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ASSESSING SOIL ENVIRONMENTAL CAPACITY ON DIFFERENT LAND USES IN A SUBURBAN AREA OF CHENGDU, CHINA

Wenjiang (China) is the area which undertakes high-intensity planting activities. Additionally, the soil environmental capacity has been a hot area of research as it plays a key role in environmental protection planning, environmental impact assessment and sustainable development. In this paper, the static model of soil environmental capacity is employed to investigate the distribution of residual soil environmental capacity in Wenjiang. The results show that the soil environmental capacity of mercury is the largest for industrial land while it is the lowest in garlic-rice planting areas; the soil environmental capacity of arsenic is the largest in city construction land while it is the lowest in ecological conservation zone; the soil environmental capacity of lead is the largest in city construction land while it is the lowest in garlic-rice planting areas; and the soil environmental capacity of chromium is the largest in city construction land while it is the lowest in garlic-rice planting areas.

1. INTRODUCTION

Following rapid economic growth, environmental issues have become the focus of the international community's attention [1]. Recently, researchers paid more attention to the environmental issues such as climate change [2], freshwater resource crisis [3], soil desertification [4], atmospheric pollution [5], and so on. Many management measures such as environmental protection planning [6], environmental impact assessment [7], and carbon trading [8] have been proposed to diminish the impact of environ-

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mental crises. In the world, environmental protection planning should be proposed before the planning of economic or industrial development is implemented by governments. Environmental capacity is one of the most important factors to make environmental protection plans. Thus, the environmental capacity which could measure the ability to accommodate pollutants has been one of the hottest topics.

Soil is a medium to link the atmosphere, groundwater, surface water, and crops together. It is one of the most important environmental factors, and its environmental capacity has been paid widespread attention to. Following with urbanization and industrialization, soil is suffering many issues such as hardening, heavy metal pollution, and deterioration [9–12]. Soil issues would be caused by the following aspects. Firstly, the improper utilization ways such as building on the plough, planting on barren, and land over-exploitation would lead to soil erosion and deterioration [13]. Secondly, overuse of fertilization would make the pH of soil decrease and the concentration of elemental heavy metal increase in grain-growing area, which would lead to soil hardening and acidification [14]. Thirdly, the pesticides could not degrade rapidly, and the toxic or harmful substances would be accumulated in the soil [15]. Lastly, the sewage irrigation would bring some heavy metals such as lead, mercury, and arsenic into the soil.

The Chinese government has done its utmost in solving the soil pollution issues. The pollutants in the soil must be investigated and their risks of pollution have to be evaluated in some special engineering sites or factories [16]. In 2016, the Action Plan for Soil Pollution Prevention and Control was proposed to remedy no less than 90% of polluted agricultural land within four years. The residual soil environmental capacity could indicate the maximum amount of pollutants could be allowed to emit into per unit area of soil. The residual soil environmental capacity is influenced by background value, standard referential value, land-use type, the amount of the pollutant entering into the soil of per unit area, self-purification ability of soil environment, etc. [17]. Based on the residual soil environmental capacity, the decision makers could judge whether each type of soil come up to standard and how many pollutants could be brought into the soil. Thus, it is necessary and significant to investigate the residual soil environmental capacity.

The static model of soil environment is employed to investigate the residual soil environmental capacity in Wenjiang, Sichuan Province, China. Section 2 of the paper describes the study areas, sampling and analysis methods and the static models of soil environment. Section 3 shows the distribution of the background value of soil environment and the soil environmental capacity of mercury, arsenic, lead, and chromium. Section 4 gives some suggestions for industrial planning based on the soil environmental capacity. Section 5 draws conclusions.

2. MATERIALS AND METHODS

Study areas. Wenjiang is located in Chengdu, crossing East longitude from 103°41′ to 103°55′, North latitude from 30°36′ to 30°52′. The mean annual precipitation is

962.54 mm, and the mean annual temperature is 16.3 °C. The soil of Wenjiang is paddy one and it is fit to plant. The planting industry plays one of the most important roles in Wenjiang, thus, the high quality soil is necessary to ensure food security. However, the human activities associated with urbanization and industrialization could influence soil quality. So it is necessary to take Wenjiang as a case to estimate the soil environmental capacity.

There are four rivers (including the Jinma River, Yangliu River, Jiang'an River and Qingshui River) and ten towns (including Shou'an town, Wanchun town, Hesheng town, Yongsheng town, Jinma town, Yongning town, Tianfu street, Liucheng street, Gongping street and Yongquan street) in Wenjiang with 264.62 km^2. In 2014, the GDP was about 36.45 billion yuan (US $ 5.95 billion), with its primary industry, second industry and tertiary industry were 1.64 billion yuan (US $ 0.27 billion), 18.93 billion yuan (US $ 3.09 billion) and 15.88 billion yuan (US $ 2.60 billion), respectively.

There are 7 land-use types, including ecological conservation zone, flowers planting areas, garlic-rice planting areas, city construction land, industrial land, vegetable planting areas and rice-vegetable planting areas. The largest area is flowers planting area, with 108.15 km^2. The areas of garlic-rice planting and city construction land are about 54.01 and 41.46 km^2, respectively. The areas of rice-vegetable planting , industrial land, vegetable planting, and ecological conservation zone are relatively small, with 26.39 km^2, 20.53 km^2, 13.09 km^2 and 0.99 km^2, respectively.

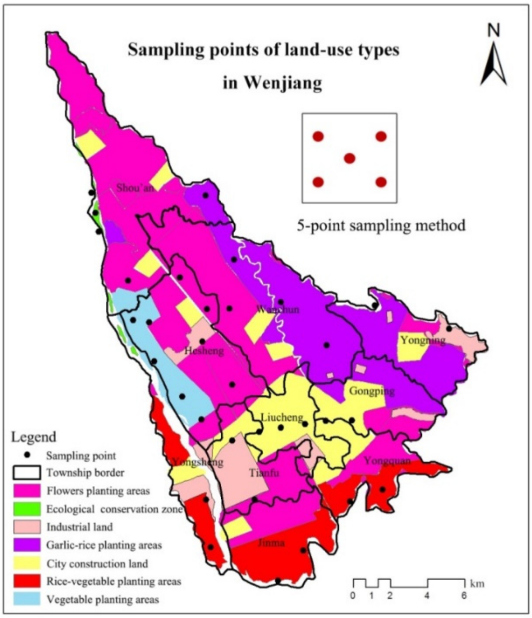

Fig.1 Sampling points of land-use types in Wenjiang

Soil sampling and analytical method. pH would influence the dissolution, sedimentation, and transformation of pollutants in soil [18]. There is significant difference in pH of different land-use types. Thus, for each land-use type, 3 to 5 control units were chosen to investigate the background value of soil. Five sampling points were set in each control unit [19, 20]. 165 sampling points were set as shown in Fig. 1.

Mercury, arsenic, lead, and chromium with the highest toxicity in soil would often threaten the food security, so they are of special concern in soil environment. The four pollutants could not be degraded by microorganisms, and they would accumulate in soil. Thus, they were chosen to assess the soil environmental capacity. Sampling and analyzing were entrusted to Zhejiang Focused Photonics Testing Company. The inductively coupled plasma mass spectrometer (EXPEC 7000, China) was used to determine the background contents of mercury, arsenic, lead, and chromium, and a pH meter (PH400, USA) was applied to determine pH.

Table 1

Standard referential values of four indexes in various land-use types [mg/kg]

Element	Mercury			Arsenic			Lead			Chromium		
pH	<6.5	6.5–7.5	>7.5	<6.5	6.5–7.5	>7.5	<6.5	6.5–7.5	>7.5	<6.5	6.5–7.5	>7.5
Ecological conservation zone[a]	0.3	0.5	1.0	30	25	20	250	300	350	250	300	350
Flowers planting areas[b]	0.3	0.5	1.0	40	30	25	250	300	350	150	200	250
Garlic-rice planting areas[b]	0.3	0.5	1.0	40	30	25	250	300	350	150	200	250
City construction land[c]	50			80			600			610		
Industrial land[d]	1140			44			250	300	350	150	200	250
Vegetable planting areas[b]	0.3	0.5	1.0	40	30	25	250	300	350	150	200	250
Rice-vegetable planting areas[b]	0.3	0.5	1.0	40	30	25	250	300	350	150	200	250

[a]Class II quality standard for soil of environmental quality standard for soils in China (GB15618-1995).

[b]Farmland environmental quality evaluation standards for edible agricultural products in China (HJ/T332--2006).

[c]Class B quality standard for soil of standard of soil quality assessment for exhibition sites in China (HJ350--2007).

[d]Environmental quality risk assessment criteria for soil at manufacturing facilities and Environmental quality standard for soils in China (HJ/T25-1999).

Calculation of soil environmental capacity. The static model of soil environmental capacity [21] was introduced to calculate the residual soil environmental capacity of each land-use type

$$W_i = \frac{\left(\left(C_{0i} - C_0\right) M_i S_i - Q_0\right) \times 10^{-9}}{S_i} \tag{1}$$

where, W_i, t/km^2, is the residual soil environmental capacity of the ith land-use type which denotes the maximum amount of jth pollutant could be allowed to emit into per unit area of the ith land-use soil type, t/km^2. C_{0i}, mg/kg, denotes the standard referential value of the jth pollutant to ensure the proper function of ith land-use type (agricultural planting, city construction, industry, and ecological conservation), it is obtained by the soil environmental quality standard of China (the references are shown in Table 1). C_0, mg/kg, denotes the background value of soil environment, it is determined by the present situation monitoring [22] with inductively coupled plasma mass spectrometer (EXPEC 7000, China). M_i, kg/km^2, corresponds to the soil mass per unit area of the ith land-use type. S_i, km^2, denotes the area of the ith land-use type, Q_0, mg, is the amount of the jth pollutant entering into the soil environment of the ith land-use type, it is available in the Wenjiang Statistical Yearbook (2015) and the environmental quality report of Wenjiang (2011–2015). The standard referential values of four indexes in the examined land-use types are shown in Table 1.

3. RESULTS

3.1. THE BACKGROUND VALUE OF SOIL ENVIRONMENT

According to the present situation, monitoring and the distributions of land-use types in Wenjiang, the spatial distributions of pollutants' concentration are shown in Fig. 2. The concentration of mercury in Northeast Wenjiang is higher than that in Southwest Wenjiang. The concentration of mercury in garlic-rice planting areas is the highest, at 0.182 mg/kg; while its concentration is the lowest in vegetable planting areas, with 0.027 mg/kg. The concentrations of mercury in flowers planting areas, industrial land, ecological conservation zone, city construction land, and rice-vegetable planting areas are 0.169 mg/kg, 0.142 mg/kg, 0.133 mg/kg, 0.322 mg/kg and 0.322 mg/kg, respectively.

The spatial distribution of arsenic in soil indicates that the concentration of arsenic is relative high beside small areas in the Southern Wenjiang. The concentration of arsenic in flowers planting areas is the highest, with 29.8 mg/kg, while its concentration is the lowest in rice-vegetable planting areas, with 22.9 mg/kg. The concentrations of arsenic in city construction land, industrial land, garlic-rice planting areas, ecological conservation zone, and vegetable planting areas are 29.7 mg/kg, 29.16 mg/kg, 27.6 mg/kg, 24.8 mg/kg and 23.9 mg/kg, respectively.

The spatial distribution of lead in Wenjiang is asymmetrical, the concentration of lead in the Northeast and Southwest is higher than that in the center. Meanwhile, its concentration in rice-vegetable planting areas is the highest, with 43.4 mg/kg; however, the concentration of lead is the lowest in city construction land, with 27.1 mg/kg; the concentrations of lead in ecological conservation zone and garlic-rice planting areas are

31.6 mg/kg and 35.1 mg/kg, respectively, in industrial land, flowers planting areas, and vegetable planting areas they are from 29.1 to 30.1 mg/kg.

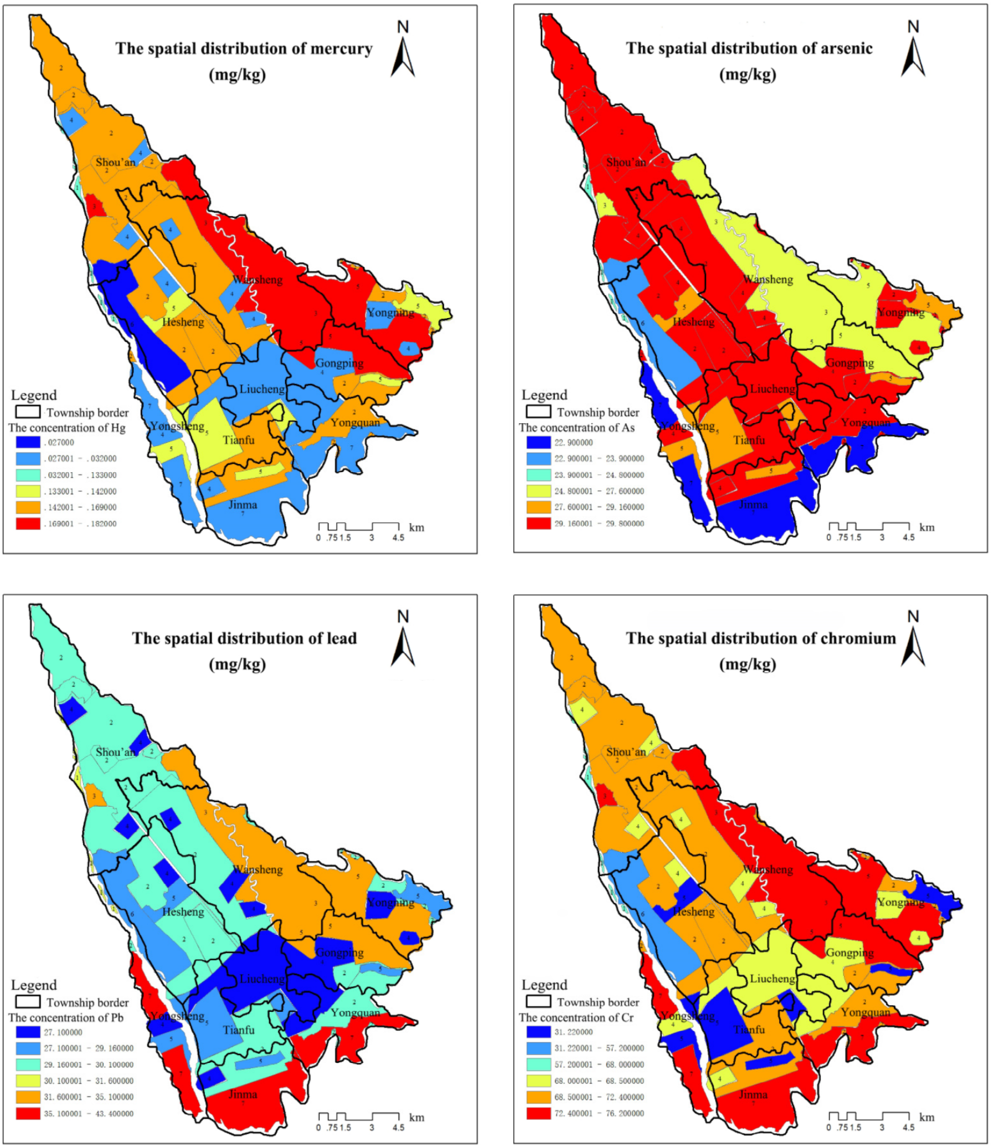

Fig. 2. The spatial distribution of four indexes in soil (mercury, arsenic, lead, chromium)

The concentration of chromium is the highest in the Southwest and Northeast. In rice-vegetable planting areas, it is the highest, with 76.2 mg/kg, while it is the lowest in industrial land with 31.22 mg/kg. The concentrations of chromium in garlic-rice planting areas, flowers planting areas, ecological conservation zone, city construction land, and vegetable planting areas are 75.8 mg/kg, 72.4 mg/kg, 68.0 mg/kg, 68.5 mg/kg and 57.2 mg/kg, respectively.

3.2. SOIL ENVIRONMENTAL CAPACITY FOR DIFFERENT LAND-USE

Based on the background and standard referential values of pollutants in soil, distributions of land-use types and the amount of the pollutant entering into the soil per unit area, the residual soil environmental capacity of pollutants were calculated according to Eq. (1), and the results are given in Table 2. The spatial distributions of residual soil environmental capacities of pollutants in Wenjiang are shown in Fig. 3.

Table 2

Residual environmental capacity of different land-use types [t/km^2]

Land-use type	Element			
	Mercury	Arsenic	Lead	Chromium
Ecological conservation zone	0.57	0.12	210.94	186.83
Flower planting areas	0.22	0.13	178.81	84.54
Garlic-rice planting areas	0.21	1.59	175.50	82.28
City construction land	33.10	33.32	379.55	358.74
Industrial land	755.23	7.85	207.18	119.44
Vegetable planting areas	0.65	0.73	212.60	127.73
Rice-vegetable planting areas	0.64	1.39	203.12	115.14

The spatial distribution of soil environmental capacity of mercury in industrial land is the largest, with 755.23 t/km^2. It is the lowest in garlic-rice planting areas, with 0.21 t/km^2. In city construction land, vegetable planting areas, rice-vegetable planting areas, ecological conservation zone, and flowers planting areas they are 33.10 t/km^2, 0.65 t/km^2, 0.64 t/km^2, 0.57 t/km^2 and 0.22 t/km^2, respectively. Thus, the soil environmental capacities of mercury in industrial land, city construction land, vegetable planting areas, and rice-vegetable planting areas are higher than those in garlic-rice planting areas. The distribution of soil environmental capacity of mercury is closely linked with land-use types, and the industrial land, city construction land, and rice-vegetable planting areas are in the South while garlic-rice planting areas are in the Northeast, so the soil environmental capacity of mercury in the Southern Wenjiang is larger than that in the Northeast. The ordering of the soil environmental capacity of mercury in seven land-use types is: garlic--rice planting areas < flowers planting areas < ecological conservation zone < rice-vegetable planting areas < vegetable planting areas < city construction land < industrial land.

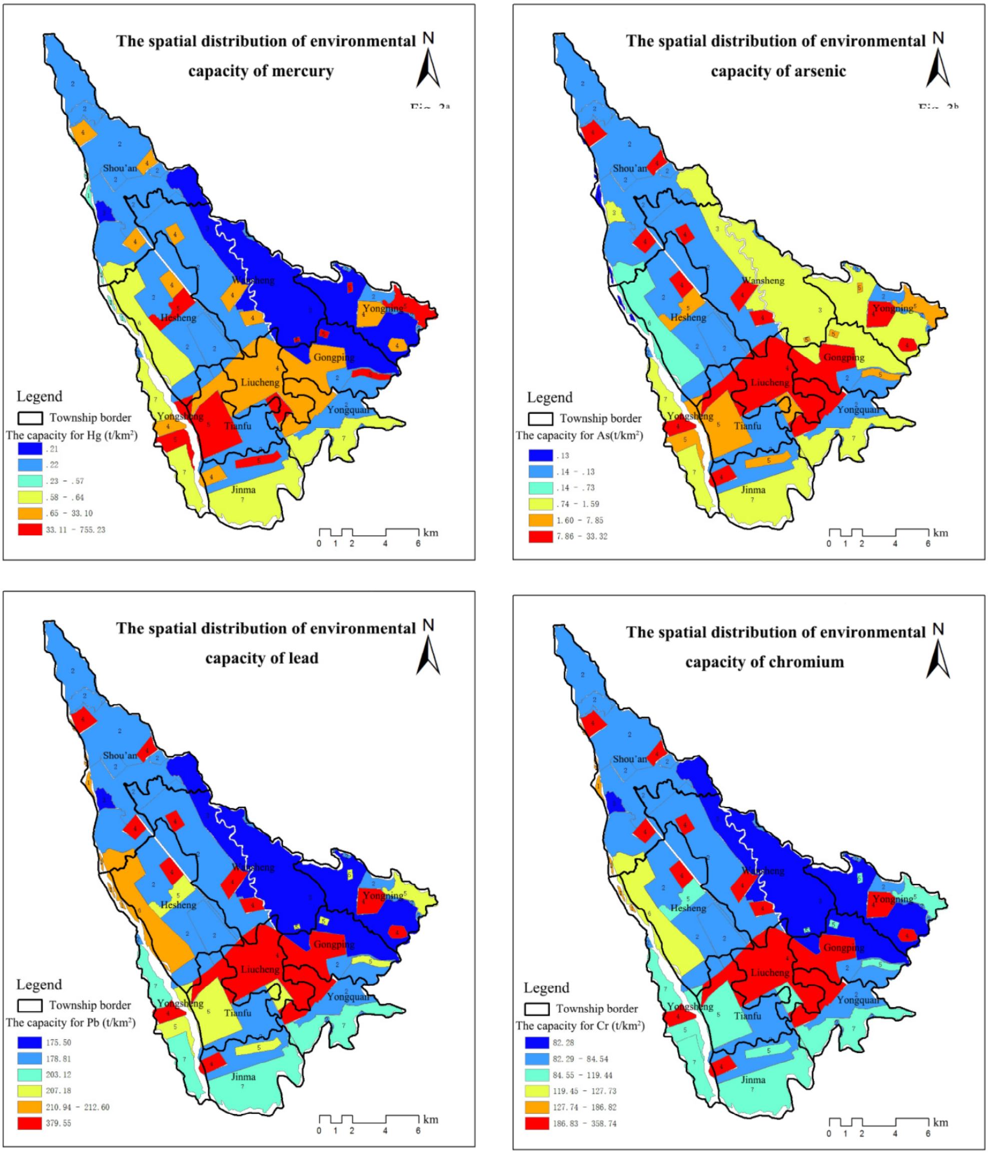

Fig. 3. Spatial distribution of residual soil environmental capacity of four indexes (mercury, arsenic, lead, chromium)

Soil environmental capacity for arsenic in city construction land is the largest, with 33.32 t/km^2 and in industrial land it is 7.85 t/km^2. However, it is the lowest in ecological conservation zone, with 0.12 t/km^2. The soil environmental capacity of arsenic is the second lowest in flowers planting areas, with 0.13 t/km^2. In garlic-rice, rice-vegetable, and vegetable planting areas they are 1.59 t/km^2, 1.39 t/km^2 and 0.73 t/km^2, respectively. Thus, the soil environmental capacities of arsenic in city construction land, industrial land, garlic-rice planting areas, and rice-vegetable planting areas are larger than those in flowers planting areas. The soil environmental capacities of arsenic in the Northeast and South are larger than that in the Northwest. The ordering of the soil environmental capacity of arsenic in land-use types is: ecological conservation zone < flowers planting areas < vegetable planting areas < rice-vegetable planting areas < garlic-rice planting areas < industrial land < city construction land.

Soil environmental capacity for lead in city construction land is the largest, with 379.55 t/km^2. Then, in vegetable planting areas it is the second largest, with 212.60 t/km^2. However, the soil environmental capacity of lead is the lowest in garlic-rice planting areas, with 175.50 t/km^2. In ecological conservation zone, industrial land, rice-vegetable planting areas, and flowers planting areas they are 210.94 t/km^2, 207.18 t/km^2, 203.12 t/km^2 and 178.81 t/km^2, respectively. Thus the soil environmental capacities of lead in city construction land and vegetable planting areas are larger than those in garlic-rice planting areas. The soil environmental capacity of lead in the South and West are larger than that in the Northeast (Fig. 3). The order of soil environmental capacity of lead in land-use types is: garlic-rice planting areas < flowers planting areas < rice-vegetable planting areas < industrial land < ecological conservation zone < vegetable planting areas < city construction land.

Soil environmental capacity for chromium in city construction land is the largest, with 358.74 t/km^2. In ecological conservation zone, it is the second largest, with 186.83 t/km^2. However, the soil environmental capacity of chromium is the lowest in garlic-rice planting areas, with 82.28 t/km^2. In vegetable planting areas, industrial land, rice-vegetable planting areas, and flowers planting areas they are 127.73 t/km^2, 119.44 t/km^2, 115.14 t/km^2 and 84.54 t/km^2, respectively. Thus, the soil environmental capacity of chromium in city construction land and ecological conservation zone are larger than that in garlic-rice planting areas. The soil environmental capacities of chromium in the South and West are larger than that in the Northeast (Fig. 3). The order of soil environmental capacity of chromium in land-use types is: garlic-rice planting areas < flowers planting areas < rice-vegetable planting areas < industrial land < vegetable planting areas < ecological conservation zone < city construction land.

4. DISCUSSION

4.1. THE ANALYSIS OF SOIL ENVIRONMENTAL CAPACITY FOR MERCURY

The standard referential values, soil background values, and the amount of the pollutant entering into the soil of per unit area, would determine the soil environmental capacity, together. The soil background value of mercury in garlic-rice planting areas is the highest, which could be caused by the overuse of chemical pesticides, the plastic films, the agricultural sludge, and sewage immigration in garlic and rice cultivation. Generally, there are many heavy metals in the pesticides and plastic films, so the overuse of plastic films and pesticides would lead to the highest soil background value of mercury in garlic-rice planting areas. In addition, the mercury in soil would also come from the soil parent materials, accumulation of mercury wastes, atmospheric wet deposition, etc. [23].

The soil environmental capacity of mercury in Southern Wenjiang is larger than that in the Northeast, and in industrial land, it is significantly larger than that in other land-use types (Fig. 3). The results would be caused by the differences between the standard referential values and soil background values of land-use types. According to the Eq. (1), the standard referential values are higher, the soil environmental capacity would be larger. The standard referential value for the industrial land is significantly higher than that for the ecological conservation zone, vegetable planting areas, garlic-rice planting areas, etc. However, the soil environmental capacity of mercury is the lowest in garlic-rice planting areas which would result from the high soil background value and low standard referential value. Based on the distribution of the soil environmental capacity in Wenjiang, the use of fertilizer, pesticide and plastic film which would refer pollution of mercury could be reduced in Shou'an and Wanchun town; the factories involved mercury should be moved to Yongning, Hesheng, and Yongsheng town.

4.2. THE ANALYSIS OF SOIL ENVIRONMENTAL CAPACITY FOR ARSENIC

The present situation monitoring indicates that the background value of arsenic in flowers planting areas is the highest, probably due to using the chemical pesticides and herbicides containing arsenic. Although the government has banned the use of chemical pesticides and herbicides with arsenic for a long time, the residual arsenic level in soil is relatively high in some regions. In addition, the soil parent materials, heavy metal mines, Roxarsone, sewage, drugs, and alcohol abuses would also affect the concentration of arsenic in soil [24].

The soil environmental capacity of arsenic in Northeast and Southern Wenjiang are larger than those in the Northwest, and the soil environmental capacity of arsenic in city construction land is the largest (Fig. 3). This may result from the differences of the standard referential values and the background values of land-use types. The standard referential value of city construction land is significantly higher than that of other land-use types. The soil environmental capacity of arsenic is the lowest in ecological conservation zone with the lowest standard referential value. Based on the distribution of the soil environmental capacity of arsenic in Wenjiang, the animal feed with arsenic additive in Jinma, Hesheng and Yongsheng town should not be ignored.

4.3. THE ANALYSIS OF SOIL ENVIRONMENTAL CAPACITY FOR LEAD

The background value of lead in rice-vegetable planting areas is the highest, which could be caused by using the chemical pesticides and herbicides containing lead. In addition, the lead in soil would be from soil parent materials, atmospheric dusts, waste dumps, metal processing, and the use of fertilizers, etc. [25].

Compared with mercury and arsenic, the soil environmental capacity of lead is relatively large and risk is relatively low. The soil environmental capacity of lead in city construction land is the largest. It would be mainly caused by the differences of the background values, the standard referential values of lead, and the amount of lead entering into the soil of per unit area. The background value of lead is the lowest in city construction land, and the standard referential value is the highest. The soil environmental capacity of lead is the lowest in garlic-rice planting areas with the relatively high background value, the lowest standard referential value, and the relatively high amount of lead entering into the soil of per unit area. Based on the distribution of the soil environmental capacity in Wenjiang, the pesticide with lead additive should be reduced and the development of the plastic industry, battery manufacture, chemical leather manufacture, and electronics industry should be limited; the factories referred lead should be moved to Shou'an and Wanchun town, where the soil environmental capacity of lead is relatively large.

4.4. THE ANALYSIS OF SOIL ENVIRONMENTAL CAPACITY FOR CHROMIUM

The soil background value of chromium in rice-vegetable planting areas is the highest, which could be caused by using chemical pesticides and fertilizers containing chromium. In addition, chromium in soil originates also from soil parent materials and atmospheric sedimentation, etc. [26]. The soil environmental capacity of chromium is relatively large and risk is relatively small. The soil environmental capacity of chromium in city construction land is the largest. The background value of chromium in city construction land is relatively low and the standard referential value is the highest. The soil environmental capacity of chromium is the lowest in garlic-rice planting areas with the relatively high background value, the lowest standard referential value, and the relatively high amount of chromium entering into the soil of per unit area. Based on the distribution of the soil environmental capacity in Wenjiang, the garbage involved chromium should be controlled in Tianfu Street, Yongsheng, and Jinma town; the factories referred to chromium should be moved to Wanchun town, where the soil environmental capacity of chromium is relatively large.

5. CONCLUSIONS

The soil environmental capacity of each land-use type has been calculated according to the static model. Then, the distribution of soil environmental capacity in Wenjiang was investigated based on the distribution of land-use types. The following conclusions would be obtained, according to the investigation results, the concentration of mercury in garlic-rice planting areas, the concentration of arsenic in flowers planting areas, and the concentration of lead and chromium in rice-vegetable planting areas should be paid more attention by the government as they are the highest, respectively.

According to the orders of the soil environmental capacity of mercury, arsenic, lead, and chromium in land-use types, the soil environmental capacity of arsenic in ecological conservation zone and the soil environmental capacity of mercury, lead, and chromium in garlic-rice planting areas should be paid more attention as they are the lowest, respectively.

According to the distribution of residual soil environmental capacity, some suggestions such as land use planning are proposed to protect the soil environment.

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