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Original Research

Distribution of Heavy Metal Contents in Soil Producing *Uncaria rhynchophylla* (Miq.) Miq. ex Havil. In Guizhou: Driven by Land Use Patterns

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Abstract

The distribution characteristics of heavy metal content in the soil of Guizhou real estate hook vine under different land use methods were explored, and the basic data for the high-quality and efficient cultivation of URM producing areas in Guizhou real estate was explored. Taking the soil of the hook vine production area as the research object, the contents of six heavy metals (Cu, As, Cd, Hg, Pb and Cr) in the root zone and non-root zone of the hook vine production area under different land use patterns were studied, and the pollution characteristics of heavy metals were evaluated by single factor and Nemerow composite index. The results showed that contents of heavy metals in URM producing areas in Guizhou are different under different forms of land use. The contents of Cu, As, Hg, Pb and Cr are invariably the highest in URM bases. It is found from the grading of soil heavy metal contents in URM producing areas, contents of all other heavy metals except Cd in forest land are compliant with standards. Under different forms of land use, only forest land is contaminated by heavy metal Cd. A certain antagonistic or synergistic action exhibits among different heavy metals. In general, soil heavy metal contents in URM producing areas in Guizhou are relatively low. Specifically, heavy metal contents in URM bases are significantly higher than those in forest land and waste land, which is mainly attributed to massive fertilization. Therefore, fertilization should be reduced in the practical production process.

Keywords: Uncaria, heavy metals, land use mode, Chinese medicinal materials, distribution characteristics

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Introduction

With rising public awareness of health and fitness in recent years, the use of medicines has increased. Chinese herbal medicines have a broad popularity with increasing market demand and planting area thanks to their greenness, environment-friendliness and less side effects. However, the advancement in industrialization and pesticide abuse have also brought about problems of pesticide residues and excessive levels of heavy metals in Chinese herbal medicines. Liu et al. [1]. found that the level of heavy metals in *Panax notoginseng* exceed limits mainly because of the mobility of heavy metals in soil into the herb. Apart from Chinese herbal medicines, excessive levels of heavy metals have also been reportedly found in soil of planting areas of *Panax notoginseng* [2]; Liu et al. [3] tested the heavy metal content of 50 traditional Chinese medicines, a total of 250 samples, and found that the copper, cadmium, lead and mercury content of some samples exceeded the standard. Soil is the most immediate environment for plant growth and is closely related to the quality of Chinese herbal medicines [4]. To a great extent, the types and contents of heavy metals in soil affect those of the same substances in Chinese herbal medicines [5]. Thus, efforts aimed at examining and assessing soil heavy metals must be heightened [6].

Presently, assessment of soil heavy metals is mainly conducted through the following methods: single and comprehensive factor index, geoaccumulation index and potential ecological risk index. Researching heavy metals in the planting environments of Chinese herbs is of great significance for addressing excessive levels of heavy metals in the production process of traditional Chinese herbal medicines. *Uncaria rhynchophylla* (Miq.) Miq. ex Havil. (URM) is an evergreen wood vine plant, the dry hooked stems and branches of which are often used as medicine. Sweet and cool natured and belonging to the liver and pericardium meridian, URM has efficacies of clearing heat, pacifying liver, calming endogenous wind and arresting convulsion [7]. With increasing demand for URM due to its good efficacies, wild URM no longer satisfies market needs and artificial cultivation has become a trend for URM production. However, the Chinese herbal production process often involves excessive heavy metals which not only adversely affect the quality of Chinese herbs but also seriously harm human health. Most existing studies of URM have focused on germplasm resources, effective components and pharmacological actions of URM [8-13], but few have addressed the soil of producing areas of URM. As such, this research examines the soil of URM's producing areas and discusses the characteristics of heavy metal contents in root and non-root zones in URM producing areas under different forms of land use, with a view of providing basic data and evidence for decisions about cultivation of high-quality URM.

Materials and Methods

General Background Information of the Researched Area

The researched area is located in the production area of URM in Jianhe County, Guizhou Province. The county lies in the center of the Qiandongnan Miao and Dong Autonomous Prefecture of Guizhou around 108°17'08″~109°04'12″ east longitude and 26°20'42″~26°55'42″. The county covers a total area of 2165.3 km^2. The Jianhe County is mainly covered by soil developed from Banxi Group slate, which is dominated by yellow soil (pH value falling between 4.2 and 5.5) with part of soil being yellow, red soil and a small fraction of yellow limestone soil and acid purple soil developed from limestone. The altitude of the researched area ranges from 348 to 1626 m. With a subtropical monsoon climate, the researched area has abundant precipitation, an average annual temperature of 16.7ºC, a frost-free period of 326 days, an average annual precipitation of 1220mm and an average annual sunshine duration of 1236.3 h [14]. The researched area is shown in Fig. 1, marked in red.

Sample Collection and Pretreatment

Typical soil from the producing area of 5-year-old URM were selected in Jianhe County, Guizhou Province. Mindful of evenly spatial distribution, we collected 46 soil samples from root and non-root zones of three URM producing areas in Jiuyang, Censong and Liuchuan towns and the peripheral natural forestland and waste grassland. Specifically, these included 30 soil samples from URM bases (15 for root and non-root zones, respectively), 10 samples from forest land (5 for root and non-root zones, respectively) and 6 samples from waste grassland (3 for root and non-root zones, respectively). An overview of the experimental sites is shown in Appendix 1. The soil samples were brought back to the laboratory, debris and plant rhizome impurities were removed, dried naturally, and ground through a 100 mesh sieve for later use.

The locations of sampling sites were recorded using GPS positioning information. Mixed samples of topsoil (0-20 cm) were taken using the random sampling method. Weigh 0.5g of soil sample (accurate to ±0.001 g) and digest it in a DS-360-36 graphite digester, using HCl-HF-HNO_3-$HClO_4$ mixed acid. Among them, hydrochloric acid 10 ml, concentrated nitric acid 15 ml, hydrofluoric acid 5 ml, perchloric acid 5 ml, nitric acid 1 ml. The required experimental reagents are shown in Appendix 2. Cu in soil was measured by the inductively coupled plasma mass spectrometry (ICP-MS) method; and As in soil by the atomic fluorescence spectrometry (AFS) method using a dual-channel atomic fluorescence spectrometer; Cd, Hg and Pb in soil were measured by the graphite furnace atomic absorption spectrometry

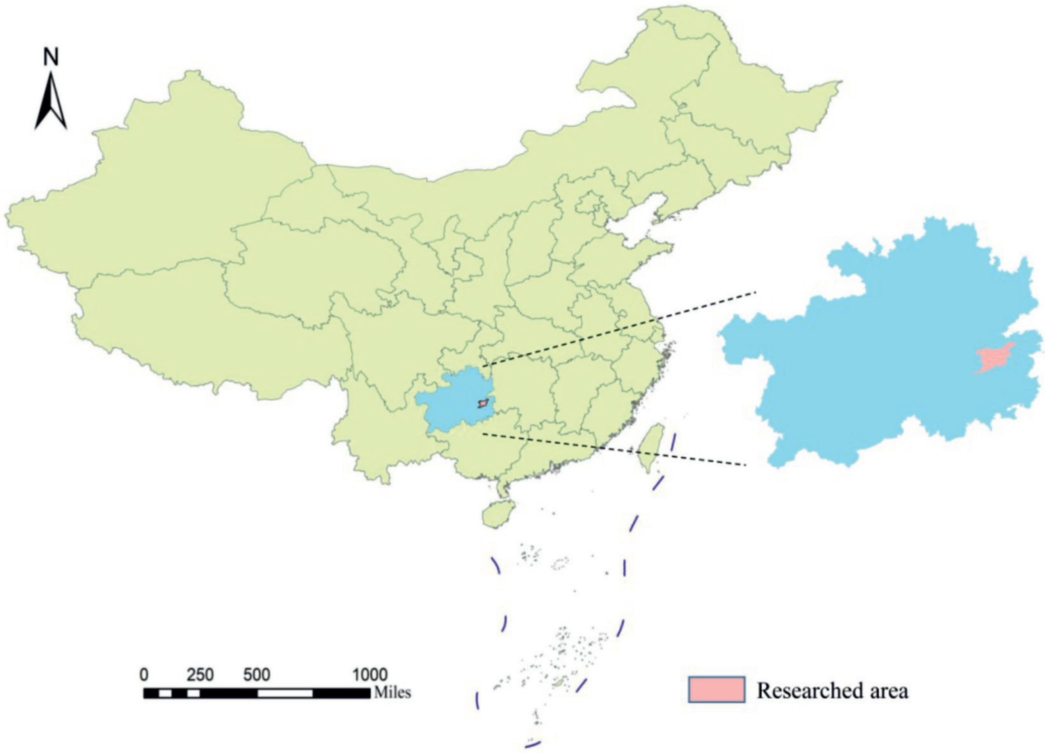

Fig. 1. The researched area.

(GFAAS) method; and Cr in soil by the flame atomic absorption spectroscopy (FAAS) method.

Assessment

Assessment of heavy metal pollution in soil was carried out by a combination of the single-factor pollution index (*Pi*) and the Nemerow composite pollution index (NIPI) methods, which is commonly used to assess heavy metal pollution in soil. The single-factor pollution index method is able to reflect the degree of pollution of each pollutant, which is expressed by $Pi = C_i/S_i$, where *Pi* is the environmental quality index of pollutant *i* in soil, C_i is the measured concentration of pollutant *i*, and S_i is the assessment criteria of the i-type pollutant. $Pi \leq 1.0$ indicates that the soil is free of pollution; $Pi > 1.0$ indicates that the soil has been polluted; and the larger the *Pi*, the higher the degree of cumulative pollution of pollutants in soil.

The Nemeroww composite pollution index (NIPI) method takes account of all single-factor pollution indexes and comprehensively reflects the overall soil pollution, which is expressed by:

$$NIPI = \sqrt{\frac{\left(\frac{1}{n}\sum_{i=1}^{n} P_i\right)^2 + P_{i(max)}{}^2}{2}} \quad (1)$$

Where NIPI is the composite pollution index of soil; $Pi_{(max)}$ is the maximum pollution index of a single pollutant in soil. Soil quality is graded based on the magnitude of the Nemerow composite pollution index. The assessment criteria for soil pollution grading are shown in Table 1 [15].

Data Analysis

In data analysis, experimental data was organized and staticized using the statistical software Excel 2016. After eliminating outliers, the mean value, standard deviation, and coefficient of variation of test data were calculated, correlation analysis and multiple comparison were conducted using the SPSS 19.0 software, and figures were drawn using Origin 2022 and ArcGIS 10.8.

Results

Characteristics of Heavy Metal Contents in URM Producing Areas

Characteristics of Heavy Metal Contents in Different URM Producing Areas

As can be seen from Fig. 2, the contents of Cu, Hg, Pb and Cr invariably exhibit a pattern of Censong Town>Jiuyang Town>Liuchuan Town, and the contents of As and Cd both exhibit a pattern of Jiuyang Town> Liuchuan Town>Censong Town. Heavy metal contents are generally higher in Censong Town. The content of Cr is the highest across different areas, while that of Hg is the lowest. The average values of Cu contents

Table 1. Classification standard of crop pollution.

Grade	NIPI	The degree of contamination [15]
I	NIPI ≤ 0.7	Safe
II	0.7 < NIPI ≤ 1.0	Cordon
III	1.0 < NIPI ≤ 2.0	Light pollution
IV	2.0 < NIPI ≤ 3.0	Medium pollution
V	NIPI > 3.0	Heavy pollution

across different areas are 7.73 mg.kg^{-1} (Jiuyang Town), 14.72 mg.kg^{-1} (Censong Town) and 4.69 mg.kg^{-1} (Liuchuan Town), respectively; the average values of As contents across different areas are 4.34 mg.kg^{-1}, 1.35 mg.kg^{-1} and 2.44 mg.kg^{-1}, respectively; the average values of Cd contents across different areas are 0.33 mg.kg^{-1}, 0.22 mg.kg^{-1} and 0.31 mg.kg^{-1}, respectively; the average values of Hg contents across different areas are 0.15 mg.kg^{-1}, 0.23 mg.kg^{-1} and 0.07 mg.kg^{-1}, respectively; and the average values of Pb contents across different areas are 18.73 mg.kg^{-1}, 25.84 mg.kg^{-1} and 17.57 mg.kg^{-1}, respectively.

Characteristics of Heavy Metal Contents in URM Producing Areas under Different Forms of Land Use

Heavy metal contents in URM producing areas under different forms of land use are shown in Fig. 3. As can be seen from the figure, both Cu and Hg contents exhibit a pattern of URM bases >waste land >forest land, the contents of As, Pb and Cr exhibit a pattern of URM bases>forest land>waste land and the contents of Cd exhibit a pattern of forest land>URM bases>waste land. Except for Cd, the contents of other 5 heavy metals are invariably the highest in URM bases. Under different forms of land use, the average values of Cu contents are 10.06 mg.kg^{-1} (URM bases), 4.61 mg.kg^{-1} (forest land) and 4.80 mg.kg^{-1} (waste land), respectively; the average values of As contents are 3.34 mg.kg^{-1}, 3.12 mg.kg^{-1} and 1.31 mg.kg^{-1}, respectively; the average values of Cd contents are 0.29 mg.kg^{-1}, 0.37 mg.kg^{-1} and 0.23 mg.kg^{-1}, respectively; the average values of Hg contents are 0.18 mg.kg^{-1}, 0.05 mg.kg^{-1} and 0.11 mg.kg^{-1}, respectively; and the average values of Pb contents are 37.1 mg.kg^{-1}, 27.11 mg.kg^{-1} and 23.41 mg.kg^{-1}, respectively.

Characteristics of Heavy Metal Contents in Root and Non-Root Zones of URM Producing Areas

As can be seen from Fig. 4, apart from the significant difference in Pb contents between the root and non-root zones of waste land, there is no significant differences in contents of the other 5 heavy metals between root and non-root zones under different forms of land use. This result indicates that heavy metal contents are not significantly different between root and non-root zones in URM producing areas. Specifically, the contents of Cu, As, Pb and Cr are invariably the lowest in root zone of waste land. This may be attributable to a certain concentrating effect of plants on heavy metals. The varieties and numbers of plants are fewer in waste land than in URM bases and forest land, and thus the contents of heavy metals in waste land are also relatively lower. In addition, URM bases, and forest land are more likely to be influenced by human interferences such as fertilization, sewage irrigation and pesticide application that increase heavy metal contents.

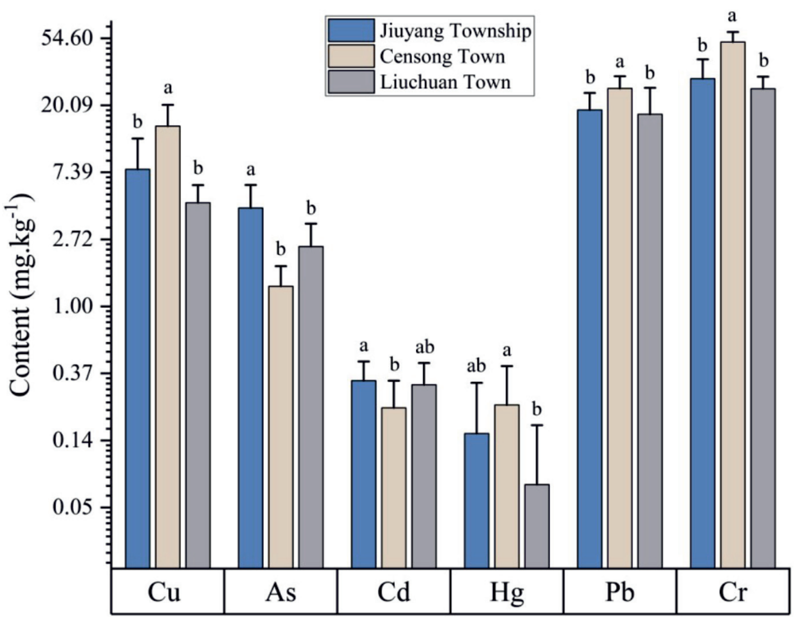

Fig. 2. Characteristics of heavy metal content in soil of different URM producing areas.
Note: Different lowercase letters indicate significant differences (P<0.05).

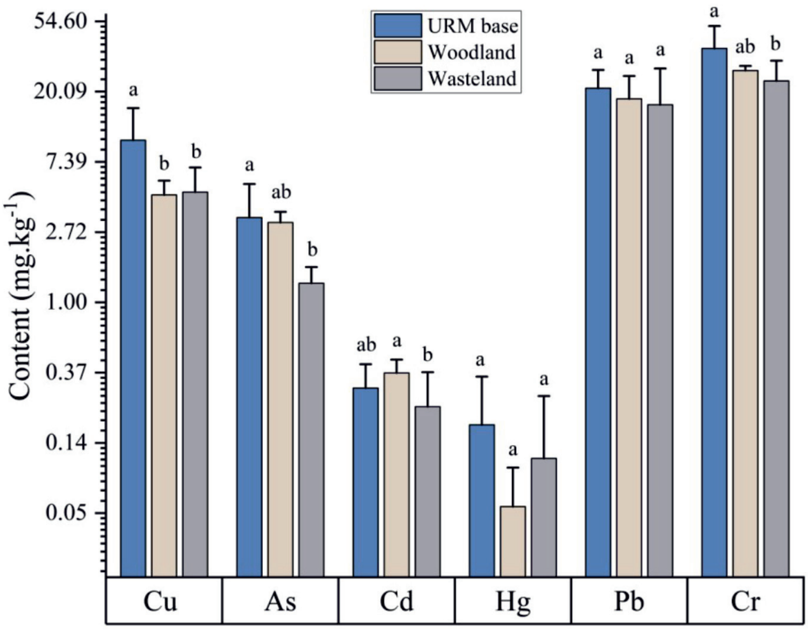

Fig. 3. Characteristics of heavy metal content in URM producing areas under different land use patterns.
Note: Different lowercase letters indicate significant differences (P<0.05).

Characteristics of Heavy Metal Contents in Soil of URM Producing Areas

Based on soil environment quality risk control standard for soilcontamination of agriculture land (Interim) (GB 15618-2018) [16] and Green Food Origin Environmental Quality (NY/T 391-2021) [17], the heavy metal contents in soil were graded (Table 2), with pH≤5.5. According to the screening values of soil contamination risks provided by GB 15618-2018, contents of heavy metals like Cu, As, Pb, Hg and Cr all conform to the standards under the three different forms of land use (URM bases, forest land and waste land); Cd contents in URM bases and waste land are compliant to the standards, but Cd content in forest land, which is 0.37 $mg.kg^{-1}$>0.30 $mg.kg^{-1}$, is not compliant to the

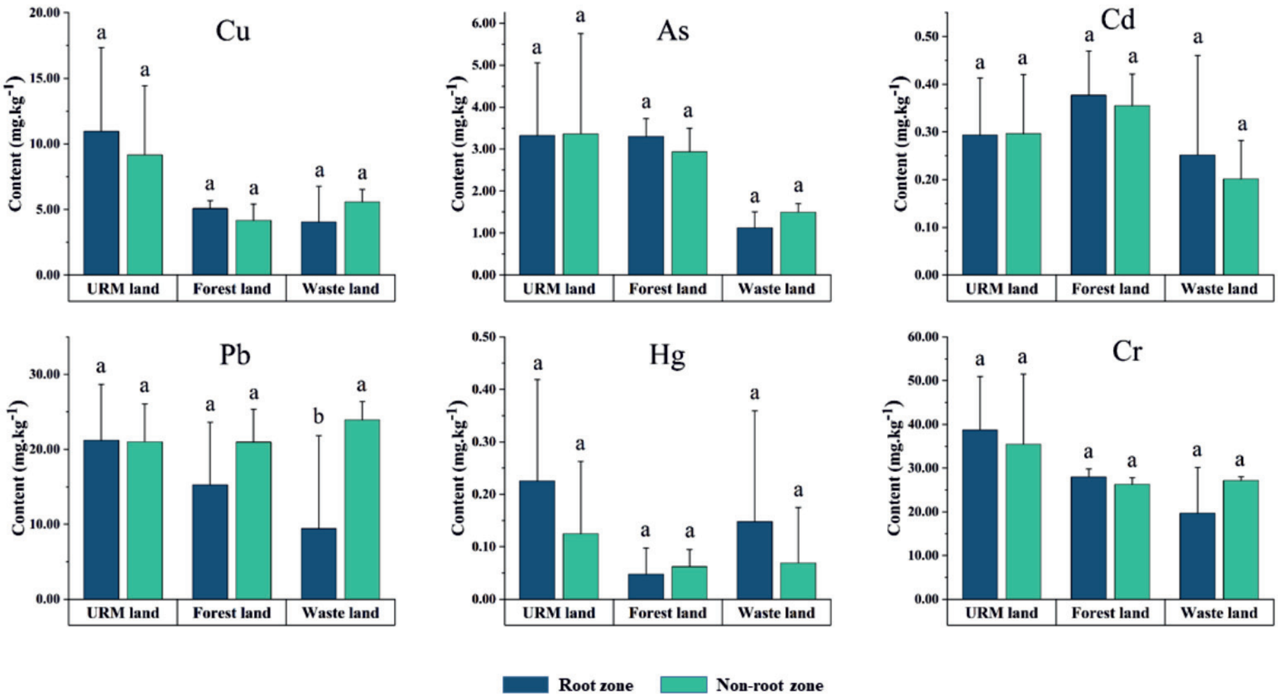

Fig. 4. Characteristics of heavy metal contents in root and non-root zones of URM producing areas.
Note: Different lowercase letters indicate significant differences (P<0.05).

Table 2. Classification of heavy metal content in soil.

Criteria	Grade	Cu (mg.kg^{-1})	As (mg.kg^{-1})	Cd (mg.kg^{-1})	Hg (mg.kg^{-1})	Pb (mg.kg^{-1})	Cr (mg.kg^{-1})
GB 15618-2018 [16]	Soil contamination risk screening values	150.00	30.00	0.30	0.50	80.00	250.00
	Soil pollution risk control value		200.00	1.50	2.00	400.00	800.00
NY/T 391-2021 [17]		50.00	25.00	0.30	0.25	50.00	120.00

standards; compared against the screening values of soil contamination risks, the contents of heavy metals As, Cd, Pb, Hg and Cr under the three forms of land use are all compliant to the standards. According to NY/T 391-2021, the contents of all other heavy metals, except for Cd in forest land, are compliant with standards under the three different forms of land use. In general, heavy metal contents in soil of URM producing areas are compliant to national standards, and the soil in URM bases does not have the problem of excessive levels of heavy metals.

Referring to the secondary criteria of GB 15618-2018, assessments of heavy metal contents under three different forms of land use (URM bases, forest land and waste land) were conducted using the single-factor index method (*Pi*) and the Nemerow composite pollution index method (NIPI), and the results are shown in Table 3. From the perspective of the single-factor pollution index, the *Pi* values of heavy metals under other forms of land use are invariably smaller than 1 except the *Pi* of Cd in forest land soil, indicating that only forest land has been contaminated by Cd. From the perspective of composite pollution index, the NIPI values of URM bases and forest land are 0.73 and 0.89 for URM bases and forest land, respectively, pointing to an alert contamination level; the NIPI value of heavy metals in waste land is 0.56<0.7, pointing to a safe contamination level; from the perspective of composite pollution index, the URM soil has not been contaminated by heavy metals under any form of land use.

Influencing Factors of Heavy Metal Contents in Soil of URM Producing Areas

As can be known from the correlation analysis between soil heavy metal contents, soil bulk density and soil specific weight (Fig. 5), the Cu content, Pb and Cr contents, and Pb and Cr contents in URM producing areas all exhibit an extremely significant positive correlation (P<0.01), while the contents of As, Hg and Cd, and Cr show a significantly negative correlation (P<0.01); no significant correlation is found among other heavy metals. Soil bulk density is extremely significantly negative correlated with contents of Cu and Hg (P<0.01) and significantly correlated with the content of Cr (P<0.05). Soil specific weight does not have a significant correlation with the content of any heavy metal.

Discussion

Characteristics of Heavy Metal Contents in URM Producing Areas

The average values of contents of heavy metals Cu, As, Hg, Pb and Cr in soil of different URM producing areas are invariably lower than the results obtained by Jia Fengchao et al [18]. in Jingoutun and Wudaoling in the central area of Chengde, with only the average content of Cd larger than the results obtained by the said researchers. It is not difficult to find from the comparisons of these two sets of results that the contents of heavy metals in different URM producing areas are relatively low. The average contents of heavy metals in different areas are ranked as Cr>Pb>Cu>As>Cd>Hg, roughly consistent with the average contents of heavy metals across different planting areas of *Paris polyphylla* var.*yunnanensis* measured by Li Hailing et al [19], which was Pb>Cr>Cu>As>Cd>Hg. As the Cr content in URM producing areas is the highest, attention should be paid to Cr content in soil during the planting process.

In comparison with the contents of Cu, Cd, Hg, Pb and Cr under different forms of land use with the

Table 3. Assessment of soil heavy metal pollution under different land use modes.

Different forms of land use	P_i						NIPI	The degree of contamination [15]
	Cu	As	Cd	Hg	Pb	Cr		
URM bases	0.20	0.11	0.98	0.58	0.08	0.15	0.74	Cordon
Woodland	0.09	0.10	1.22	0.18	0.07	0.11	0.89	Cordon
Wasteland	0.10	0.04	0.76	0.36	0.07	0.09	0.56	Safe

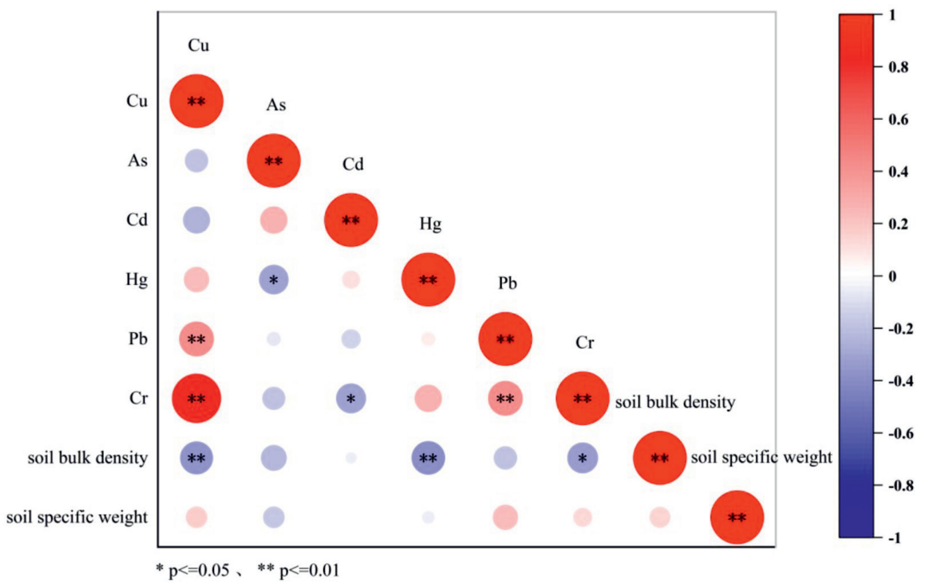

Fig. 5. Correlation analysis of heavy metal content, soil bulk density and soil specific gravity in URM producing areas.

results obtained by Qiu Lefeng et al [20]. in Hangzhou Bay (contents of Cu, Cd, Hg, Pb and Cr are 30.50, 0.18, 0.13, 26.62 and 69.69 $mg.kg^{-1}$, respectively), the contents of Cu, Pb and Cr in URM producing areas are lower, the Cd content is relatively higher, and the Hg content is close to that of the latter research. Compared with results obtained by Su Cuilan and Yang Le [21] in Wangmo County (As content being 16.86 $mg.kg^{-1}$), the As content in URM producing areas is much lower. Therefore, under different forms of land use, the contents of the other 5 heavy metals, except for Cd, in soil of URM producing areas are invariably lower. Compared with nationwide background values of soil heavy metals (contents of Cu, As, Cd, Hg, Pb and Cr are 21.00, 9.00, 0.18, 0.03, 22.00 and 53.00 $mg.kg^{-1}$, respectively) [18], contents of heavy metals like Cu, As and Cr in root and non-root zones of URM producing areas are lower, those of Cd and Hg are higher and that of Pb is close or slightly lower. Compared with contents of soil heavy metals in root and non-root areas of *Lonicera confusa* producing areas found by Liu Xiaolan et al. [22]. In Guizhou, the contents of soil heavy metals in root and non-root zones of URM producing areas show no significant difference.

Grading the contents of soil heavy metals in URM producing areas helps determine whether they are compliant with national criteria. Referring to the soil contamination screening values and soil contamination risk regulation values provided by GB 15618-2018 and NY/T 391-2021, it was found that only the Cd content in forest land across the three forms of land use (URM bases, forest land and wasteland) is not compliant to the criteria. In general, the soil only has a certain level of Cd contamination, which is consistent with findings of precedent studies [19, 23]. From the perspective of single-factor pollution index, only forest land out of the three different types of land use has Cd contamination, which is consistent with findings of Luo et al [24]. From the perspective of composite pollution index, forest land and URM bases have an alert level of contamination, wasteland has a safe contamination level and URM producing bases have no heavy metal contamination under different forms of land use, which is consistent with findings of precedent studies [25].

Influencing Factors of Heavy Metal Contents in Soil of URM Producing Areas

This research shows that Cd content in URM producing areas is relatively high. This is mainly attributed to the fact that the Guizhou Province is a region with high background heavy metal values. In addition, pollution discharges from industrial and mining enterprises such as lead and zinc mines and nonferrous metal smelting companies, as well as over-application of fertilizers [26, 27] can also cause Cd contamination. Statistical results show that a total of 660,000 kg of Cd enters soil on a yearly basis across the world, with fertilization representing a contribution as high as 55%. Studies show that excessively high level of Cd in soil can cause Cd concentration in traditional Chinese herbal medicines [24]. Therefore, attention should be paid to the excessive Cd levels in soil. In general, except Cd, the contents of the other 5 heavy metals (Cu, As, Hg, Pb and Cr) in URM producing areas all exhibit a pattern of highest levels in URM bases, which is mainly attributed to long-term fertilization. Phosphate fertilizer is one of the most commonly used fertilizers. Rock phosphate, the raw material of phosphate fertilizer, contains a certain amount of heavy metal pollutants like As, Cd, Pb and Cr, resulting in considerable contents of Cu, As, Cd, Pb and Cr in the finished product [26]. Therefore, it is imperative to pay attention to rational fertilization and artificial management during the planting process. To address excessive heavy metal levels, firstly, artificial management can be strengthened or chemical fertilizers can be reduced or changed to organic fertilizers. Secondly, plants having a hyper-cumulative effect on out-of-limit heavy metals can be selected to change the traditional monotonous planting of URM. Instead, interplanting the aforementioned plants can be implemented to absorb and remove the out-of-limit heavy metals in soil.

The correlations between heavy metals indicate that they share similar or opposite sources. Any two of the Cu, Pb, Hg and Cr exhibit an extremely significant positive correlation or positive correlation, indicating that they share a similar pollutant source. The URM producing areas is a typical karst area, and there are a large number of soluble carbonate bedrocks in the territory, and the weathering of carbonate bedrock has a strong enrichment effect on the elements in the product [28, 29], leading to a strong positive correlation between part of the heavy metals (Cu, Pb, Hg and Cr). In addition to natural factors, human factors also have a great influence on soil [30], long-term application of fertilizers that contain a certain amount of heavy metal pollutants like Cu, Pb, Hg and Cr also leads to a relatively strong positive correlation between these elements. As mainly comes from industrial production, application of arsenic-containing pesticides, combustion of coal, arsenic-containing sewage and dust and fume. Cd is mainly from industrial pollutant sources [31]. The correlation analysis results show that there is a certain antagonism or synergy between the heavy metals [32]. In general, apart from human and industrial pollutant sources, plant root zones also have a certain effect on soil heavy metal contents. Studies show that during long-term plant management, nutrient transfer in soil induced by root system activities of populus can activate heavy metals. Specifically, populus detoxifies heavy metals mainly through storage in barks and withering and falling of leaves, thereby reducing heavy metal contents in soil [33]. Further, the difference in soil heavy metal contents between root and non-root zones may be attributed to the control of root exudates over the destinations of heavy metals, which transform heavy metals into organic chelates that are attached to the inorganic colloid surface of soil and difficult to absorb followed by a reaction that transform them into organic and non-organic compounds [34].

Conclusions

Contents of heavy metals in URM producing areas in Guizhou are different under different forms of land use. The contents of Cu, As, Hg, Pb and Cr are invariably the highest in URM bases. It is found from the grading of soil heavy metal contents in URM producing areas, contents of all other heavy metals except Cd in forest land are compliant with standards. Under different forms of land use, only forest land is contaminated by heavy metal Cd. A certain antagonistic or synergistic action exhibits among different heavy metals. In general, soil heavy metal contents in URM producing areas in Guizhou are relatively low. Specifically, heavy metal contents in URM bases are significantly higher than those in forest land and wasteland, which is mainly attributed to massive fertilization. Therefore, fertilization should be reduced in the practical production process.

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Conflict of Interest

The authors declare no conflict of interest.

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Appendix

Appendix 1. Overview of the sampling site.

Sample number	Sampling location	Geographical location	Altitude (m)	Sampling depth (cm)	Sampling mode	Land use patterns
1	Jiuyang Township, Jianhe County	N26°38′58.03″; E108°30′46.53″	723	0-20	Surface root zone soil	URM base
2	Jiuyang Township, Jianhe County	N26°38′58.03″; E108°30′46.53″	723	0-20	Surface non-root zone soil	URM base
3	Jiuyang Township, Jianhe County	N26°38′58.43″; E108°30′48.50″	744	0-20	Surface root zone soil	URM base
4	Jiuyang Township, Jianhe County	N26°38′58.43″; E108°30′48.50″	744	0-20	Surface non-root zone soil	URM base
5	Jiuyang Township, Jianhe County	N26°38′58.12″; E108°30′48.50″	782	0-20	Surface root zone soil	URM base
6	Jiuyang Township, Jianhe County	N26°38′58.12″; E108°30′48.50″	782	0-20	Surface non-root zone soil	URM base
7	Jiuyang Township, Jianhe County	N26°38′58.87″; E108°30′49.74″	783	0-20	Surface root zone soil	URM base
8	Jiuyang Township, Jianhe County	N26°38′58.87″; E108°30′49.74″	783	0-20	Surface non-root zone soil	URM base
9	Jiuyang Township, Jianhe County	N26°38′59.55″; E108°30′51.53″	774	0-20	Surface root zone soil	URM base
10	Jiuyang Township, Jianhe County	N26°38′59.55″; E108°30′51.53″	774	0-20	Surface non-root zone soil	URM base
11	Jiuyang Township, Jianhe County	N26°38′53.10″; E108°30′35.93″	780	0-20	Surface root zone soil	URM base
12	Jiuyang Township, Jianhe County	N26°38′53.10″; E108°30′35.93″	780	0-20	Surface non-root zone soil	URM base
13	Jiuyang Township, Jianhe County	N26°38′52.94″; E108°30′35.51″	781	0-20	Surface root zone soil	URM base
14	Jiuyang Township, Jianhe County	N26°38′52.94″; E108°30′35.51″	781	0-20	Surface non-root zone soil	URM base
15	Jiuyang Township, Jianhe County	N26°38′53.08″; E108°30′34.63″	779	0-20	Surface root zone soil	URM base
16	Jiuyang Township, Jianhe County	N26°38′53.08″; E108°30′34.63″	779	0-20	Surface non-root zone soil	URM base
17	Jiuyang Township, Jianhe County	N26°38′52.99″; E108°30′32.66″	774	0-20	Surface root zone soil	URM base
18	Jiuyang Township, Jianhe County	N26°38′52.99″; E108°30′32.66″	774	0-20	Surface non-root zone soil	URM base
19	Jiuyang Township, Jianhe County	N26°38′52.86″; E108°30′32.24″	776	0-20	Surface root zone soil	URM base
20	Jiuyang Township, Jianhe County	N26°38′52.86″; E108°30′32.24″	776	0-20	Surface non-root zone soil	URM base
21	Censong Town, Jianhe County	N26°44′11.64″; E108°26′45.40″	508	0-20	Surface root zone soil	URM base
22	Censong Town, Jianhe County	N26°44′11.64″; E108°26′45.40″	508	0-20	Surface non-root zone soil	URM base
23	Censong Town, Jianhe County	N26°44′11.64″; E108°26′45.40″	508	0-20	Surface root zone soil	URM base
24	Censong Town, Jianhe County	N26°44′11.64″; E108°26′45.40″	508	0-20	Surface non-root zone soil	URM base
25	Censong Town, Jianhe County	N26°44′09.94″; E108°26′43.70″	503	0-20	Surface root zone soil	URM base

Appendix 1. Continued.

26	Censong Town, Jianhe County	N26°44′09.94″; E108°26′43.70″	503	0-20	Surface non-root zone soil	URM base
27	Censong Town, Jianhe County	N26°44′08.27″; E108°26′45.41″	499	0-20	Surface root zone soil	URM base
28	Censong Town, Jianhe County	N26°44′08.27″; E108°26′45.41″	499	0-20	Surface non-root zone soil	URM base
29	Censong Town, Jianhe County	N26°44′08.90″; E108°26′44.86″	499	0-20	Surface root zone soil	URM base
30	Censong Town, Jianhe County	N26°44′08.90″; E108°26′44.86″	499	0-20	Surface non-root zone soil	URM base
31	Liuchuan Town, Jianhe County	N26°37′54.97″; E108°33′36.73″	819	0-20	Surface root zone soil	Wood land
32	Liuchuan Town, Jianhe County	N26°37′54.97″; E108°33′36.73″	819	0-20	Surface non-root zone soil	Wood land
33	Liuchuan Town, Jianhe County	N26°37′54.36″; E108°33′35.52″	796	0-20	Surface root zone soil	Wood land
34	Liuchuan Town, Jianhe County	N26°37′54.36″; E108°33′35.52″	796	0-20	Surface non-root zone soil	Wood land
35	Liuchuan Town, Jianhe County	N26°37′54.21″; E108°33′37.45″	831	0-20	Surface root zone soil	Wood land
36	Liuchuan Town, Jianhe County	N26°37′54.21″; E108°33′37.45″	831	0-20	Surface non-root zone soil	Wood land
37	Liuchuan Town, Jianhe County	N26°37′54.69″; E108°33′38.09″	827	0-20	Surface root zone soil	Wood land
38	Liuchuan Town, Jianhe County	N26°37′54.69″; E108°33′38.09″	827	0-20	Surface non-root zone soil	Wood land
39	Liuchuan Town, Jianhe County	N26°37′54.62″; E108°33′38.52″	821	0-20	Surface root zone soil	Wood land
40	Liuchuan Town, Jianhe County	N26°37′54.62″; E108°33′38.52″	821	0-20	Surface non-root zone soil	Wood land
41	Liuchuan Town, Jianhe County	N26°38′16.25″; E108°33′32.64″	706	0-20	Surface root zone soil	Waste land
42	Liuchuan Town, Jianhe County	N26°38′16.25″; E108°33′32.64″	706	0-20	Surface non-root zone soil	Waste land
43	Liuchuan Town, Jianhe County	N26°38′16.31″; E108°33′32.82″	775	0-20	Surface root zone soil	Waste land
44	Liuchuan Town, Jianhe County	N26°38′16.31″; E108°33′32.82″	775	0-20	Surface non-root zone soil	Waste land
45	Liuchuan Town, Jianhe County	N26°38′16.77″; E108°33′32.06″	801	0-20	Surface root zone soil	Waste land
46	Liuchuan Town, Jianhe County	N26°38′16.77″; E108°33′32.06″	801	0-20	Surface non-root zone soil	Waste land

Appendix 2. Experimental reagents required.

Serial number	Reagent	Purity	Manufacturer
1	HNO_3	Premium grade pure	Sinopharm Chemical Reagent Co., Ltd
2	$HClO_4$	Premium grade pure	Sinopharm Chemical Reagent Co., Ltd
3	HF	Premium grade pure	Sinopharm Chemical Reagent Co., Ltd
4	HCL	Premium grade pure	Sinopharm Chemical Reagent Co., Ltd