

Geochemical characteristics of soil selenium and evaluation of Se-rich land resources in the central area of Guiyang City, China

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Abstract Based on the results of multipurpose regional geochemical surveys of the Guizhou Province, geochemical characteristics of soil Se and Se-rich land resources in the central area of Guiyang City were studied and evaluated. Major conclusions are as follows: (1) the Se content in surface soil of the central area of Guiyang City was 0.17–2.89 mg kg⁻¹, and the average was 0.78 mg kg⁻¹, which were respectively 2.6 and 3.9 times of the national background value of soil and the world background value of soil. The Se content in deep soil was 0.11–1.48 mg kg⁻¹, and the average was 0.44 mg kg⁻¹, which were respectively 1.5 and 2.2 times of the national background value of soil and the world background value of soil. The soil Se content decreased with the increase in the soil depth on the vertical profile, and the surface soil had a higher Se content. (2) Distribution of Se content was mainly affected by parent material, physicochemical properties of soil and other components, soil type, and land use type. Parent material played a key role, as the soil Se content was mainly originated from parent rock and increased with the background value of Se in parent rock, physicochemical properties of soil and other components had certain influences upon the Se content. Se was shown to have a significant linear positive correlation with S and organic carbon but no significant correlation with pH value. Se content varied with different types of soil as follows: skeleton soil > yellow soil > paddy soil > limestone soil > purple soil. Land use type also had

certain influences upon the soil Se content as follows: dry land > construction land > garden plot > grassland = garden plot > forest land. (3) Taking 0.4 mg kg⁻¹ ≤ ω (Se) < 3.0 mg kg⁻¹ as the standard for Se-rich soil, Se-rich soil of the study area covered an area of 2224 km² and 92.5% of the total area; the remaining is general soil. The study area had no Se-excess soil. Therefore, the central area of Guiyang City has a high proportion of Se-rich land, a large area of Se-rich land resources, and a moderate selenium enrichment strength, which have been rarely seen anywhere and provide advantageous resources for the development of Se-rich featured agriculture.

Keywords Central area of Guiyang · Soils · Selenium · Geochemical characteristics · Evaluation of Se-rich land resource

1 Introduction

Selenium (Se) is a typical dispersed element with an abundance in the earth's crust of only 0.05–0.09 mg kg⁻¹ (Liu et al. 1984). However, it is one of essential trace elements for human body and animals, and it can improve animals' immunity as well as enhance the anti-cancer and anti-aging ability of human body (Ben et al. 2011; Kolachi et al. 2011; Heath et al. 2010). Additionally, it has obvious antagonistic effects on toxicity of heavy metals such as cadmium (Cd), arsenic (As), mercury (Hg), and silver (Ag) (Jarzya and Falandysz 2011). Se deficiency may lead to white muscle disease, Keshan disease, Kaschin-Beck disease, and other Se-deficient diseases in the human body and animals (Tan 1996; Zhang et al. 1990). Excessive Se intake has toxic actions on human body and animals and consequently causes trichomadecis

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and nail discolouration to human body as well as staggers to animals (Xue et al. 2011; Ellis and Salt 2003; Thomson 2004; Ben et al. 2011). Human body obtains Se mainly from food (Hu et al. 2010), and soil is the storeroom of edible Se. This in turn determines the Se content in food, vegetables and even drinking water (Tan et al. 2002; Li et al. 2012; Qin et al. 2013). Therefore, Se content in soil directly affects the content of Se in food in any given area as well as health of human and animals. China is a Se-deficient country, where more than ten provinces and autonomous regions lack Se in varying degrees. This Se-deficient region covers about 72% of national territorial area. Coal measure strata of Permian, Cambrian black shale of Cambrian, and other Se-rich rocks that are widely distributed in Guizhou Province establish a solid basis for Se enrichment in soils. Taking different investigation methods, He Yalin and Wang Ganlu have studied soil Se in the Guizhou Province and have drawn the conclusion that the average Se content in this region's soil could reach 0.37 and 0.39 mg kg⁻¹, higher than the world average value and the national average value (He 1996; Wang and Zhu 2003). Most areas belong to the moderate Se content category, but others are Se-deficient areas or Se-rich areas. The above studies provide basic data for further research, exploitation and utilization of Se-rich land resources. However, distribution characteristics of regional and local soil Se and Se-rich land resources have been rarely studied in the Guizhou Province, with the exception of some authors who have studied Se enrichment of soil and crops in Kaiyang County and Fenggang County (Li et al. 2004; Lian et al. 2011; Liu et al. 2012). However, there is little research on Se geochemical distribution, Se-rich survey and evaluation in Guiyang City. Therefore, based on the geochemical survey results of the multipurpose region in Guizhou Province, the author studies geochemical characteristics of soil Se in the center area of Guiyang City and evaluates Se-rich soil resources, which may provide a scientific basis for the efficient utilization of land resources and the establishment of a Se-rich agricultural production base.

2 Material and method

2.1 Study area

The research area is located in the main urban area of Guiyang City and covers seven administrative areas at the district (or county) level in the central area such as Yunyan District, Nanming District and Xiaohe District, as well as suburbs such as Huaxi District, Baiyun District, Wudang District and Jinyang New District. The geographical coordinates are 106°30'02"–106°59'29" of east longitude

and 26°10'37"–26°49'56" of northern latitude, with a total area of 2404 km².

Guiyang City is located in the middle of hills in the Guizhou Plateau and at the watershed between the Yangtze River and the Pearl River. Its terrain turns high in the southwest to low in the northeast. Guiyang City is a basin, where mountains and hills cover more than 80% of the total area, but dam fields cover a small area; there are also a few canyons and other landforms.

The research area is located in the first-level geotectonic unit- Yangtze Block of the South China plate. At its north side is the fourth-level geotectonic unit-Guiyang complex tectonic deformation area, and at its south side is the fourth-level geotectonic unit-Guiding north-south tectonic deformation area. The stratum is fully developed from the Cambrian system to the Quaternary system with accumulative maximum thickness of above 10,000 m. The Triassic system is most widely distributed and covers about 50% of the total area, followed by Dyas and Cambrian strata. Most areas are covered with neritic platform carbonate rocks, and only a few are covered with terrestrial river-lake red rocks.

Closely related to carbonatite parent rock, the main soil types are yellow soil, limestone soil, paddy soil and purple soil, which cover 50.97%, 29.85%, 17.42% and 1.61% of the total area, respectively. Limestone soil mainly consists of argillaceous soil and arenopelitic lime soil, and yellow soil mainly consists of silicoferrite yellow soil. Located in a karst mountainous area, the study area features more mountains and less dam fields, heavily stony desertification, no plains, and a low land utilization rate. As fast urbanization and rapid increase in land usage for transportation occurs, cultivated land, garden pot, forestland, water area and unused land in Guiyang City and surrounding towns decreases sharply. Land resources utilization focuses on agricultural land (including grassland, cultivated land and forest land), followed by construction land and unused land, as well as water area and special use area.

2.2 Sample collection

According to *Multipurpose Regional Geochemical Investigation Specification* (1/250,000) (China Geological Survey 2005), surface and deep soil samples were collected using two-layer partition method. The sampling density of surface soil was 1 piece/km², sampling depth at 0–20 cm, and a sample comprising equivalent soil was collected from at least five sampling points in the sampling lattice within a radius of 50 m, with the sample weight of ≥1000 g. The sampling density of deep soil was 1 piece/4 km², the sampling depth was 150–200 cm, soil samples were collected by using twist drill, and the sample weight was ≥1000 g. Considering representativeness, uniformity and controllability, sampling points were allocated in

paddy fields, dry land, garden plot and forestland in order to avoid man-made pollution and recent cumulous soil. Samples were naturally dried and underwent 20 mesh sieves. A surface soil sample comprising equivalent soils was collected from four sampling points per 4 km², and a deep soil sample comprising equivalent soils was collected from four sampling points per 16 km². 2404 surface soil samples containing 601 pieces for combinatory analysis were collected, and 601 deep soil samples containing 151 for combinatory analysis were collected.

Exceedingly Se-rich areas were selected for a survey of litho geochemistry and vertical soil profile and Se enrichment investigation of crops. Rock sample collection method was as follows: selected areas had completely exposed stratigraphic units and well exposed bed rock, allocated the rock profile perpendicular to the direction of strata, and the space between sampling points was 200–500 m. With the stratum as the unit, 2–3 samples collected from each unit, and the sample weight was ≥ 500 g. Sample collection method of vertical soil profile was as follows: one sample was collected using twist drill every 50 cm within a depth of 0–200 cm, and the sample weight was equal to or more than 1000 g. The collection method of plant (crop) samples can be referenced in *Technical Requirements on Regional Ecological and Geochemical Evaluation* (Trial) (DD2005-03).

2.3 Sample analysis

Nanjing Mineral Resources Supervision and Test Center of the Ministry of Land and Resources was authorized to analyze 54 components of soil samples as follows: SiO₂, Al₂O₃, Fe₂O₃, K₂O, Ba, Br, Cl, Cr, Cu, Ga, Mn, Nb, Ni, P, Pb, Rb, S, Sr, Ti, V, Y, Zn and Zr as well as a part of Na₂O, MgO and CaO were determined with X-ray fluorescence spectrometry (XRF); inductively coupled plasma mass spectrometry (acid soluble ICP-MS) was used to determine Be, Bi, Cd, Ce, Co, La, Li, Mo, Sc, Th, Tl, U and W; atomic fluorescence spectroscopy (AFS) was used to determine As, AC Arc emission spectroscopy (OES) was used to determine Hg, Se, Sb and Bi; Ag, B and Sn; non-flaming graphite

furnace atomic absorption spectrometry (GFAAS) was used to determine Au; inductively coupled plasma mass spectrometry (acid soluble ICP-MS) was used to determine Ge and I; F was determined with ion selectivity electrode (ISE); N was determined with the potassium dichromate-sulfuric acid digestion distillation volumetric method; C was determined with tube furnace combustion non-aqueous titration; Corg was determined with the potassium dichromate volumetric method; pH value was determined with potentiometry and pH meter. The analytic quality was monitored in strict accordance with the requirements in *Multipurpose Regional Geochemical Investigation Specification*, accuracy and precision of national first-class soil standard substances (GBW series) were monitored, errors of sampling and analysis were evaluated through more than 2% of replicate samples and more than 3% of replicate analysis, and the monitoring and analytic quality of anomalous points were randomly inspected.

2.4 Data processing and drawings

Statistical analysis of geochemical parameters was realized using EXCEL and SPSS software, geochemical maps were made by GeoMDIS (multipurpose edition) and Mapgis6.7 map-making software.

3 Results and discussion

3.1 Distribution characteristics of Se content in soil

3.1.1 Geochemical distribution characteristics of Se in surface and deep soil

According to the analysis results of the Se content in surface soil and deep soil in the central area of Guiyang City, geochemical parameters of Se were obtained (Table 1). The Se content in surface soil was 0.17–2.89 mg kg⁻¹, and the average was 0.78 mg kg⁻¹, respectively 2.6 and 3.9 times of the background value of national soil and the background value of world soil. The Se content in deep soil

Table 1 Geochemical parameters of soil Se

Soil type	<i>N</i>	<i>X</i> _{min}	<i>X</i> _{max}	<i>X</i> _{me}	<i>X</i> _{mo}	\bar{X}	<i>S</i>	<i>C</i> _v %
Surface soil	601	0.17	2.89	0.68	0.44	0.78	0.38	49.7
Deep soil	151	0.11	1.48	0.38	0.24	0.44	0.24	54.1
National soils (China environmental monitoring centre 1990)						0.29		
World soils (Lisk 1972)						0.20		

The Se content is expressed in mg kg⁻¹, *N* stands for the statistical number of samples, *X*_{min} stands for the minimum value, *X*_{max} stands for the maximum value, *X*_{me} for the mean, *X*_{mo} for the modus, \bar{X} for the average value, *S* for the standard deviation, and *C*_v for the variable coefficient

was 0.11–1.48 mg kg⁻¹, and the average was 0.44 mg kg⁻¹, respectively 1.5 and 2.2 times of the background value of national soil and the background value of world soil. The variable coefficient of the Se content in surface soil and deep soil was 49.7% and 54.1%, indicating little change in the Se content in soil.

3.1.2 Distribution characteristics of Se in vertical soil profile

Generally, soil is of layered characteristics, and minerals and elements of different soil layers have different content characteristics. In order to study distribution rule of Se in soil at different depths, seven vertical soil profiles were allocated in the deep soil sampling lattices (TS44 and TS46) in exceedingly Se-rich areas in Zhuchang Town and Yanshanhong Town of the Baiyun District, and soil samples were collected from top to bottom every 50 cm within a depth of 0–200 cm, with analysis results shown in Table 2. Figure 1 showed changes in the soil Se content with the soil depth, Table 2 and Fig. 1 showed the distribution order of Se on the vertical profile: Surface layer > top-middle layer > bottom-middle layer > bottom layer. The soil Se content decreased with the increase of depth along the soil profile, Se content of surface soil was about twice of that at depth, and the Se content was higher in the surface soil than in the deep soil. The high Se content in surface soil could occur for two reasons: (1) the surface soil was rich in iron and aluminum, and peat and humus that can absorb Se. Besides, Se can be easily combined or absorbed by soil humus when the soil solution is acidic, but it can hardly be dissolved, migrated and lost through eluviations. (2) Se content of surface soil was generally higher than parent materials. Not only did it reflect downward enrichment of Se in the soil-forming process but it also may be affected by input of exogenous Se (such as atmospheric precipitation, irrigation and fertilization etc.).

3.2 Influencing factors of Se content in soil

The Se content in soil is mainly affected by parent material and physicochemical properties of soil, soil type, and land utilization type, each of which will be discussed below.

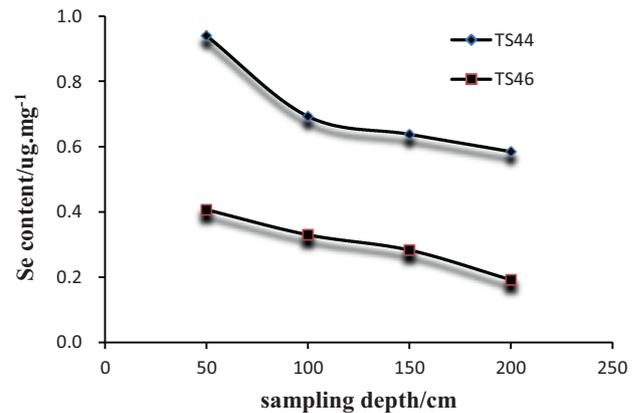


Fig. 1 Distribution of Se content on the vertical soil profile

3.2.1 Influences of parent material upon Se content in soil

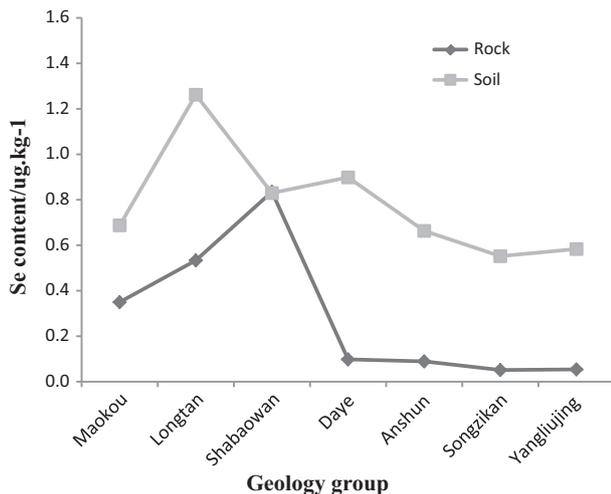
Soil is formed due to rock weathering, and the Se content in soil is largely determined by the Se content in parent material and parent rock (Zhang et al. 2002). In this paper, one rock profile was allocated in Zhuchang-Yanshanhong's exceedingly Se-rich areas, rocks and corresponding soil samples that were selected from different stratigraphic units were analyzed and studied, with results shown in Table 3. Figure 2 shows a comparison of rocks in different stratigraphic units and the Se content in soil. Table 3 and Fig. 2 demonstrates that Se in rocks was unevenly distributed in different stratigraphic units, and Se content was listed from highest to lowest as follows: Shabaowan group > Longtan group > Maokou group > Daye group > Anshun group > Yangliujing group > Songzikan group. Se content in soil of different geological units was as follows: Longtan group > Daye group > Shabaowan group > Maokou group > Yangliujing group > Anshun group > Songzikan group. Except for Shabaowan group, the Se content in soil increased with the increase in the Se content in rock, indicating the inheritance between soil Se and rock Se. The Se content in soil was obviously higher than the Se content in rock in most geological units. Except for the enrichment coefficient of the Shabaowan group was 0.99, all the other enrichment coefficients could reach 1.96–10.80, and the Yangliujing group had the highest enrichment coefficient. Thus, soil Se was mainly originated from

Table 2 Distribution characteristics of Se content on the vertical soil profile (unit: mg kg⁻¹)

Sample No.	Surface layer (0–50 cm)	Top-middle layer (50–100 cm)	Middle-bottom layer (100–150 cm)	Bottom layer (150–200 cm)
TS44 (include 4 profiles)	0.94	0.693	0.638	0.585
TS46 (include 3 profiles)	0.407	0.33	0.283	0.192

Table 3 Comparison of Se content in parent rock and in soil of Se-rich areas (unit: mg kg⁻¹)

Geology group	Maokou	Longtan	Shabaowan	Daye	Anshun	Songzikan	Yangliujing
Rock	0.35	0.53	0.84	0.10	0.09	0.05	0.05
Soil	0.69	1.26	0.83	0.90	0.66	0.55	0.58
Soil/Rock ratio	1.96	2.37	0.99	9.17	7.43	10.72	10.80

**Fig. 2** Comparison of Se content in rocks and soils of different strata

parent material or parent rock, and downward enrichment of Se occurred in the weathering and soil-forming process of parent material or parent rock.

3.2.2 Soil property and other components

Se content is largely determined by composition and properties of parent material (rock), especially underdeveloped soil (Wang and Zhang 1996). Cosmid and iron-aluminum oxides have great influences upon Se accumulation and eluviation in a soil-forming process, and the total Se content is positively associated with the cosmid content. In other words, the more sticky the soil textures, the higher the Se content (Gunnar 1971). Eluviation is a major external cause to low-se soil, and most Se in soil exists in the form of leached anionic salt and eluviates with aluminum compounds and clay minerals in humid areas. Thus, most low-Se areas are distributed in humid areas of temperate zones and cold temperate zones. Organic matters, iron and manganite in soil have significant effects on Se content, such as active iron absorbed Se and organic Se (Hou et al. 1991; Wu et al. 1997). The Se content in neutral soil and alkaline soil is not confined to pH, as the Se content in acid soil increases sharply with the decrease in pH value (Yang et al. 2012).

Table 4 shows the correlation analysis results of Se with other components in soil. The correlation coefficient with S and Corg (organic carbon) was greater than 0.7, whereas

the correlation coefficient with S was the maximum ($R = 0.764$), the correlation coefficient with Mo, total carbon (TC), V and Nb was greater than 0.6, that with Ti and Fe was greater than 0.5, and that with Cr, P, Cu, U, Sr and Ge was greater than 0.4. The correlation coefficient with SiO₂, K₂O, Na₂O, CaO and MgO showed no significant correlation, and the correlation with pH value was 0.074, which also showed no significant correlation.

The correlation analysis results show a linear positive correlation between S and Se in soil; the higher the S content is, the higher the Se content is. This occurs mainly because both S and Se are VI A elements in the periodic table of elements and have the same valence electron structure and many approximate geochemical parameters, and they have widespread isomorphous substitution phenomena. Se is closely related to carbon (including total carbon and organic carbon) in soil, while organic carbon represents one of soil's organic matters. They have a significant linear positive correlation because organic matter plays an important role in absorption and fixation of soil Se, and the higher the content of organic matters in soil is, the stronger the adsorption capacity of Se is, thus resulting in a higher content of Se in soil (Shang et al. 2015). Some researchers even think that more than 80% of Se in surface soil is combined with organic matters (Zhao et al. 2005).

The pH value of soil can indirectly affect changes in the state of soil Se by means of redox potential, adsorbing capacity of clay minerals, and generalities of soil microbial activity (Zhang et al. 2005). Generally speaking, the Se content in soil is negatively correlated to pH, that is, the higher the soil pH value is, the lower the Se content is. This research demonstrated that the correlation coefficient between the Se content in soil and pH value was -0.074 and showed no significant correlation. Thus, the Se content in soil cannot be affected by pH value, perhaps because the soil in the research area was mainly neutral to alkaline.

3.2.3 Soil type

The research area mainly consists of karst and a few clastic rocks in low and medium mountains. The research area has complex soil types such as yellow soil, limestone soil, skeleton soil, paddy soil and purple soil. Yellow soil has extremely complex parent material, as rocks in different geological times can be formed through weathering; limestone soil is mainly formed through surface weathering

Table 4 Correlation analysis of Se and other elements/indexes

Elements	R	Elements	R	Elements	R	Elements	R
S	0.764**	La	0.395**	Hg	0.187**	Zr	-0.085*
Corg	0.752**	N	0.371**	Cl	0.184**	CaO	0.082*
Mo	0.675**	SiO ₂	-0.342**	Rb	-0.180**	pH	-0.074*
TC	0.671**	Zn	0.317**	Na ₂ O	0.176**	Ba	0.044
V	0.659**	Be	0.316**	Ag	0.158**	Pb	0.041
Nb	0.635**	Sc	0.315**	I	0.149**	Li	0.029
Ti	0.550**	Y	0.295**	Bi	0.148**	Tl	0.010
TFe ₂ O ₃	0.511**	Br	0.289**	B	-0.138**	W	0.007
Cr	0.495**	Sb	0.279**	Au	0.136**	Th	-0.041
P	0.483**	Ni	0.248**	Cd	0.128**	MgO	-0.051
Cu	0.476**	Ga	0.232**	Mn	0.114**	K ₂ O	-0.058
U	0.462**	As	0.223**	F	0.109**		
Sr	0.430**	Ce	0.220**	Sn	0.095**		
Ge	0.405**	Co	0.213**	Al ₂ O ₃	0.092*		

R correlation coefficient

* Significant correlation on the 0.05 level (one sided)

** Significant correlation on the 0.01 level (one sided)

of limestone, dolomite and other carbonatite; paddy soil mainly develops in intermountain basins, and the parent material is Holocene series alluvial-diluvial sediment; skeleton soil is mainly distributed in hilly areas around intermountain basins as well as low and middle mountains, and the parent material is residual deposit. Purple soil is mainly generated from weathered materials of purples sandstone with Jurassic system and cretaceous system as the parent material. Considering different influences (such as irrigation and fertilization) of downward enrichment and human activities arising from distribution and soil-forming process of Se in the parent material of different soils, the Se content in soil is different. Table 5 shows geochemical parameters of Se in different soils, and it shows no significant differences in the Se content in different soils, as the Se content in skeleton soil could reach the maximum (0.87 mg kg⁻¹), the Se content in yellow soil, limestone soil, paddy soil and skeleton soil was approximate, while

Table 5 Soil Se geochemical parameters of different land-use types (unit: mg kg⁻¹)

Soil types	<i>N</i>	<i>X</i> _{max}	<i>X</i> _{min}	<i>S</i>	<i>Cv</i> %	\bar{X}
Yellow soil	227	2.79	0.24	0.42	53.65	0.78
Limestone soil	165	1.93	0.17	0.29	39.64	0.73
Skeleton soil	111	2.89	0.31	0.45	51.11	0.87
Paddy soil	90	2.09	0.26	0.36	48.60	0.75
Purple soil	8	0.66	0.39	0.10	18.15	0.54

The Se content is expressed in mg kg⁻¹, *N* stands for the statistical number of samples, *X*_{min} for the minimum value, *X*_{max} for the maximum value, \bar{X} for the average value, *S* for the standard deviation, and *Cv* for the variable coefficient

the Se content in purple soil was the minimum (0.54 mg kg⁻¹).

3.2.4 Land use type

The study area is a karst landform featuring more mountains and less dam fields, heavily stony desertification, no plains, and a low land utilization rate. As fast urbanization and rapid increase in land for transportation, cultivated land, and garden plot occurs, forestland, water area, and unused land in Guiyang City and surrounding towns decreases sharply. Dependent on practical situations, the research area consists of dry land, forestland, grassland, paddy field, garden plot and construction land. On account of differences in reconstruction method and degree of different land use types, texture, cosmid and organic matter of soil affect Se distribution and thus may cause differences in the soil Se content of different land use types. Table 6

Table 6 Soil Se geochemical parameters of different land-use types

Land use types	<i>N</i>	<i>X</i> _{max}	<i>X</i> _{min}	<i>S</i>	<i>Cv</i> %	\bar{X}
Grass land	221	2.38	0.17	0.37	50.62	0.73
Forest land	153	2.60	0.29	0.35	49.41	0.72
Paddy land	113	1.90	0.26	0.31	42.47	0.73
Dry land	84	2.89	0.48	0.48	47.78	1.00
Garden land	5	0.86	0.67	0.08	10.02	0.76
Construction land	25	2.00	0.36	0.40	41.53	0.96

The Se content is expressed in mg kg⁻¹, *N* stands for the statistical number of samples, *X*_{min} for the minimum value, *X*_{max} for the maximum value, \bar{X} for the average value, *S* for the standard deviation, and *Cv* for the variable coefficient

shows soil Se geochemical parameters of different land use types, and the results demonstrated that the soil Se content of different land use types was: dry land > construction land > garden plot > grassland = paddy field > forest land.

3.3 Evaluation of Se-rich land resources

3.3.1 Evaluation standard

At present, investigation, evaluation, and the development and utilization of Se-rich land resources have been emphasized, but a uniform standard for Se-rich soil has not been developed in China. In reference to former research results (Tan 1989, Li et al. 2000a, b), and according to $\omega(\text{Se}) \geq 0.4$ of most soils in the research area, $0.40 \text{ mg kg}^{-1} \leq \omega(\text{Se}) < 3.0 \text{ mg kg}^{-1}$ was used as the standard for Se-rich soil, $\omega(\text{Se}) \geq 3.0 \text{ mg kg}^{-1}$ as the standard for Se-excess soil and $\omega(\text{Se}) < 0.4 \text{ mg kg}^{-1}$ as the standard for general soil. Then, Se-rich soil was divided into first-class Se-rich soil ($0.4\text{--}0.8 \text{ mg kg}^{-1}$), second-class Se-rich soil ($0.8\text{--}1.6 \text{ mg kg}^{-1}$) and third-class Se-rich soil ($1.6\text{--}3.0 \text{ mg kg}^{-1}$). The soil Se geochemical map was drawn with Mapgis 6.7 software and Se-rich land resources in the research area were analyzed and evaluated.

3.3.2 Se-rich land resources evaluation

According to above-mentioned standards, the status quo of Se-rich land resources in the research area was studied (Table 7) and the soil Se geochemical map was drawn (Fig. 3). As shown in Table 7, general soil in the central area of Guiyang City covered an area of 180 km^2 , accounting for 7.49% of the total area. Se-rich soil covered an area of 2224 km^2 and 92.5% of the total area, with first-class Se-rich soil was the most widely distributed (1332 km^2) and covered 55.41% of the total area; second-class Se-rich soil covered an area of 792 km^2 and 32.95% of the total area; third-class Se-rich soil covered an area of 100 km^2 and 4.16% of the total area. The research area had no Se-excess areas. As shown in Fig. 3, Se-rich soil in the research area had significant regional distribution

characteristics. First-class Se-rich soil was mainly distributed in the Wudang District, the mideast and southeast of the Huaxi District and the mideast of the Baiyun District; second-class Se-rich soil was mainly distributed in the Yunyan District, the Nanming District, the Jinyang District, the southwest of the Huaxi District, the Baiyun District as well as the neighboring area between the Baiyun District and Xiuwen County in the middle of Guiyang City; third-class Se-rich soil covered a small area and was mainly distributed in the northwest of the Huaxi District and the neighboring area between the Baiyun District and Zhuchang Town of the Jinyang District. Third-class Se-rich soil and the stratum of Dyas Longtan group had a coupling relationship. Longtan group consisted of a major coal bed that had a higher background value of rock Se and abundant carbonic matters, and the soil Se content also had a higher background value. Meanwhile, abundant carbonic matters were conducive to absorption and fixation of Se and soil Se enrichment. Therefore, third-class Se-rich soil was closely related to distribution of coal mine. For example, the largest Se-rich soil area in the northwest of the Huaxi District was utilized by more than ten coal mines such as the Caichong coal mine, the Aofanchong coal mine and the Jiuan coal mine. Moreover, Longtan group of coal measure strata affected distribution of second-class Se-rich soil. General soil (non-selenium-rich soil) was mainly distributed in the neighboring area between the southeast of the Huaxi District and Huishui County. It had a lower background value and less carbonic matters probably because of distribution of the devonian system stratum or because the devonian system stratum mainly consisted of quartz sandstone and calcilithite. As a result, a lower background value of soil and a lower content of carbonic matters which was inconducive for absorption and enrichment of Se were obtained.

Thus, the research area was exceedingly rich in soil Se, except for 180 km^2 (7.49%) of general soil, and Se-rich soil covered an area of 2224 km^2 (92.51%). High enrichment degree and regional block distribution have been rarely seen anywhere and provide advantageous resources for the development of the selenium enrichment industry and featured agriculture.

Table 7 Se-rich land resources statistics

Soil grade	$\omega(\text{Se})$ (mg kg^{-1})	Sample number	Area (km^2)	Proportion (%)
Ordinary soil	<0.4	45	180	7.49
Se-rich soil				
First Se-rich	0.4–0.8	333	1332	55.41
Second Se-rich	0.8–1.6	198	792	32.95
Third Se-rich	1.6–3.0	25	100	4.16
Excess Se soil	>3.0	0	0	0.00

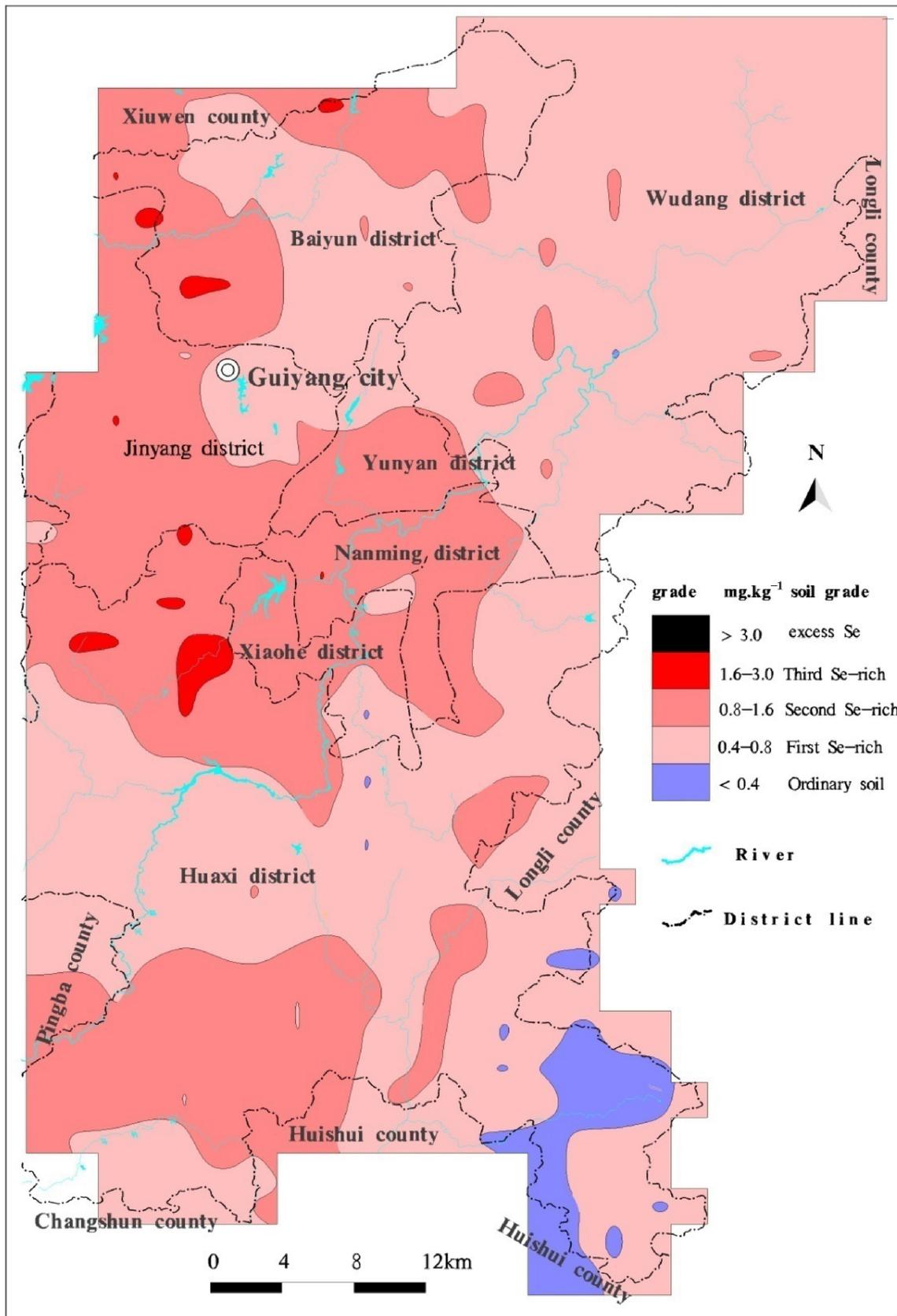


Fig. 3 Se-rich land resources geochemical evaluation diagram in the central area of Guiyang City

4 Conclusions

Based on the results of the multipurpose regional geochemical survey of Guizhou Province, geochemical characteristics of soil Se and Se-rich land resources in the central area of Guiyang City were studied and evaluated. Major conclusions are as follows:

- (1) The Se content in surface soil of the central area of Guiyang City was 0.17–2.89 mg kg⁻¹, and the average was 0.78 mg kg⁻¹, which were respectively 2.6 and 3.9 times of the national background value of soil and the world background value of soil. The Se content in deep soil was 0.11–1.48 mg kg⁻¹, and the average was 0.44 mg kg⁻¹, which were respectively 1.5 and 2.2 times of the national background value of soil and the world background value of soil. The soil Se content decreased with the increase in the soil depth on the vertical profile, and the surface soil had a higher Se content.
- (2) Distribution of Se content was mainly affected by parent material, physicochemical properties of soil and other components, soil type, and land utilization type. Parent material played a decisive role, the soil Se content mainly originated from parent rock and increased with the growth in the background value of Se in parent rock; physicochemical properties of soil and other components had certain influences upon the Se content. Se was shown to have a significant linear positive correlation with S and organic carbon but no significant correlation with pH value. Se content varies with different type soil of soil as follows: skeleton soil > yellow soil > paddy soil > limestone soil > purple soil. Land use type had certain influences upon the soil Se content as follows: dry land > construction land > garden plot > grassland = garden plot > forest land.
- (3) With 0.4 mg kg⁻¹ ≤ ω (Se) < 3.0 mg kg⁻¹ as the standard for Se-rich soil, Se-rich soil of the research area covered an area of 2224 km² and 92.5% of the total area; the remaining is general soil. The research area had no Se-excess soil.

In conclusion, the central area of Guiyang City has a high proportion of Se-rich land, a large area of Se-rich land resources and a moderate selenium enrichment strength, which have been rarely seen and provide advantageous resources for the development of Se-rich featured agriculture.

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