different degrees. In addition, the constitution and quantity of soil zoocenosis are reduced with aggravated pollution. In a heavily polluted soil, dominant species and common species are reduced. Heavy metal pollution also affects the diversity, evenness, and density class group indices of soil zoocenosis. Thus, heavy metal contents in soil directly influence the quantity, richness, biomass, and community constitution of invertebrates such as earthworms and nematodes, among others.

Impact on soil enzymes: Soil enzyme, a biocatalyst, is a

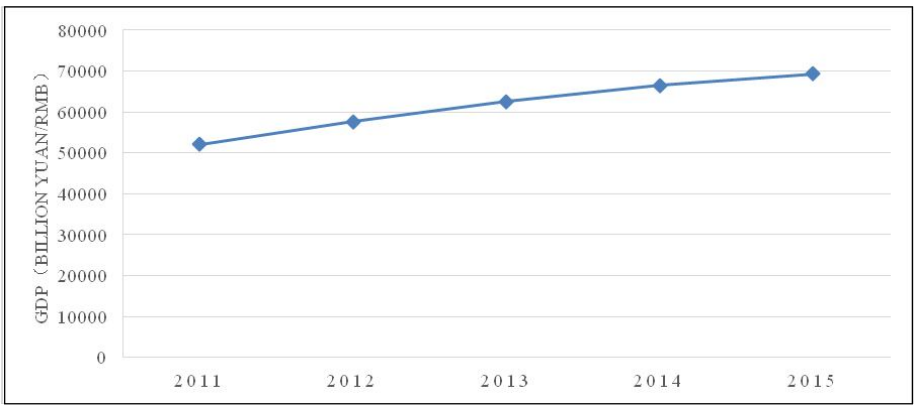

Fig. 1: GDP output of the Jing-Jin-Ji region (2011-2015).

sensible biological indicator of soil fertility, because it can directly reflect strength and direction of biochemical processes. Soil enzyme activity is easily influenced by soil physiochemical properties and biological activity. Given that environmental pollution affects the soil enzyme activity, the level of pollution can also depict the environmental status of soil to a certain degree.

Impact on people dwelling around the forest: Heavy metals in soil, especially in topsoil, can easily enter the human body and adversely affect the human health. Excessive Cd intake can cause organ lesions and a decrease in bone mineral density, further resulting in fractures, whereas, Pb ingestion can cause degradation of reproductive functions, weak immunity, and abdominal pain. Long-term ingestion of Cr causes skin and respiratory lesions with anabrosis and inflammation, whereas, long-term inhalation of Ni can cause rhino carcinoma and lung carcinoma, as well as diseases such as contact dermatitis and pneumonia. After metal Hg enters the human body, it combines with electronegative radicals (e.g., sulfydryl groups) in in-vivo enzymes or proteins to deter energy generation, protein consumption, and nucleic acid synthesis, and consequently affects the normal functions and cell growth. Thus, heavy metal pollution of forest soil causes major hazards to humans.

SOURCES OF HEAVY METAL POLLUTION IN FOREST SOIL

Atmospheric dry and wet deposition: With rapid industrial development, the rate of fossil fuel combustion in the Jing-Jin-Ji region has increased daily, as shown in Fig. 2. Trace metals and acid gases in discharged waste gas alter the balance of trace substances in the atmosphere. Atmospheric pollutants such as Hg, Pb, Cd, and Zn released by human activities eventually penetrate forest ecosystems through dry and wet deposition. Forests are a multi-layer structure. After precipitation, pollutants in the atmosphere penetrate the ground layer (moss and lichen) and litter layer, and the arborous, shrub and herb layers in between. In other words, pollutants are leached into multiple layers in forest soil with rainfall.

Industrial activities and transportation: Industrial activities and transportation constitute the main sources of heavy metal pollution of urban forest ecosystems. High-density urban population has significantly changed the living environment of urban dwellers, and excessive concentration of industrial, commercial, and household garbage has caused a number of ecological/environmental problems, such as degradation of ecological functions, environmental pollution, and heat island effect. Dusts and wastes generated by industrial production (Fig. 3) directly pollute urban forests. Heavy metal elements emitted by urban construction projects and industrial waste gases enter the atmosphere, then into urban forest ecosystems, through atmospheric precipitation. At present, industry-related atmospheric precipitation ranks first among the exogenous input factors of heavy metal pollution in forest ecosystems.

Automotive exhaust emission in Beijing and industrial pollution in Tianjin and Hebei significantly affect atmospheric conditions. Industrial pollution exerts a major influence on the atmospheric environment, as depicted in Table 1.

The urban forests of several large and medium-sized cities in China suffer from different degrees of heavy metal and other types of pollution. Heavy metal pollution of forest soil in urban centers (i.e., areas with the densest human activities) is regarded as the most serious type of pollution. Urban areas have expanded, thus, although the degree of pollution in urban centers has decreased, the effect of pollution has expanded toward the suburbs. Along highways, forest soils are polluted by transportation-related heavy metals such as Pb and Cd. In particular, automobile exhausts

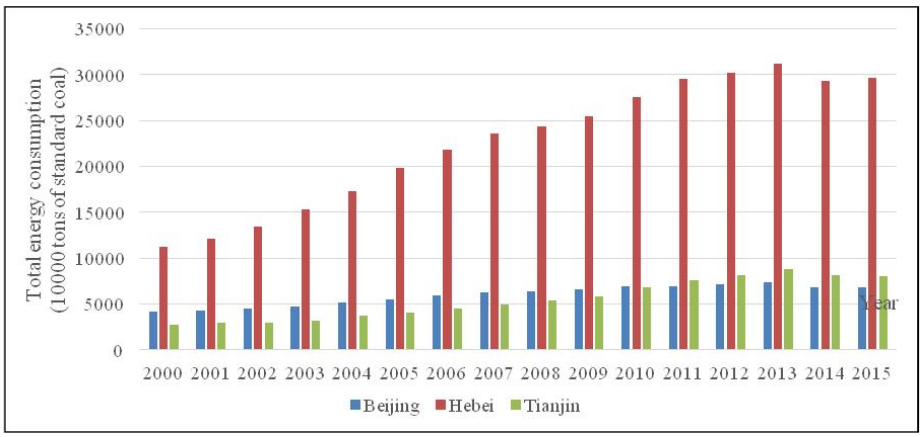

Fig. 2: Total energy consumption in the Jing-Jin-Ji Region (2000-2015).

contain Pb whereas tire wear generates dust. Thus, the closer the forest from the highway is, the higher the heavy metal accumulation in forest soil. Accordingly, as the distance between forest and highway increases, the heavy metal contents in soil exponentially decreases.

Fertilization of man-made forests: In a man-made forest ecosystem, unreasonable fertilization is regarded as one of the main causes of heavy metal pollution of forest soil. In China, the number and area of man-made forests has increased. However, degraded soil quality was observed in man-made forests for China fir, poplar, *Larix gmelini*, *Eucalyptus* and *Pinus sylvestris*. To manage the rapid growth of man-made forests, large quantities of fertilizers are applied; however, these applied fertilizers contain varying contents and types of heavy metals (e.g., P, K, N, and compound elements).

Sludge application and sewage irrigation in local forests are also regarded as sources of heavy metal pollution of man-made forest ecosystems. When sludge is used, heavy metals (Cr, Cu, Ni, and Zn) penetrate the humus and leaching layers of forests. Plant roots are also affected by Cu and Ni contents.

Mining: Mining not only harms the forest, but it also pollutes the soil surrounding the forest. Many large and medium-sized copper, lead-zinc, and rare earth mines were constructed near the Jing-Jin-Ji region. These mines conduct activities such as smelting and metal processing, which have already caused notable environmental problems in this region.

Under the effects of natural stresses, wastewater continuously brings pollutants to surrounding forests where they permeate, diffuse and migrate into underground water. Heavy metals can even reach pollution level, which in turn poses serious harm to the surrounding forests. Heavy metal pollution results in forest degradation, biodiversity loss, reduction and quality degradation of forest products, damage of ecosystem structure, and decline of functions and stability of forest ecosystems. Forest plants amass heavy metal contents in varying degrees. Consequently, highly concentrated heavy metals and mining hazards have altered the distribution of original plant populations and species diversity.

CONTROL MEASURES AGAINST HEAVY METAL POLLUTION IN FOREST SOIL

Economic-industrial structural adjustments to the legal governance system: On the basis of the actual conditions in the Jing-Jin-Ji region, industrial restructuring can include the transformation from a labour-intensive industry to an economic-technological and high value-added one to attain the advantages of those similar to economic, technological, and innovative development zones. In addition, high-tech industries should be actively introduced and cultivated, and clean production should be promoted. The government should actively develop new types of environment-friendly pillar industries, such as the automobile, bio-pharmaceutics, photo-electronics, and agricultural industries (including byproduct processing), to facilitate sustainable economic development in the Jing-Jin-Ji region. Therefore, corresponding laws are necessitated to enhance the citizen behavior and truly implement the governance of laws.

At present, China has enacted atmospheric and water pollution prevention laws and corresponding control mechanisms, and a solid waste pollution prevention law. In general, heavy metal soil pollution is derived from waste emissions in the atmosphere, water bodies and solids. A similar case is observed for the heavy metal pollution of forest soil in the Jing-Jin-Ji region, the only difference being the varying degrees of effects caused by different pollutants.

Table 1: Industrial Waste Gas Emission in the Jing-Jin-Ji Region (2012).

Province and city	Proportion of industrial sulfur dioxide in total sulfur dioxide in this region (%)	Proportion of industrial nitrogen oxide in total nitrogen oxide in this region (%)	Proportion of industrial smoke dust in total smoke dust in this region (%)
Beijing	63.2	48.1	46.2
Tianjin	96.0	82.4	70.2
Hebei	92.4	67.8	85.4

Local governments should formulate urban soil environmental protection plans, organize urban ecological environmental governance, and clarify the special protection order of farm-oriented arable lands in urban areas. From these principled law stipulations, local governments should impose requirements to enterprises that cause heavy metal pollution of urban soil and to market entities involved in agricultural production. Among organizations involved in agricultural production and operations, laborers should manage agricultural lands by reasonably applying fertilizers and pesticides. These organizations should also enhance their use of organic fertilizers to improve soil fertility, prevent land pollution and damage, and prevent soil fertility degradation. In executing national environmental laws, local governments should strictly prosecute law breakers.

Strengthened environmental awareness of individuals through social supervision: The soil environment in urban forests is an important constituent of the urban ecosystem. Protecting the soil environment in urban forests is necessitated for the long-term survival of urban residents; it is also a precondition of long-time economic development and social progress. Ineffective soil environmental protection of urban forests hinders and restricts effective economic development.

Problems associated with the soil protection of urban forests in the Jing-Jin-Ji region cannot be radically solved through administrative orders alone. In other words, soil protection ultimately requires the enthusiasm of governments at all levels, various departments, and the general public. Motivation implies popularization of laws, regulations, and rules regarding environmental protection. In addition, scientific knowledge regarding environmental protection should be publicized. Efforts should focus on improving people's awareness of protecting the urban soil environment and strengthening their consciousness about environmental protection. By using these methods, people can collectively contribute to the protection and improvement of the living environment.

Local governments should extensively conduct publicity and education activities for urban soil environmental protection and intensify law supervision and enforcement against urban soil environmental pollution.

Strict and effective control of pollution sources: Prevention and control of heavy metal pollution of forest soil should start with the source of pollution. In the Jing-Jin-Ji region, the main sources of heavy metal pollution are transportation, industrial activities, urban wastes, and atmospheric precipitation. Meanwhile, motor vehicle exhaust and dust generated by tire wear are regarded as the main sources of non-point heavy metals pollution in the region.

Governments should require owners of motor vehicles to use clean energy and enhance their management of scrapped cars. Cars with exhaust gas emissions that fall below environmental standards should be forbidden to operate, and fabrication techniques should be improved by tire rubber manufacturers. Moreover, governments should improve the road traffic management system, ban road markets, avoid traffic jams, and maintain smooth traffic. Moreover, clean production techniques should be developed during industrial production. In addition, governments should strictly implement the "three wastes" approach, especially the recovery and comprehensive application of heavy metals in exhaust gas, waste residue, and sludge, to prevent complex types of environmental pollution. Small manufacturing plants that cannot treat wastes should be closed or sanctioned. Large enterprises that cause major pollution hazards should be stopped from operating until internal corrections (e.g., establishment of waste treatment facilities) are conducted.

The energy structure and combustion modes in the Jing-Jin-Ji region should be changed. Governments should expand the usage amounts of clean fuels (e.g., liquefied and natural gas) and discourage low-efficient yet high-polluting small combustion facilities. Moreover, governments should radically eliminate the use kilns, bullet furnaces, and small boilers with low-energy use efficiencies because they contribute to urban environmental pollution. The technological transformation of existing heating boilers should be considered to improve thermal efficiency and subsequently realize emission standards. In addition, governments should discourage the use of dust-cleaning

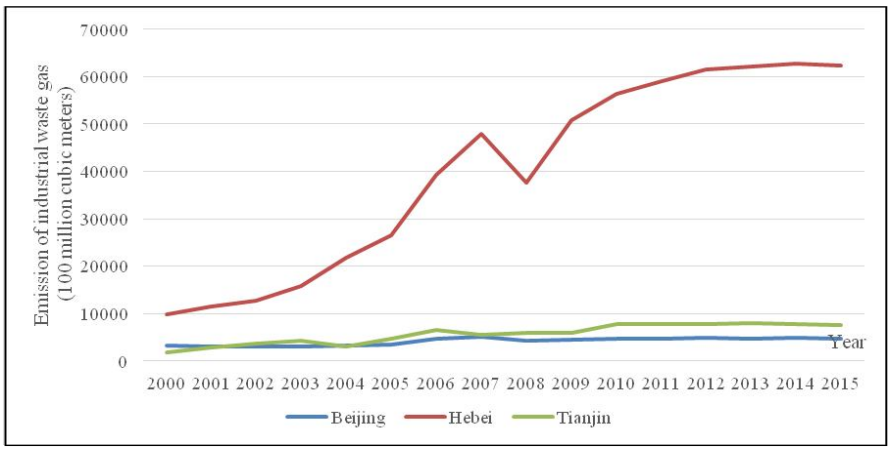

Fig. 3: Industrial waste gas emissions in the Jing-Jin-Ji Region (2000-2015).

equipment with low efficiency and actively develop highly efficient dust catchers. To enhance the usage and management of dust-cleaning units, centralized heating components should be reasonably expanded to optimize heat supply layout, reduce energy consumption, elevate heat supply levels, and improve heat supply efficiency.

Prevention and control of atmospheric precipitation pollution: Controlling transportation and industrial waste gas emission is the main effective measure for preventing and governing heavy metal pollution of forest soil in the Jing-Jin-Ji region. In addition, strictly controlling flying dusts from soil and buildings can also prevent heavy metal pollution. The Jing-Jin-Ji region has a fragile ecological environment (i.e., loose soil, arid land, minimal rain in spring and autumn, but with great wind power), and dust pollution is prominent depending on the weather.

In surrounding regions and the urban areas in Jing-Jin-Ji region, green land area should be expanded and bare land surface should be reduced to the best extent possible as a means to control dust pollution in the Jing-Jin-Ji region. Dust control should be systematically engineered, and effective control measures should be undertaken from building construction and completion to demolition. With regard to lands after building demolition, measures against dust pollution should be immediately considered prior the construction of a new building. Moreover, temporary but strict measures should be observed along the roads used by construction sites. For instance, watering, hardening, or covering of construction agents should be implemented (i.e., stacked materials and lands during construction; watering for dust reduction; and proper garbage and residual disposal), especially during backfilling. Garbage, waste soil, and gravels from construction sites should be cleared and transported in a timely manner. Vehicles transporting waste soil should be covered; in addition, before they leave the construction site, the outer parts and wheels should be cleared of soil, as they are regarded as possible carriers of wastes. As soon as the construction project is completed, waste soil should be timely cleared from urban roads. All damaged green lands and sidewalks around the construction project should be recovered.

CONCLUSIONS

The physicochemical properties and nutrient status of forest soil are closely related to wood growth, forest products (i.e., quality safety), ecological environment, and human health. A comprehensive understanding of the hazards and sources of forest soil pollution is needed to continuously improve the level of productive forces and maintain the balance of forest ecosystem, which essentially is a governance concern.

Taking the Jing-Jin-Ji region as an example, domestic and foreign literature on heavy metal pollution and forest soil are analyzed, and the hazards and sources of heavy metal pollution of forest soil are established. The degree of human activity, urbanization, and industrialization is closely related to the degree of heavy metal pollution of forest soil. The hazardous effects of heavy metal contents are manifested by plants, soil animals, soil enzymes, and people dwelling around the forest. The main sources of heavy metal pollution of forest soil are atmospheric dry and wet deposition, industrial activities and transportation, man-made forest fertilization and mining activities.

The findings of this study can provide references for situational analysis, environmental diagnosis, and protection of forest soil affected by heavy metal pollution. This study particularly emphasizes hazards and sources to highlight the relevant control measures against heavy metal

pollution of forest soil. Future in-depth studies may focus on the spatial distribution, systematic framework on prevention and control, physiochemical properties, and measurement indices (e.g., degree) of heavy metal pollution of forest soil.

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