

Heavy Metal Characteristics and Comprehensive Quality Index Evaluation of Soil-Crop System in 11 Cities of Yunnan Province, China

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Abstract

Yunnan province in China is a high background area of soil heavy metals, and agricultural planting and industrial and mining activities are relatively frequent, which aggravate soil heavy metal pollution. However, at present, there are few reports on the overall or large-scale soil-crop pollution and risk assessment of heavy metals in Yunnan Province. This study through 11 cities in Yunnan province of China farmland soil-crop systems of heavy metal lead, cadmium content, enrichment coefficient is analyzed, and using the method of potential ecological harm index, index of compressive quality to evaluate heavy metal pollution soil-crop system risk. Results showed that the average content of soil heavy metal Cd and Pb were 1.31 mg/kg, 64.17 mg/kg, which are higher than the background value of Yunnan province. The average contents of Pb and Cd in the edible parts of crops were 0.20 mg/kg, 0.08 mg/kg. The average content of heavy metals in crops in Diqing (Pb) and Nujiang (Cd) was 0.72 mg/kg and 0.148 mg/kg. The enrichment coefficients of heavy metals in edible parts of crops were the largest in Diqing (Pb) and Zhaotong (Cd). The average value of ecological risk index of Pb element in soil is 2.79, which indicates that the study area is in a slight ecological hazard, the average value of the ecological risk index of Cd in soil is 126.43. The average value of the comprehensive quality impact index (IICQ) is 4.27, which indicates that the study area is moderately polluted. In this study, the contents of heavy metals Cd and Pb in soils and crops in different administrative regions were determined, and the heavy metals Pb and Cd in soil-crop system of Yunnan province, China were evaluated, it is expected to have important scientific and theoretical significance for the safe use of cultivated land to export safe

agricultural products and promote the sustainable development of agriculture in Yunnan Plateau.

Keywords

Index of Compressive Quality, Heavy Metals, Soil-Crop System

1. Introduction

Soil provides us with raw materials such as plants and animals for daily use, that is, “everything grows in soil”. As a non-renewable resource, soil is the material basis for sustainable development (Zhang & Wu, 2018). The quality of soil environment is directly related to the quality and safety of agricultural products, even the ecological environment of cultivated land and human health. (Jing et al., 2016; Zhang, 2017; Jia et al., 2020) Cd is severely polluted in other regions, especially Europe, the United States and Hunan (Manfred et al., 2017; Li, 2020). However, the overall situation of soil environment in China is not optimistic, and the environmental quality of arable land soil is worrying, with an over-standard rate of 19.4% (Bulletin of National Soil Pollution Survey, 2014). Xu Qisheng et al. (2018) found in their research on soil heavy metal pollution in central and southern China that: Pb and Cd exceeded the standard to varying degrees, Cd was the most serious, and Hunan province was the most serious area. Zhang et al. (2021), based on the statistics of literature data related to heavy metals in arable soil in China, found that the content of heavy metals in soil in southwest China was higher than that in other regions, and Pb in soil in Yunnan province had the highest exceeding background value (1.91 times). Cultivated soil in Hunan and Yunnan provinces had the most serious heavy metal pollution. Zeng Min et al. (2019) investigated the soil and crops in Jijie Town, Gejiu City and found that the average concentration of Pb and Cd in the soil exceeded the environmental quality standard, but Pb and Cd in only some crops exceeded the limit value of pollutants in food.

As a daily dietary necessity, crops contain nutrients needed by the human body, but with the gradual improvement of public living standards, the demand for pollution-free crops is also increasing. Huo Yanhui et al. (2021) analyzed and studied the reported heavy metal content of crops in China and showed that different crops have different absorption and enrichment abilities of heavy metal elements in soil. Leaf vegetable crops are easy to enrich Cd, legume crops are easy to enrich Pb, while onion, garlic, solanum, root and stem crops have weak ability to absorb and enrich heavy metals. Ran Jiwei et al. (2019) studied the surrounding area of Gejiu tin mine in Yunnan and showed that Pb and Cd in crops were 12.10 and 16.16 times higher than the food safety limit respectively. Yunnan province is an important plateau characteristic agricultural production place, so the investigation and risk analysis of crop heavy metal pollution in

Yunnan province should be put on the agenda.

At present, researches on the quantitative relationship of heavy metal content in soil-crop system are mostly carried out in greenhouse or field plot experiments, which are quite different from the actual field production (Zeng et al., 2013). In addition, the research scope of heavy metal pollution in agricultural products is small and single. Therefore this study in order to further understand the farmland soil heavy metal accumulation characteristics in Yunnan province and the pollution degree of risk, not only in Yunnan province typical farmland soil, also took its corresponding crop edible part related to the investigation and determination, through the analysis on risk evaluation method in Yunnan province farmland soil-crop systems of heavy metal pollution risk profile. In order to find the correlation between the heavy metal content in soil and the heavy metal accumulation in crops, and then put forward the agricultural pollution prevention and safety production countermeasures according to local conditions.

2. Materials and Methods

2.1. Study Area

Yunnan province is located in the southwest border of China, within the range of 21°08' - 29°15'N and 97°31' - 106°11'E, with a total area of 394,100 km². It is a plateau mountainous province, and the mountainous area accounts for 88.64% of the total area of the province. The terrain of Yunnan province descends in a ladder form from north to south. The characteristics of high latitude and high altitude, low latitude and low altitude are consistent, make the climate between the north and the south show obvious vertical differences. There are 19 soil groups, 36 subgroups and 150 soil genera distributed in Yunnan. There are 458 known mineral areas in central Yunnan province. Yunnan is a large agricultural province with prominent regional characteristics in China and an important production base of plateau agricultural and sidby-products. The main crops include rice, corn, wheat, beans, potatoes, tobacco, sugar cane, tea, rubber, flowers, pineapple, banana, mango, coffee and so on.

2.2. Test Soil Samples

A total of 619 pairs of cultivated soil samples (0 - 20 cm) and corresponding crop samples were collected from Qujing, Zhaotong, Kunming, Yuxi, Wenshan, Honghe, Lijiang, Dali, Nujiang, Diqing and Puer using five-point sampling method and three-point sampling method, and brought back to the laboratory. Remove non-soil sundries such as stones and weeds in the soil, and then dry the soil naturally, pass through 0.15 mm, 1 mm and 2 mm sieve according to the measurement requirements of each index, and store for later use. The sampling points are shown in **Figure 1**.

The crop samples corresponding to soil in 11 counties were taken, the edible parts were washed with running water to remove impurities such as soil and yellow leaves, and the surface moisture was dried with absorbent paper after the

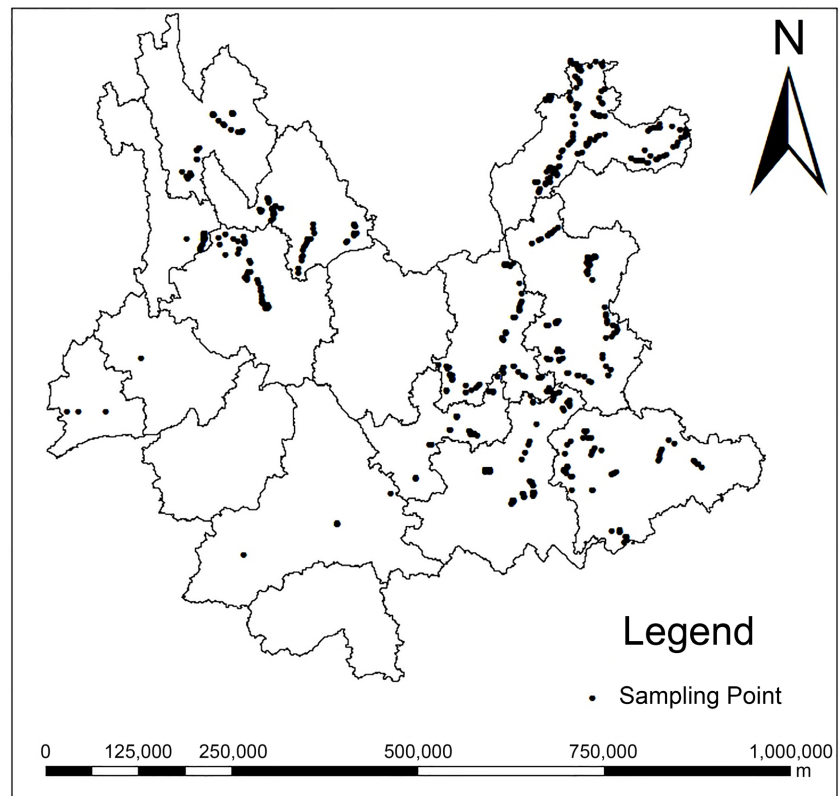


Figure 1. Samples collection points in the study area.

water was too pure. After weighing the fresh weight, the samples were put into the oven at 105°C for half an hour, and then dried continuously at 75°C, and the dry weight was weighed and ground for later use.

2.3. Test Items and Methods

The pH value was measured by glass electrode method, and the soil-water mass ratio was 2:5.

Flame atomic absorption spectrometer and graphite furnace atomic absorption spectrometer (Shimadzu-AA6880) were used in the detection.

2.4. Heavy Metal Pollution Assessment

1) Single pollution index method and index of compressive quality.

Single pollution index method: (Nazzal et al., 2021)

$$P_i = C_i / S_i$$

P_i is the single factor pollution index of pollutant i in crops. C_i is the measured data of pollutant i in crops; S_i is the evaluation standard of pollutant i .

2) index of compressive quality (Han et al., 2018)

$$RIE = \frac{\sum_{i=1}^N \left(\frac{C_i}{C_{si}} \right)^n}{N}$$

$$DDDB = \frac{\sum_{i=1}^N \left(\frac{C_i}{C_{Bi}} \right)^{\frac{1}{n}}}{N}$$

$$DDSB = \sum_{i=1}^N \left(\frac{C_{si}}{C_{Bi}} \right)^{\frac{1}{n}}$$

$$IICQ_s = X \times (1 + RIE) + Y \times \frac{DDDB}{DDSB}$$

relative impact equivalent, RIE; deviation degree of determination concentration from the background value, DDDB; deviation degree of soil standard from the background value, DDSB; n is to measure the oxidation number of element i ; n is the number of measured elements; C_i is the detected concentration of heavy metal element i ; C_{si} is the screening value of soil environmental quality of element i ; C_{Bi} is the background value of element i .

Quality index of agricultural products, QIAP

$$QIAP = \frac{\sum_{i=1}^N (P_{APi})^{\frac{1}{n}}}{N} = \frac{\sum_{i=1}^N \left(\frac{C_{APi}}{C_{LSi}} \right)^{\frac{1}{n}}}{N}$$

CAPi corresponds to the content of agricultural element i at soil points; CLSi is the limit standard of heavy metal element i in agricultural products comprehensive quality impact index (IICQ):

$$IICQ = IICQ_s + IICQAP$$

The number of soil X exceeding screening value; the number of soil Y exceeding background value; Z is the number of elements of IICQs; K is the background correction factor.

2.5. Data Processing Methods

Basic data processing was performed using Microsoft Excel, while significance variance, correlation, and clustering analysis were conducted by SPSS. Point import and Kriging spatial interpolation were analyzed by ArcGIS.

3. Results and Analysis

3.1. Accumulation Characteristics of Pb and Cd Heavy Metals in Soils of Different Administrative Regions

The soil pH value in the whole study area ranges from 4.23 to 7.86, with an average value of 6.84. The soil is acidic, and the coefficient of variation of pH is 9.15%, indicating that there is little difference in soil pH in the study area. **Table 1** shows the heavy metal content in the soil of the whole sample in the study area. The contents of heavy metal Cd and Pb in soil ranged from 0.02 to 31.98 mg/kg and 2.68 to 889.92 mg/kg, respectively, with an average of 1.31 and 64.17 mg/kg, respectively. However, only the average content of Cd exceeded the screening value by 4.33 times (see **Table 2** for screening values). The average

Table 1. Soil Cd and Pb heavy metal contents (mg/kg).

	Cd (mg/kg)	Pb (mg/kg)
average	1.31	64.17
maximum	31.98	889.92
median	0.61	32.07
minimum	0.02	2.68
standard deviation	2.55	110.35
coefficient of variation	195.32	171.96
background value of Yunnan province	0.218	40.6
Risk screening value	pH ≤ 5.5	0.3
	5.5 < pH ≤ 6.5	0.3
	6.5 < pH ≤ 7.5	0.3
	pH > 7.5	0.6

Table 2. Cd heavy metal content and overstandard rate in soils of different administrative regions.

city	Cd (mg/kg)	Cd over standard rate%
Qujing	2.68	92.31
Zhaotong	0.77	79.55
Kunming	1	71.43
Yuxi	1.49	82.14
Wenshan	0.76	66.07
Honghe	1.24	72.73
Lijiang	0.4	55.77
Dali	0.35	12.12
Nujiang	4.03	90
Diqing	0.7	77.42
Puer	0.41	33.33

contents of heavy metals Cd and Pb have exceeded the soil background value, and the multiple of exceeding the standard is Cd (5.96) > Pb (1.57), which indicates that there is a certain accumulation of heavy metals Cd and Pb in Yunnan soil, among which Cd accumulation is the most serious. The variation coefficient of Cd and Pb heavy metals in the study area from large to small is Cd (195.15) > Pb (172.04).

All samples were divided into 11 cities according to administrative regions. The contents of heavy metal Cd and Pb in soils of different administrative regions and their exceedances of screening values were shown in **Table 1**.

The accumulation and overstandard of heavy metals in soils of different administrative regions are significantly different. The accumulation and overstandard of the two heavy metals in soils of different administrative regions are as

shown in **Table 2** and **Table 3**.

Cd content as shown in **Table 2**: among the 11 cities, the Cd content in soil in descending order is: Nujiang > Qujing > Yuxi > Honghe > Kunming > Zhaotong > Wenshan > Diqing > Puer > Lijiang > Dali; the soil content in Nujiang was the highest (4.03 mg/kg), while the soil content in Dali was the lowest (0.35 mg/kg). Among them, the content of Cd in Nujiang, Qujing and Yuxi is higher than the average content of the whole study area. Cd content in soil samples in all cities exceeded the background value, from large to small, respectively, nujiang, Qujing, Yuxi, Honghe, Kunming, Zhaotong, Wenshan, Diqing, Puer, Lijiang, Dali. Cd content was 18.5, 12.30, 6.84, 5.69, 4.60, 3.52, 3.47, 3.20, 1.87, 1.86, 1.58 times higher than the background value. In terms of the over standard rate of soil samples, the Cd rate of soil samples in Qujing was the highest, which was 92.31%. The exceedant rate of soil samples in Dali was the lowest, 12.12%.

Pb content as shown in **Table 3**: among the 11 cities, the Pb content in soil in descending order is: Nujiang > Honghe > Diqing > Qujing > Kunming > Zhaotong > Yuxi > Lijiang > Dali > Wenshan > Puer; the soil content in Nujiang was the highest (166.58 mg/kg), and the soil content in Puer was the lowest (26.51 mg/kg). The Pb content in Nujiang, Honghe, Diqing and Qujing is higher than the average Pb content in the whole study area. The Pb content in Nujiang, Honghe, Diqing, Qujing, Kunming and Zhaotong soil samples exceeded the background value by 4.10, 3.28, 2.45, 2.07, 1.40 and 1.03 times, respectively. In terms of the over standard rate of soil samples, Nujiang had the highest Pb over standard rate, which was 40%. No samples in Dali exceeded the standard.

In conclusion, according to the average content of heavy metals in soil of various cities, the content of Pb and Cd in soil of Nujiang is the highest. The proportion of soil samples exceeding the screening value was highest in Qujing (Cd) and Nujiang (Pb).

Table 3. Pb heavy metal content and overstandard rate in soils of different administrative regions.

city	Pb (mg/kg)	Pb over standard rate%
Qujing	11.54	84.04
Zhaotong	2.27	41.67
Kunming	9.09	56.9
Yuxi	5.36	32.66
Wenshan	1.79	27.86
Honghe	29.09	133.25
Lijiang	1.92	31.66
Dali	0	28.01
Nujiang	40	166.58
Diqing	29.03	99.34
Puer	0	26.51

3.2. Accumulation of Cd and Pb in Edible Parts of Crops in Different Administrative Regions

The contents of Heavy metals in edible parts of all crop samples in the study area are shown in **Table 4**. The contents of Pb and Cd in edible parts of crops are in the range of 0 - 4.95 mg/kg and 0 - 2.15 mg/kg, respectively, with the average contents of 0.20 and 0.08 mg/kg, respectively. The variation of Pb (224.39) > Cd (183.51).

The contents of Pb and Cd in edible parts of crops in different administrative regions vary greatly, and their contents are shown in **Table 5** and **Table 6**. The enrichment coefficient can reflect the enrichment degree or enrichment ability of plants to heavy metals, which reflects the difficulty of element migration in soil-plant system to a certain extent, indicating the enrichment of heavy metals in plants.

Heavy metal enrichment coefficient = heavy metal content in edible parts of crops/heavy metal content in soil \times 100%. The enrichment of edible parts of crops in different administrative regions is shown in the table (Sun et al., 2021).

Table 4. Soil Cd and Pb heavy metal contents (mg/kg).

	Cd (mg/kg)	Pb (mg/kg)
average	0.08	0.2
maximum	2.15	4.95
median	0.03	0.06
minimum	0	0
standard deviation	0.14	0.45
coefficient of variation	183.51	224.39

Table 5. Content, bioconcentration factors and over standard rate of Cd heavy metals in edible parts of crops in different administrative regions.

city	Cd (mg/kg)	Cd over standard rate%	bioconcentration factors%
Qujing	0.09	8.43	51.67
Zhaotong	0.09	16.54	66.17
Kunming	0.06	8.71	40
Yuxi	0.06	7.85	47.62
Wenshan	0.02	3.58	31.71
Honghe	0.05	5.86	41.38
Lijiang	0.04	11.58	36.36
Dali	0.04	7.93	12.12
Nujiang	0.15	7.03	71.43
Diqing	0.02	5.21	19.35
Puer	0.06	8.7	44.44

Table 6. Content, bioconcentration factors and over standard rate of Pb heavy metals in edible parts of crops in different administrative regions.

city	Pb (mg/kg)	Pb over standard rate%	bioconcentration factors%
Qujing	0.37	0.83	58.33
Zhaotong	0.1	0.33	39.1
Kunming	0.06	0.17	35.79
Yuxi	0.08	0.43	28.57
Wenshan	0.06	0.3	39.02
Honghe	0.06	0.2	51.72
Lijiang	0.1	0.4	45.45
Dali	0.1	0.35	18.18
Nujiang	0.66	1.11	100
Diqing	0.72	1.38	100
Puer	0.05	0.38	55.56

Pb and Cd contents in the edible parts of crops are compared according to the limits of GB 2762-2012 “Limits of Pollutants in Food”, and the exceedances are shown in **Table 5** and **Table 6**.

The accumulation of the two heavy metal elements is as follows:

Pb content: among the 11 cities, the Pb content in edible parts of crops in descending order is: Diqen > Nujiang > Qujing > Zhaotong > Dali > Lijiang > Yuxi > Kunming > Honghe > Wenshan > Puer; the highest Pb content was 0.72 mg/kg in the edible parts of crops in Diqen, while the lowest Pb content was 0.05 mg/kg in Puer. At the same time, the enrichment coefficient of Pb in the edible parts of crops in Diqing-zhou was the highest (1.38%), and that in Kunming was the lowest (0.17%). Nujiang and Deqen had the highest rate of 100%. Dali was the least at 18.18%.

Cd content: among the 11 cities, the content of Cd in edible parts of crops in descending order is: Nujiang > Zhaotong > Qujing > Kunming > Yuxi > Puer > Honghe > Dali > Lijiang > Diqen > Wenshan; among them, the content of Cd in the edible part of crops in Nujiang was the highest (0.148 mg/kg), while that in Wenshan was the lowest (0.022 mg/kg). According to the size of crop enrichment coefficient, zhaotong had the largest enrichment coefficient (16.54%), and Wenshan had the smallest (3.58%). Nujiang had the highest Cd excess rate (71.43%). Dali had the lowest at 12.12 percent.

In conclusion, according to the analysis of heavy metal content in edible parts of crops in various cities (prefectural), it can be seen that the content of heavy metal in Diqen (Pb) and Nujiang (Cd) is the highest. The enrichment coefficient of edible parts of crops was the largest in Diqen (Pb) and Zhaotong (Cd), Nujiang (Pb) and Deqen (Pb) have the largest sample over-standard rate. Pb (46.53%) was higher than Cd (45.72%).

3.3. Enrichment Characteristics of Heavy Metals in Different Crops

1) Pb content as shown in **Figure 2**: among the five main crop types, the Pb content in edible parts of crops in descending order was legume > tubers > cereals > leafy vegetable > Brassica. The content of Pb in edible part of legumes was the highest (0.33 mg/kg), and that in leafy vegetables was the lowest (0.12 mg/kg). According to the enrichment coefficient, legumes (1%) > tubers (0.58%) > cereals (0.54%) > brassicas (0.51%) > leafy vegetables (0.34%).

2) Cd content as shown in **Figure 2**: among the five main crop types, the content of Cd in edible parts of crops in descending order: leafy vegetables > tubers > Brassica > legumes > cereals; among them, the content of Cd in edible part of leaf vegetable was the highest (0.10 mg/kg), and that in cereal was the lowest (0.03 mg/kg). According to the enrichment coefficient, legumes (16.99%) > tubers (14.1%) > leafy vegetables (12.55%) > brassicas (11%) > cereals (4.8%).

3.4. Risk Analysis of Heavy Metal Contamination in Soil-Crop System

1) Single pollution index method and index of compressive quality

Pb: The spatial distribution of potential ecological risk of Pb element in the surface soil of cultivated land in the study area is shown in **Figure 3**. The high value region of potential ecological risk index is in the northern region of Qujing and the southern region of Honghe. The average value of Pb ecological risk index in soil was 2.79, indicating that the study area was in slight ecological hazard as a whole. 99.84% of the points were slight ecological hazard, and 0.16% of the points were moderate ecological hazard.

Cd: The spatial distribution of potential ecological risk of Cd element in the

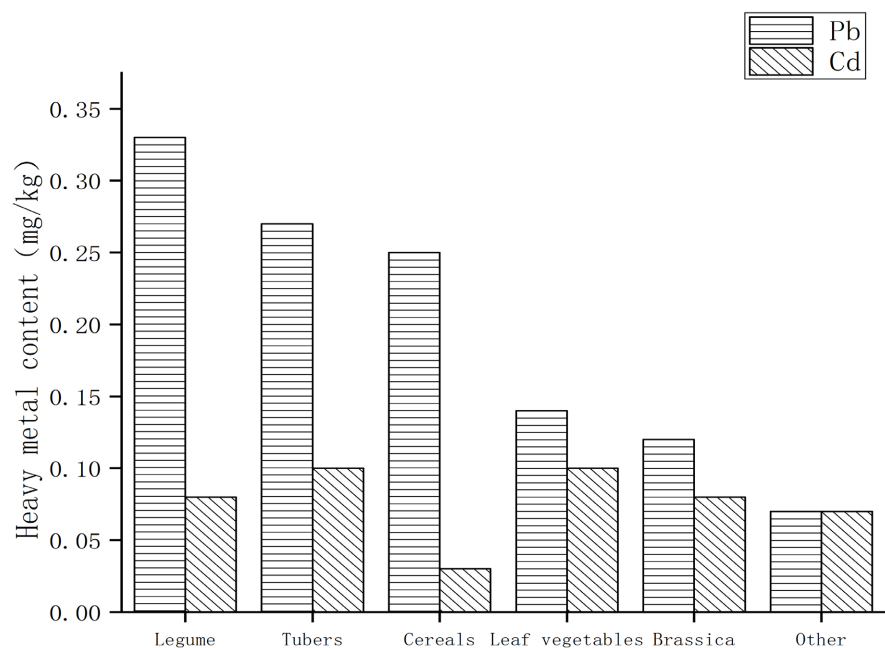


Figure 2. Heavy metal contents of edible parts of different crop types (mg/kg).

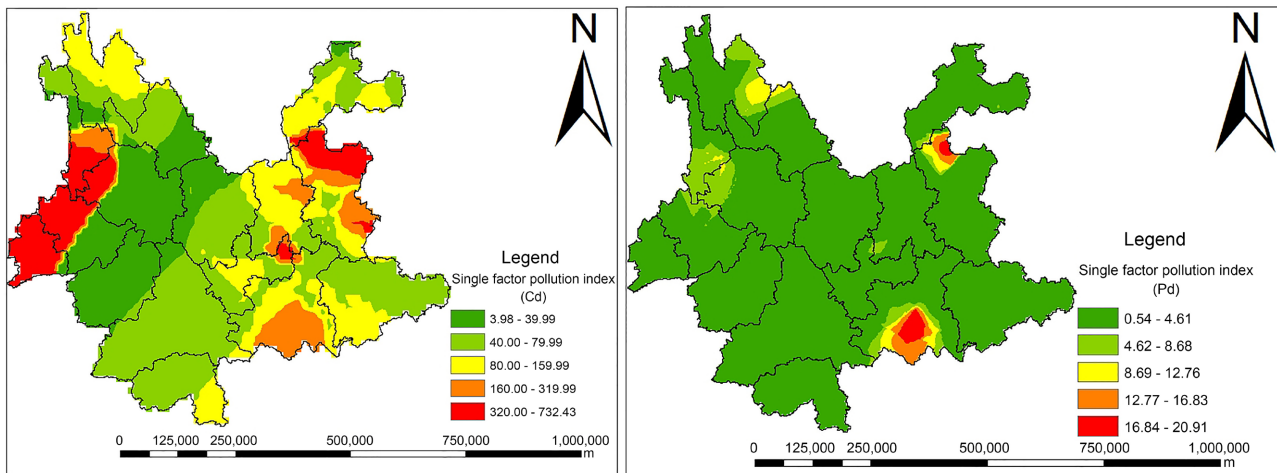


Figure 3. Spatial distribution of potential ecological risks of heavy metals in soil (Pb and Cd).

surface soil of cultivated land in the study area is shown in **Figure 2** and **Figure 3**. The region with high value of potential ecological risk index of Cd element in soil is in the western part of Yunnan, and the whole range of eastern Yunnan is also affected to varying degrees. According to Hakanson potential ecological risk classification standard (Deng et al., 2019), the average value of Cd element ecological risk index in soil is 126.43, which indicates that the study area is in a relatively strong ecological risk, and the site of 30.69% is a slight ecological risk 30.86% of the sites were moderate ecological hazards, 21.97% were strong ecological hazards, 7.92% were very strong ecological hazards and 8.56% were extremely strong ecological hazards.

2) Index of compressive quality

Figure 4 shows the comprehensive soil quality Impact Index (IICQs) and agricultural product Quality Index (IICQAP) in Yunnan Province. The parameters and standard values of soil background values are shown in **Table 1**. The contents of heavy metals in edible parts of crops are referenced, and the standard limits of GB 2762-2012, GB 15199-1994 and GB 13106-1991. The mean value of IICQs and IICQAP in the study area was 2.97 and 0.14 respectively. The severely polluted soils (IICQS > 5) were mainly concentrated in qujing, Honghe and Nujiang rivers. Most of the crops were clean or slightly polluted (IICQAP < 2), and the highest value of IICQAP appeared in Zhaotong in eastern Yunnan and southern Nujiang in western Yunnan.

1) At 19.06%, both soil and crops were not polluted, and the soil environmental quality was good. 2) 1.62% indicates that the soil is not polluted, but the crops are polluted, and the comprehensive environmental quality of the soil is in the sub-health state. 3) At 49.27% of the sites, the soil was polluted, but the crops were in the limited quality standard, and the comprehensive environmental quality of the soil was in the state of sub-pollution, requiring close attention. 4) At 29.4% of the sites, the soil and crops were polluted to varying degrees.

Figure 5 shows IICQ of cultivated land comprehensive quality impact index in the study area. The average value of IICQ was 3.12, indicating that the study

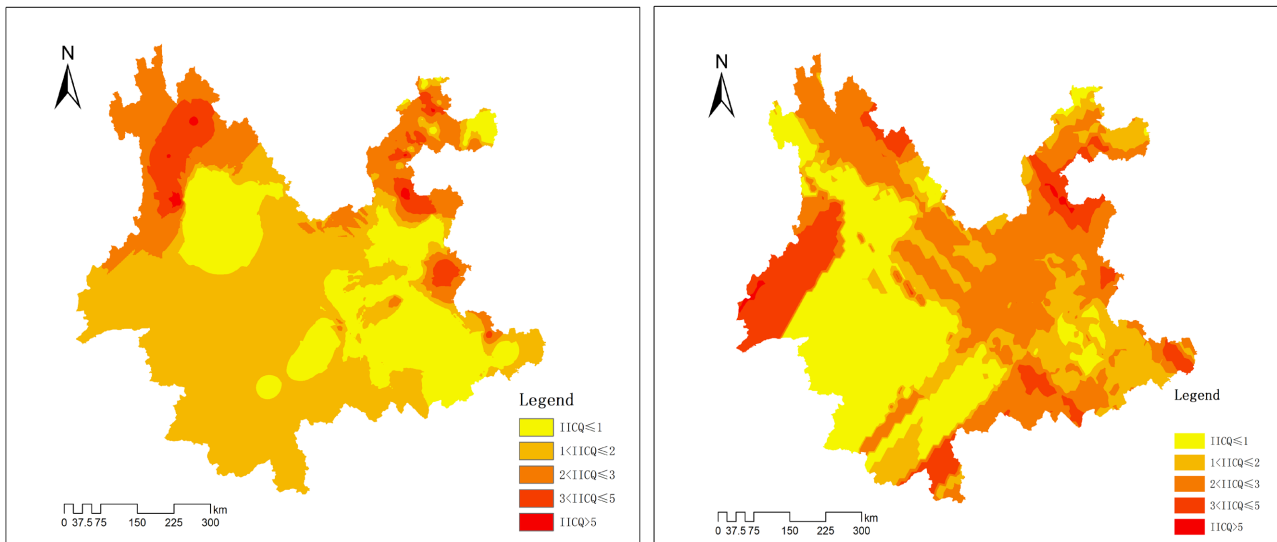


Figure 4. Spatial distribution of IICQS and IICQAP values of soils and crops in Yunnan province.

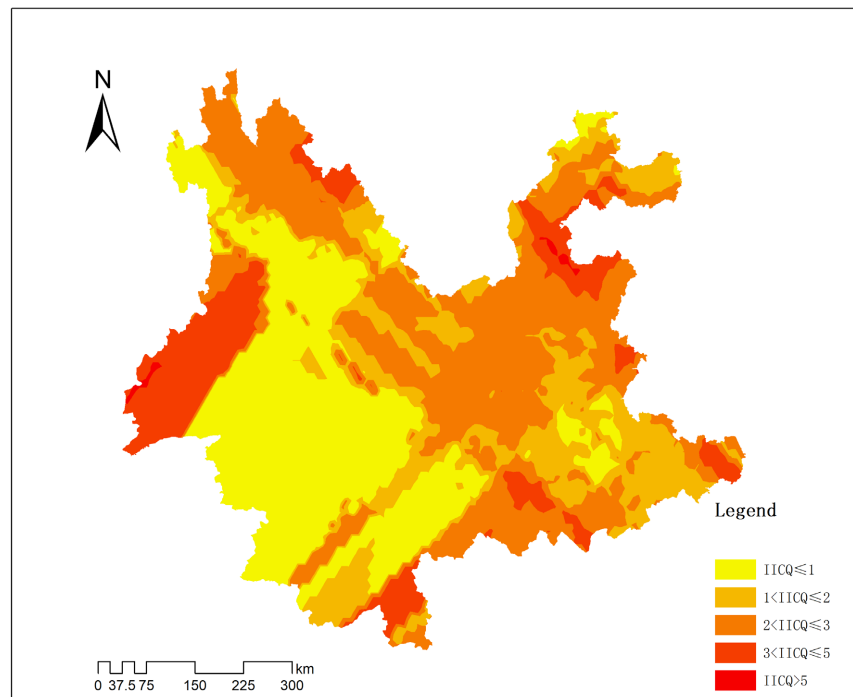


Figure 5. Spatial distribution of IICQ values of soils and crops in Yunnan province.

area was moderately polluted as a whole. 21.1% of the sites were clean, 0.48% were slightly polluted, 42.83% were mildly polluted, 49.81% were moderately polluted, and 14.65% were severely polluted.

4. Discussions

The cumulative pollution of heavy metal Cd in soil in the study area is the most serious, which is consistent with the investigation results of Zhang Xuhui et al. (2019) in Yunnan province. The comprehensive potential ecological risk in the

northern part of Qujing is too high and Cd element in the soil in this area has extremely strong ecological harm, which is the same as Yuan et al. (2022), Liu Xiaoyan et al. (2016), Yang Muqing et al. (2017), Zhou Yan et al. (2018). Huang Jiixin et al. (2022) studied mining areas in the middle and upper reaches of Lancang River and showed that Pb and Cd were seriously and consistently polluted in the soil of the mining area. Liu Juan et al. (2021) also pointed out that the high pollution degree of heavy metal Cd in soil of bi River basin was consistent with the extremely strong potential ecological risk in the west Yunnan region in this study. Lead and zinc ores are almost everywhere in Yunnan province, so Pb and Cd background values are relatively high in many regions of Yunnan province (Wang et al., 2021). Coefficient of variation is an indicator to measure the relative dispersion degree of each test value in a set of data and can reflect the average variation degree of the total sample value (Li et al., 2017). The two heavy metals Cd (195.15) > Pb (172.04) in the study area may have obvious regional differences in their spatial distribution (Zhao et al., 2022), which may be related to the complex geological background of Yunnan Province and the existence of mineral development and man-made source pollution in some areas.

Among the cities in this study, Pb and Cd pollution in the edible parts of crops in Diqen and Nujiang are relatively serious, which is similar to the locations with high Pb and Cd content in soil, and also consistent with the serious Pb and Cd pollution in water, soil and hair samples in the middle and upper reaches of The Lancang River according to the study of Li Jinpeng et al. (2019). Among the edible parts of different crop types, legume is easier to absorb Pb. This is consistent with reports that cowpea and soybean usually have the largest dry matter production and can be absorbed in large quantities from acidic Zn, Pb, Cu ore. Huang Chunxia & Huang Lixing et al. (2021) also investigated the heavy metal pollution of food crops in Guangxi manganese ore recovery area and showed that the contents of Zn, Pb, Cd in legume crops were relatively high, which may be related to the heavy metal tolerance of legume plants. Among different crop types, leaf vegetables are easier to absorb Cd, which is consistent with Chang Tong et al. (2020) study on Cd content of edible vegetables such as leaf vegetables, beans, roots, melons and fruits and found that leaf vegetables have the highest Cd overstandard rate. Therefore, legume crop planting should be reduced in areas where heavy metal pollution is more serious, such as Qujing, Honghe, Nujiang and other administrative areas where heavy metal elements exceed the standard and have a high degree of overlap. Reduce the planting of leafy vegetables in areas with high Cd pollution. However, there are only 6 samples in Puer due to the problem of sample retention and placement, and their representativeness may be poor.

5. Conclusion

1) The average contents of Pb and Cd in soil were 64.17 mg/kg and 1.31 mg/kg, respectively. The average content of Pb and Cd has exceeded the background

value. Nujiang (Pb, Cd) had the highest average content of heavy metals in soil, while Nujiang (Pb) and Qujing (Cd) had the highest over-standard rate of heavy metals in soil.

2) The average contents of Pb and Cd in the edible parts of crops were 0.20 and 0.08 mg/kg, respectively. Among the 10 cities involved in the study area (except Puer), the highest average contents of heavy metals were found in Diqen (Pb) and Nujiang (Cd). The enrichment coefficients of heavy metals in edible parts of crops were the largest in Diqen (Pb) and Zhaotong (Cd), while Pb and Cd exceeded the standard in Nujiang and Diqen were the highest. The average content of Pb in legume crops and Cd in leafy vegetable crops is the highest, and the crop type with the highest enrichment coefficient of all elements in different crop types is legume. Therefore, the planting of legume crops should be reduced, while the planting of leafy vegetable crops should be reduced in areas with more serious Cd pollution.

3) The potential ecological risk assessment showed that the study area was at the critical level of low ecological risk and moderate ecological risk as a whole. The potential ecological risk of heavy metal Cd in soil was the highest, while that of other elements was slight ecological risk. The average value of IICQ was 3.12, indicating that the study area was moderately polluted as a whole. 21.1% of the sites were clean, 0.48% were slightly polluted, 42.83% were mildly polluted, 49.81% were moderately polluted, and 14.65% were severely polluted.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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