Evaluation of the chemical forms of soil heavy metals and their contamination risks

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Abstract

Soil heavy metals undergo dissolution, precipitation, complexation, adsorption and coalescence to form different forms of heavy metals, which in turn affect their activity, bioavailability and ecological effects [1-2]. Although the total amount of heavy metals in soil can be an important indicator for assessing environmental pollution, it often does not determine their biological effectiveness and environmental risk, but the different chemical forms and morphological ratios of heavy metals in soil play a crucial role in characterising the ecological effects [3-5]. Using heavy metal morphology as the object of study can effectively reveal the bioavailability, migration patterns and potential environmental hazards of soil heavy metals, which can be a guide for predicting long-term heavy metal changes and environmental and ecological risks.

Keywords

Heavy metals; Environmental pollution; Soil.

1. Introduction

Tessier (1979) classified heavy metals as exchangeable, carbonate-bound, Fe-manganese oxide-bound, organic matter-bound and residue-based, based on the site, mode, activity and biotoxicity of their binding to the soil [9]. Among them, the exchangeable state usually refers to the ions exchanged and adsorbed on clay minerals and other components [10], which are extremely sensitive to changes in the environment, easily migrated and transformed so that they can be absorbed and used by plants, and are the main form that causes environmental pollution, and therefore are the components that need to be focused on in morphological studies; the carbonate-bound state refers to the part of the metal ions that are bound to the carbonate precipitation, and in this form the When acidic conditions gradually increase, the bound fraction is released back into the environment and not only pollutes the environment again, but may also be used by organisms. It is a form with strong ionic bonding, so it is not easily released under normal environmental conditions, but its transfer is facilitated by changes in redox potential [11-12]; the organic matter-bound state, also known as the reducible state, is defined as a chelated salt with heavy metal ions as the central ion and organic matter as the ligand in the soil. This form is normally stable and not readily absorbed by plants. However, if the redox potential changes, the organic matter may react, resulting in the leaching of heavy metals from this form; the residue form is a product of natural geological weathering processes, often in the form of crystalline minerals, and is generally the main form in which heavy metals exist. Compared to other forms, heavy metals in the residual form are largely unreleased in the normal environment, remain stable in the environment for long periods of time, and are difficult for plants or microorganisms to take up, making them the least toxic [13].

2. Application of the Testier sequential extraction method

Currently, the Tessier sequential extraction method is widely accepted and applied to the morphological study of soil heavy metals by scholars at home and abroad. In a domestic study, Mou Xinli et al. (2013) analysed the morphology of six heavy metals in agroforestry soils in the Three Gorges reservoir area, and the results showed that the residue state of Zn, Pb, Cr and Cu accounted for the highest proportion of the total in the area, while the Fe-Mn oxide-binding state accounted for the largest proportion of Cd, followed by the reducible state [14]. Chen Tao et al. (2014) investigated the chemical morphology of Cd in agricultural soils in typical foul irrigation areas and found that under long-term foul irrigation conditions, agricultural soil Cd was mainly in the exchangeable and carbonate-bound states, with the other three forms accounting for a relatively low proportion [3]. In addition, Wu Xianliang (2018) extracted five different morphological heavy metals from the whole amount according to the way the soil was combined with heavy metals and assessed the contamination level of soil heavy metals in the coal mining area of Qianxi [15]; Yang Yuping (2019) et al. analysed the soil heavy metals around the mining area of Xiangnan on the basis of chemical morphology, and the results showed that Cd was mainly in the exchangeable state and Pb in the residue state was the most abundant [16]. Nannoni (2011) extracted heavy metals from agricultural soils near a typical smelter in Kosovo, and found that the main forms of heavy metals were residues, except for the exchangeable state of Cd, which accounted for a relatively large proportion of heavy metals [17]; SK Pandey et al. (2016) extracted the heavy metal morphology of coal ash generated from the production activities of a thermal power plant in India and found that in addition to the residual state, the Fe-Mn oxidation-bound Cd, Cu and Zn were also present in high levels [18].I Massas et al. (2013) investigated the accumulation of heavy metals in soils of the Thriassio Plain, Greece, based on morphological distribution characteristics and found that Pb was present in the highest exchangeable state and higher concentrations of Cu and Ni in the residual state, and the highest levels of Zn in the oxidizable state, indicating a greater activation release of Pb and Zn under the influence of foul irrigation or rainfall [19].

3. Progress in heavy metal pollution risk assessment research

Investigating heavy metal pollution and assessing the potential environmental risks can provide some theoretical basis for preventing and controlling heavy metal pollution and developing control and remediation strategies. In the past, most studies were mainly based on allometric indicators, combined with background values of heavy metals or national standard thresholds to assess the pollution status and environmental risks. The commonly used methods include single factor pollution index, Nemero integrated pollution index, potential ecological hazard index, ground accumulation index and grey correlation analysis. For example, Bo Luji et al. (2021) applied the ground accumulation index and potential ecological index to analyse the pollution level and ecological risk of heavy metals in soil from a garlic production area in Shandong, and found that the overall soil quality of the production area was at a clean level and the potential ecological risk was low [20].Fu (2016) used single-factor and integrated pollution indices to contaminate heavy metals in rice soil from a typical e-waste dismantling area were evaluated, and the results showed that there was heavy contamination of Cd and Pb, and the combined regional contamination level was moderate [21]. However, as the mechanisms of soil heavy metal contamination continue to be explored, it has been found that although the total amount of soil heavy metals can be an important indicator for the assessment of the regional pollution status, it does not provide sufficient information on the biological toxicity and availability, and does not provide a comprehensive picture of the environmental risks that may be caused by heavy metals [22-23]. Heavy metals present in the soil environment in different chemical forms present different toxicities and have widely varying environmental impacts and mechanisms of action. Therefore, taking the characteristics of different forms of heavy metals as an entry point can reveal the current pollution status and potential environmental risks of regional heavy metals in a more comprehensive and clear manner [24-25].

4. Chemical form-based approach to environmental pollution and risk assessment of heavy metals

The main methods for environmental risk assessment based on heavy metal endowment morphology include the ratio of secondary phase to primary phase (RSP) [26], risk assessment code (RAC) and bioavailability index (BMI) [27], and scholars at home and abroad have made some progress in this area. Based on heavy metal morphology, Mou Xinli (2013) and others used the secondary phase compared to primary value method (RSP) and Tucker3 model to assess the pollution level and environmental risk of heavy metals in agricultural and forest soils in the Three Gorges reservoir area, respectively, and the results showed that the soil pollution in the study area's fading zone was more serious, and the potential ecological risk of Cd was the greatest, while the risk of Cr was the least [14]. Wang Fangting (2020) investigated the environmental risk posed by heavy metals in soils of the Pearl River Delta using the RAC index and found that there was a very high potential risk for Cd, while this high risk was generalised throughout the study area [28].Nemati et al. (2011) evaluated the environmental risk of heavy metals in sediments from Selangor, Malaysia using the RAC index and found that some samples of Cd and Zn showed Sundaray et al. (2012) analysed the chemical forms of heavy metals in Indian estuarine sediments and applied the RAC method for risk assessment, and the results indicated that the biological activity of Cd in the region was high and had posed a serious environmental risk [30].Ji et al. (2019) introduced the bioavailability index BMI to investigate the environmental risk of heavy metals in Baiyangdian sediments and found that the BMI index was similar to the toxicity index (TRI), indicating a serious potential environmental risk level [31].

5. Conclusion

The evaluation of heavy metal pollution based on different chemical forms is complex, and the advantages and disadvantages of different evaluation methods also differ greatly. At present, scholars at home and abroad have mostly focused on sediment heavy metals, but there is a lack of research on soil heavy metals, especially in agricultural fields around industrial and mining enterprises. Therefore, this study selects the agricultural fields around an industrial park in northwest China as the study area, evaluates the soil heavy metal pollution status based on different forms, and uses GIS to visualize and express the potential environmental risks of heavy metals.

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