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Distribution Pattern and Influencing Factors of Soil Selenium in Northern Hebei Province, China

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Abstract—According to the 1:50000 scale soil geochemical survey from a several of key selenium (Se) rich areas in the traditional considered Se deficiency area of northern Hebei Province, China, the content, distribution, and the influencing factors of surface soil Se distribution in this area were determined. The Se concentration of surface soil in this area was calculated to be 0.06–3.74 mg/kg, with a mean of 0.4 mg/kg. The Se-rich (Se $\geq$ 0.4 mg/kg) domains are about 116.8 km^2, accounting for 29.05% of the total areas. The concentration of Se in surface soils tends to decrease in the north and increase in the south. The soil Se content and distribution were affected by various factors. Soil parent rocks were the initial sources of Se, but their effects on soil Se content and distribution were limited. The Se content in surface soil had a strong positive correlation with organic carbon (C_{org}), S, and Fe_2O_3, but a weak correlation with topographic parameters. The Se content of various soil types, including meadow chestnut soil, calcareous meadow soil, gley meadow soil, and saline meadow soil, and land use types, including natural grassland and other grassland, were relatively high, mainly because of the indirect effect from abundant organic matter and high water content in soil. Additionally, the analysis result of GeoDetector showed that S and C_{org} were the main driving factors of soil Se distribution and the influence of other factors was limited.

Keywords: soil selenium, distribution pattern, influence factors, GeoDetector, Hebei province

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INTRODUCTION

Selenium is important for human health and has many functions such as antioxidant, antivirus, enhancing immunity, protecting and repairing cells (Rayman, 2002, 2000; Skalny et al., 2019). Thus, a moderate intake of Se is associated with cancer and cardiovascular disease protection (Lubiński et al., 2018). However, the appropriate threshold range of Se is very narrow, that is, both deficient and excessive intake could led to diseases (Natasha et al., 2018; Supriatin et al., 2015). For example, Keshan disease (KSD) and Kashin-Beck disease (KBD) are world-recognized Se deficiency diseases (Jones et al., 2017; Wang et al., 2020), while poisoning including loss of finger-nail, alopecia, dizziness, vomiting, and nervous system and respiratory system disorder could be caused by excessive Se intake (Rayman, 2012; Rayman et al., 2018).

Selenium in soil could affect human healthy by its intake through the food chain (Ahmed et al., 2019). Globally, soil Se content varies greatly from 0.01 mg/kg to 2.00 mg/kg, with an average of 0.40 mg/kg (Dinh et al., 2018a; Natasha et al., 2018). Ermakov and Kovalsky (1974) systematized ~2500 publications and estimated the average Se content in soils of the world as 0.3 mg/kg. Soil Se deficiency areas can be found in most countries of the world, including Great Britain, France, India, China, Italy, Russia, etc. (El-Sayed et al., 2020; Golubkina, 2007; Rahman et al., 2013), but some countries including China, Canada, the United States, Venezuela, Brazil, Ireland, India and Colombia also have world-famous selenium-rich areas (Chang et al., 2019; Dinh et al., 2018a; Vinceti et al., 2013; Wang et al., 2020; Winkel et al., 2012). The distribution of Se in the soil of China is very uneven. The Se-deficient or Se-poor regions cover 72% of the land; there is a wide low-Se belt from the northeast to the southwest (Wang and Gao, 2001; Yu et al., 2014). However, there are several Se-rich areas, such as Enshi Prefecture, Hubei Province (Chang et al., 2019), Ziyang County, Shaanxi Province (Ni et al., 2016), Kaiyang County, Guizhou Province (Ren and Yang, 2014), Taoyuan County, Hunan Province (Ni et al., 2016), etc.

The distribution of Se in soil is affected by many factors. For a long time, soil parent rocks have been regarded as the main control of soil Se content (Li et al., 2012). Selenium content in the surface soil of Enshi Prefecture, Hubei Province, Ziyang County and Langao County, Shaanxi Province is closely related to soil parent rocks (Hao et al., 2021; Luo et al., 2004; Yang et al., 2015). In the process of soil formation, the control effect of soil parent rock gradually decreases, while the impact of physicochemical properties including soil texture, pH, organic content, and oxide content gradually increases (Liu et al., 2021; Wang et al., 2013). Clay minerals, organic matter, iron and aluminum oxides affect soil Se content through adsorption (Dinh et al., 2018b; Matos et al., 2017; Tan et al., 2002), while pH influences indirectly soil Se content through controlling Se adsorption by these phases (Matos et al., 2017). Furthermore, climate factors have an effect on the distribution of soil Se through controlling atmospheric deposition, and more than 80% of atmospheric Se migrates into soil through wet deposition. Therefore, precipitation is the key factor in determining the distribution of soil Se (Dinh et al., 2018a; Feinberg et al., 2020; Song et al., 2019). For example, soil Se content of southeast China and northeast Brazil is greatly affected by precipitation (Wang et al., 2020; Williams Araújo do Nascimento et al., 2021). On the other hand, human activities, such as coal-fired emission, agricultural chemicals usage, irrigation water, different land use types, etc., also have a certain impact on soil Se distribution (Galinha et al., 2015; Smith, 2008; Xiao et al., 2020). In particular, coal-fired emission is considered to be the most influential factor (Nriagu and Pacyna, 1988; Yang et al., 2007). High Se content in the surface soil of Xuzhou City, Jiangsu Province and Kailuan Coal Mine Field, Hebei Province was affected by coal-fired emission (Huang et al., 2009; Zhang et al., 2012).

Northern Hebei Province is located in the low Se belt of China. It was once an epidemic area of Keshan disease, which was not basically eliminated until the 1970s (Li et al., 1992). In 2016, the 1 : 250000 scale geochemical survey of land quality was carried out in northern Hebei Province and detected several Se-rich areas (Se ≥ 0.4 mg/kg) (Tan, 1989). This finding has significant meanings for Se deficiency areas. In order to further understand the distribution of Se in soil, a detailed soil geochemical survey in the Se-rich key areas were implemented on the 1 : 50000 scale in 2018. Based on the survey data form 2018, this study focused on the following aspects: (1) calculating soil Se content in the study area; (2) analyzing the spatial distribution of soil Se; (3) discussing the effects of different factors on soil Se distribution.

MATERIALS AND METHODS

Study Area

The study area is located in Guyuan County, northern Hebei Province (Fig. 1a). Its geographic coordinates are 115°21′–115°55′ E and 41°26′–41°46′ N, and the total area is 402 km^2. The study area consists of 6 subareas, subarea I-subarea VI, covering an area of 54.37, 66.08, 63.50, 73.75, 76.00 and 68.30 km^2, respectively. Its climate is of the temperate continental steppe type, the average annual temperature is 1.6°C, the maximum and minimum annual sunshine time is 3246 and 2616 hours, and the annual precipitation is 426 mm. The altitude is basically above 1300 meters, and the altitude of subarea I–subarea III is lower than that of subarea IV–subareaVI (Fig. 1b).

The exposed strata in the study area are mainly Holocene alluvial deposits and Pleistocene aeolian deposits of the Malan Formation. The rhyolites of the Late Jurassic Zhangjiakou Formation and andesites of the Late Jurassic Yixian Formation also occur (Fig. 1c). The soil types include chestnut soil, meadow chestnut soil, alkaline chestnut soil, calcareous meadow soil, gley meadow soil, saline meadow soil, and calcareous regosol. The most widespread are chestnut and gley meadow soils (Fig. 1d). The land use types are various, including irrigated land, dry land, other garden, forest land, other woodland, natural grassland, artificial grassland, other grassland, and village. Among them, the natural grassland is the most widely distributed (Fig. 1e).

Notes:

In 1a, ItoV-the number of subarea, VPIto VPVIII-the number of vertical profile;

In 1c, Q_h – Holocene, Q_pm – Malan Formation of Late Pleistocene, J_3z – Zhangjiakou Formation of Late Jurassi,

J_3y – Yixian Formation of Late Jurassic;

In d, 1 – chestnut soil, 2 – meadow chestnut soil, 3 – alkaline chestnut soil, 4 – Calcareous meadow soil, 5 – gley meadow soil, 6 – saline meadow soil, 7 – calcareous regosol;

In e, 1 – irrigated land, 2 – dry land, 3 – other garden, 4 – forest land, 5 – other woodland, 6 – natural grassland, 7 – artificial grassland, 8 – other grassland, 9 – village.

Sample Collection and Preparation

The samples of surface soil, vertical profile soil, and rock were collected. The surface soil samples and vertical profile soil samples were collected from August 3, 2018 to September 11, 2018. During this period, the weather was sunny with little rain, and the difference between day and night temperatures was great (5 and 25°C). The test of all soil samples was finished on September 17, 2018. Rock samples were collected from October 5, 2018 to October 16, 2018, when the weather was sunny, and the daily temperature was between 3 and 15°C. The test was completed on November 3, 2018. A total of 3853 surface soil samples were collected. Eight vertical profiles were completed

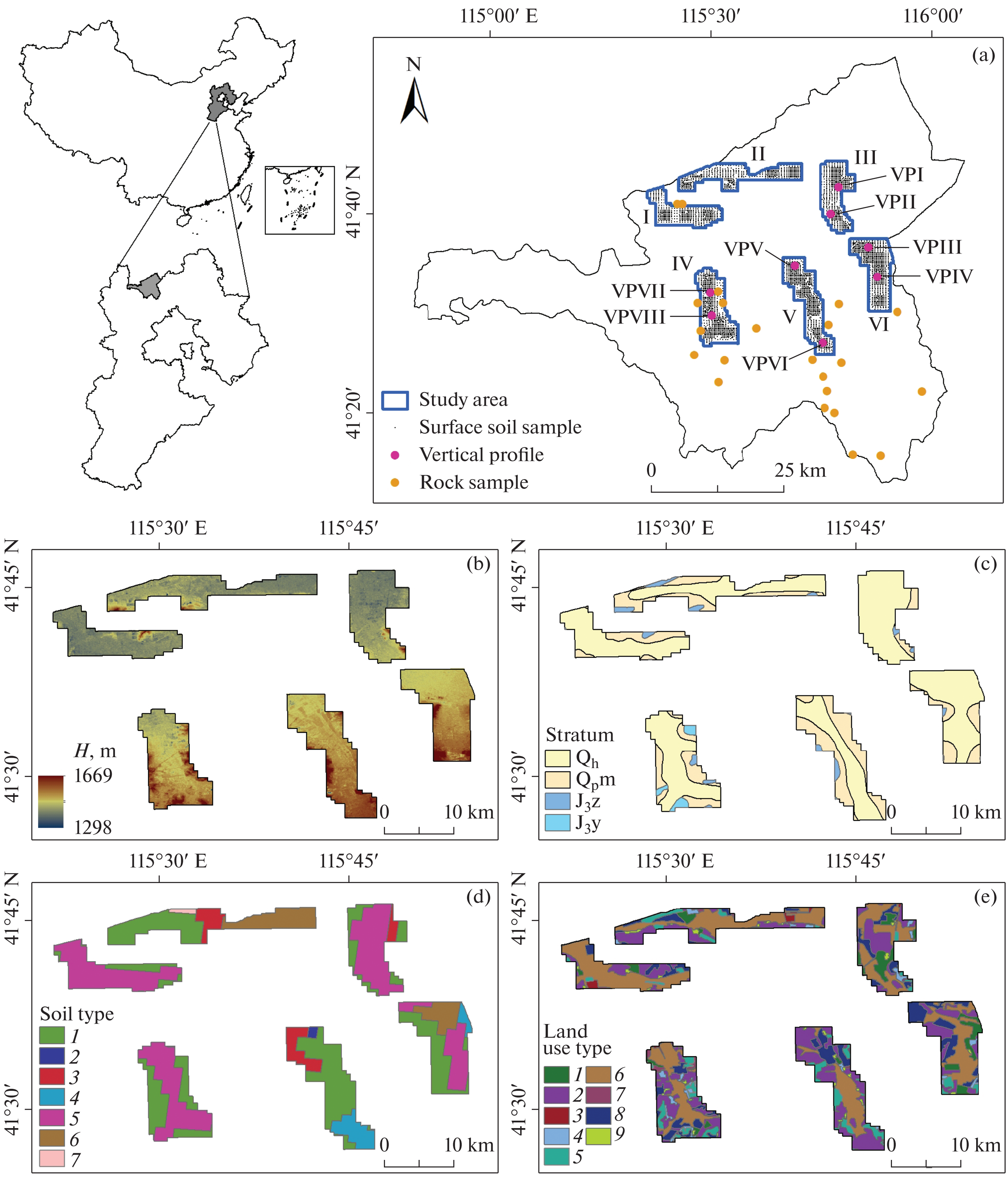

Fig. 1. Location (a), topography (b), geological (c), soil type (d), and land use type (e) of the study area.

with 6 soil samples for each profile (48 soil samples); 22 rock samples were also collected (Fig. 1a).

The sampling depth of surface soil was 0–20 cm, the sampling density was 4–16 samples per square kilometer, and each sample weighed more than 1000 g. The sampling medium was all kinds of mature soil, while the obvious punctiform contaminated sites, recently deposited soil, and ridge of field were avoided during sampling. A total of 8 vertical profiles were set up in subareas III–VI (Fig. 1a). The sampling pit was

Table 1. Analysis methods of soil and rock samples

Sample type	Indicators	Analytical method	Instrument model	Detection limit
Surface soil	Se	AFS	AFS-3000	0.003
	pH	ISE	PHS-25	0.10*
	C_{org}	VOL	–	0.016**
	S	XRF	$Axios^{max}$	6.5
	Fe_2O_3	XRF	$Axios^{max}$	0.02**
	Al_2O_3	XRF	$Axios^{max}$	0.03**
Vertical profile	Se	AFS	AFS-3000	0.003
Rock	Se	AFS	AFS-3000	0.003

* Is dimensionless, ** is %, and others are mg/kg.

1.2 m long, 0.6 m wide, and 1.2 m deep. Soil samples were collected consecutively from top to bottom at a 20 cm interval on the sunny smooth surface, and each sample weighed more than 500 g. After natural drying, the sample was crushed to pass through a 20-mesh nylon sieve, and 200 g of the material were placed in a special sample bag and sent to the laboratory for chemical analysis. Fresh rock samples were collected from different strata in Guyuan County, 1–2 pieces from each stratum and about 2 kilogram per sample. In total, 10 samples of magmatic rocks (andesite, trachyte, granite porphyry, and rhyolite), 6 sedimentary rock samples (mainly, tuffs), and 6 metamorphic rock samples (gneiss, metamorphosed monzonitic granite, and metamorphosed diorite) were collected.

Chemical Analysis and Quality Control

The samples were analyzed and tested in the laboratory of the No.4 Geological Brigade, Hebei Bureua of Geology and Mineral Resources Exploration. Selenium was analyzed in surface soil, vertical profile soil, and rock samples by atomic fluorescence spectrometry (AFS) after digesting in nitric acid-perchloric acid-hydrochloric acid (HNO_3-$HClO_4$-HCl); C_{org} in surface soil samples was analyzed by volumetry (VOL) after digesting in potassium dichromate ($K_2Cr_2O_7$) and concentrated sulfuric acid (H_2SO_4); S, Fe_2O_3, and Al_2O_3 in surface soil samples were analyzed by X-ray fluorescence spectrometry (XRF) after powder pressing; pH of surface soil samples was determined by ion selective electrode (ISE) after dissolving in CO_2 distilled water. The analytical methods, instrument mode, and detection limits are listed in Table 1.

Internal controls were used during analysis to ensure the accuracy and precision. National certified reference materials (CRMs) and laboratory replicate samples were analyzed simultaneously with samples to ensure the quality of analysis. The analysis accuracy was estimated by inserting five CRMs within every 50 samples and analyzing them simultaneously for Se, C_{org}, S, Fe_2O_3 and Al_2O_3 and inserting two CRMs after every 50 samples when analyzing pH. 5% samples were selected randomly and re-analyzed by the most experienced analysts in the laboratory to ensure the analysis precision. The accuracies and precisions of Se, C_{org}, S, Fe_2O_3 and Al_2O_3 are listed in Table 2. The relative deviation (RD) of pH between the original and re-analyzed samples should be within $|\Delta pH| \leq 0.1$. The accuracies and precisions of all measured parameters in all samples satisfied the analytical requirements of the standard of methods used in the national geochemical survey of land quality of China (CGS, 2014) and the code of geochemical rock survey of China (Ministry of Land and Resources of the People's Republic of China, 2014).

GeoDetector

GeoDetector is a new statistical method of detecting spatial heterogeneity and revealing the driving forces behind it. There are 4 types of detectors: factor detector, interaction detector, risk detector, and ecological detector (Wang et al., 2010; Wang and Xu, 2017). In this study, factor detector and interaction detector were applied to analyze the influence of different factors on the spatial distribution of soil Se. More specifically, factor detector was used to detect spatial heterogeneity of the dependent variable (Se), and q value was applied to measure the interpretation ability of different factors to spatial differentiation of the dependent variable. The value range of q is from 0 to 1, and the greater the value, the stronger the interpretation ability. In addition, changes in the explanatory ability of different factors for dependent variables related to their mutual interaction were assessed by using interaction detector including nonlinear attenuation, single-factor nonlinear attenuation, double-factor enhancement, independent and nonlinear enhancement (Wang and Xu, 2017).

The factors affecting the spatial distribution of soil Se include soil parent rocks, soil physicochemical properties, principal element content (pH, C_{org}, S, Fe_2O_3, and Al_2O_3), topography (elevation(H), slope,

Table 2. Allowance of accuracy and precision for chemical analysis

Concentration range	Accuracy	Precision
–	$\Delta \log \bar{C}_i = \lvert \log \bar{C}_i - \log C_s \rvert$	$RD = \lvert C_1 - C_2 \rvert / \frac{1}{2}(C_1 + C_2)$
<3 detection limit	≤0.12	≤30%
>3 detection limit	≤0.10	≤25%
1%–5%	≤0.07	–
5%	≤0.05	–

CRMs national certified reference materials, $\bar{C}_i$ the average determined value of CRMi, C_i the determined value of CRMi, *Cs*, the recommended value of CRMi, C_1 the first determined value, C_2, the redetermined value.

aspect, and topographic wetness index (TWI)), soil type, and land use type.

As GeoDetector required, factor variable data should be typological variables. That is, discretization is required when factor variables are numeric. The discretization can be based on professional knowledge or classification methods, such as equal interval, quantile, and natural discontinuity point classification methods (Wang and Xu, 2017). Soil parent rocks, soil type, and land use type are typological variables while other factors are numerical variables. The slope was divided into 6 categories: flat (<5°), flat gentle (5–8°), gentle (8–15°), gentle steep (15–25°), steep (25–35°), and sharp steep (>35°) (Liu et al., 2021). The aspect was classified into 9 categories: flat, north (337.5–22.5°), northeast (22.5–67.5°), east (67.5–112.5°), southeast (112.5–157.5°), south (157.5–202.5°), southwest (202.5–247.5°), west (247.5–292.5°), and northwest (292.5–337.5°). Other numerical variables were assigned to 9 categories by using the natural discontinuity point classification method. The classification results of impact factors are shown in Table 3.

Statistical Analysis

The following statistical parameters of Se content in soil and rock samples were calculated by MS Excel: minimum, maximum, mean, median, standard deviation, and variation coefficient. Moreover, the spatial distribution map of soil Se was drawn by ArcGIS 10.2, and the vertical variation map of soil Se was drawn by Origin 2022. SPSS 18.0 was applied to analyze the Spearman correlation coefficient between soil selenium content and pH, C_{org}, S, Fe_2O_3, Al_2O_3, elevation, slope, aspect, and TWI, and GeoDetector was utilized to analyze the influence of different factors on the spatial distribution of soil Se.

RESULTS AND DISCUSSION

Soil Se Content

The Se content of surface soil in the study area was 0.06–3.74 mg/kg, with a mean of 0.4 mg/kg (Table 4). The soil Se content of 6 subareas decreased from the south to the north in the sequence subarea VI (0.49 mg/kg) > subareaV (0.41 mg/kg) > study area (0.40 mg/kg) = subarea IV (0.40 mg/kg) > subarea III (0.37 mg/kg) > subarea I(0.37 mg/kg) > subarea II (0.34 mg/kg) (Table 4). Coefficient of variation (CV) reflects the variability of element content. CV less than 0.2 means low variability of element distribution, 0.2 – 0.5 means moderate variability, 0.5–1 means high variability, greater than 1 means abnormally high variability (Nezhad et al., 2015). The CV of surface soil selenium in the study area was 0.84 (Table 4), indicating a strong spatial distribution variability.

The Se content of surface soil in the study area was similar to the global value (Natasha et al., 2018), but higher than that in China and Hebei (Hou et al., 2020) (Table 5). Appropriate intake of Se is conducive to the health and longevity of humans. Excessive intake could lead to selenosis, and deficient intake could cause Keshan disease (KSD) and Kashin-Beck disease (KBD). Compared with the areas of selenosis, KSD, KBD, and longevous areas (Table 5), the surface soil Se content in the study area was far lower than that in the selenosis areas (Ziyang, Shanxi, and Yutangba, Hubei) and higher than that in the KSD and KBD areas. It was 2.56 times that of Zhangjiankou, Hebei, 2.08 times that of Songpan, Tibet and, 2.63 times that of Zamtang, Sichuan. In addition, it was lower than that in the longevous area of Yongfu, Guangxi but higher than that in Yongjia, Zhejiang and Rugao, Jiangsu by factors of 1.04 and 3.08, respectively. Overall, the selenium content of surface soil in the study area is relatively high.

Soil Se Spatial Distribution

Generally, soil Se content is classified as Se-deficient (<0.125 mg/kg), Se-marginal (0.125–0.175 mg/kg), Se-sufficient (0.175–0.40 mg/kg), Se-rich (0.40–3.0 mg/kg), and Se-excessive (>3.0 mg/kg) (Tan, 1989). According to this classification, the distribution pattern of surface soil Se in the study area was delineated by the inverse distance weighting method (IDW). As shown in Fig. 2, the surface soil in the study area was dominantly Se-sufficient and Se-rich. The area of Se-rich soils was about 116.8 km^2, accounting for 29.05% of

Table 3. The classification results of impact factors

Factor	1	2	3	4	5	6	7	8	9
Stratum	Q_h	Q_pm	J_3z	J_3y	–	–	–	–	–
pH	5.39–7.14	7.14–7.55	7.55–7.88	7.88–8.17	8.17–8.41	8.41–8.62	8.62–8.85	8.85–9.19	9.19–10.35
C_{org}, %	0.11–1.45	1.45–2.19	2.19–2.92	2.92–3.65	3.65–4.51	4.51–5.61	5.61–7.08	7.08–9.34	9.34–15.70
S, mg/kg	88.37–403.63	403.63–613.80	613.80–802.95	802.95–1013.12	1013.12–1265.33	1265.33–1601.60	1601.60–2042.96	2042.96–2631.43	2631.43–5447.71
Fe_2O_3, %	0.99–2.21	2.21–2.60	2.60–2.93	2.93–3.27	3.27–3.57	3.57–3.90	3.90–4.35	4.35–4.93	4.93–8.06
Al_2O_3, %	6.53–9.34	9.34–10.01	10.01–10.50	10.50–10.95	10.95–11.37	11.37–11.78	11.78–12.23	12.23–12.83	12.83–16.09
H	1298–1392	1392–1409	1409–1426	1426–1442	1442–1458	1458–1475	1475–1499	1499–1540	1540–1669
Slope, °	0.00–5.00	5.00–8.00	8.00–15.00	15.00–25.00	25.00–35.00	35.00–64.14	–	–	–
Aspect	Flat	North	Northeast	East	Southeast	South	Southwest	West	Northwest
TWI	0.84–6.10	6.10–7.18	7.18–8.48	8.48–9.93	9.93–11.38	11.38–12.76	12.76–14.42	14.42–16.74	16.74–21.30
Soil type	Chestnut soil	Meadow chestnut soil	Alkaline chestnut soil	Calcareous meadow soil	Gley meadow soil	Saline meadow soil	Calcareous regosol	–	–
Land use type	Irrigated land	Dry land	Other garden	Forest land	Other woodland	Natural grassland	Artificial grassland	Other grassland	Village

H: elevation; TWI: topographic wetness index; Q_h: Holocene; Q_pm: Malan Formation of Pleistocene; J_3z: Zhangjiakou Formation of Late Jurassic; J_3y: Yixian Formation of Late Jurassic.

Table 4. The statistical characteristic of soil Se content (mg/kg)

Area	Num.	Minimum	Median	Maximum	Mean	STD	CV
Study area	3853	0.06	0.30	3.74	0.40	0.34	0.84
Subarea I	470	0.09	0.29	3.18	0.37	0.33	0.89
Subarea II	572	0.07	0.22	2.25	0.34	0.29	0.84
Subarea III	601	0.06	0.32	1.86	0.37	0.25	0.67
Subarea IV	706	0.06	0.24	3.74	0.40	0.40	0.99
Subarea V	786	0.09	0.32	2.13	0.41	0.29	0.71
Subarea VI	718	0.08	0.36	2.69	0.49	0.43	0.87

Num.: number of samples; STD: standard deviation; CV: coefficient of variation.

Table 5. Se content of surface soil in the study area and other areas (mg/kg)

Region	Se	Regional type	Source
World	0.4	–	(Natasha et al., 2018)
China	0.26	–	(Hou et al., 2020)
Hebei, China	0.2	–	(Hou et al., 2020)
Ziyang, Shanxi, China	0.50–16.96(4.78)	Selenosis	(Du et al., 2018)
Yutangba, Hubei, China	0.41–42.3(4.75)	Selenosis	(Zhu et al., 2008)
Zhangjiankou, Hebei, China	0.066–0.263(0.156)	Keshan disease	(Ge et al., 2000)
Songpan, Tibet, China	0.059–0.305(0.192)	Kashin-Beck disease	(Wang et al., 2017)
Zamtang, Sichuan, China	0.091–0.262(0.152)	Kashin-Beck disease	(Zhang et al., 2009)
Yongjia, Zhejiang, China	0.157–0.633(0.382)	Longevity county	(Xu et al., 2018)
Yongfu, Guangxi, China	0.27–1.40(0.80)	Longevity county	(Shao et al., 2018)
Rugao, Jiangsu, China	0.051–0.168(0.130)	Longevity county	(Sun et al., 2008)
Study area	0.06–3.74(0.40)	–	This study

the total area. The areas of Se-rich soils in the 6 subareas decreases in the sequence subarea VI (27.17 km^2) > subarea V (27.10 km^2) > subarea IV (18.22 km^2) > subarea III (16.9 km^2) > subarea II (15.11 km^2) > subareaI (12.3 km^2), illustrating an overall increase from the north to the south.

Factors Influencing Soil Se Distribution

Soil parent rock. The Quaternary sediments are most abundant in the study area, and the rocks from upstream are the original material sources. In Guyuan County, the average Se content of rock samples was 0.06 mg/kg: 0.05 mg/kg in magmatic rocks, 0.06 mg/kg in sedimentary rocks, and 0.08 mg/kg in metamorphic rocks, which is lower than the average of the earth's crust, 0.13 mg/kg (Rudnick and Gao, 2014). Compared with the Se-rich area in China, the Se content of Guyuan rock samples is much lower than that of the carbonaceous siliceous rocks of Yutangba, Enshi Prefecture, Hubei Province (8390 mg/kg) (Song, 1989) and the black shale of Ziyang, Shaanxi Province (303 mg/kg) (Long and Luo, 2017), indicating that Guyuan does not have Se-rich soil parent rocks.

Variations in Se content from the surface to deep layers can be clearly seen in the soil vertical profile. In comparison with surface soil, there is a lower external influence for deep soil, which makes its composition and content similar to the parent rock (Cheng et al., 2014; Dai et al., 2011). As shown in Fig. 3, the Se content of surface soil in the study area was significantly higher than that in deep soil, and the Se content decreased gradually from top to bottom, indicating that the surface soil was controlled by both soil parent rock and other factors.

Soil physicochemical properties. Spearman correlation analysis (Table 6) showed that the Se content of surface soil in the study area showed a strong positive correlation with C_{org}, S, and Fe_2O_3, while the correlation with pH and Al_2O_3 was low, indicating that soil Se content was greatly affected by C_{org}, S, and Fe_2O_3 but less affected by pH and Al_2O_3. In order to observe the relationship between Se content and soil physical and chemical properties, Tables 7–11 show the statistical parameters of pH, C_{org}, S, Fe_2O_3, and Al_2O_3 in different regions.

The soil C_{org} content in the study area was 2.95% and showed a strong correlation with soil Se content,

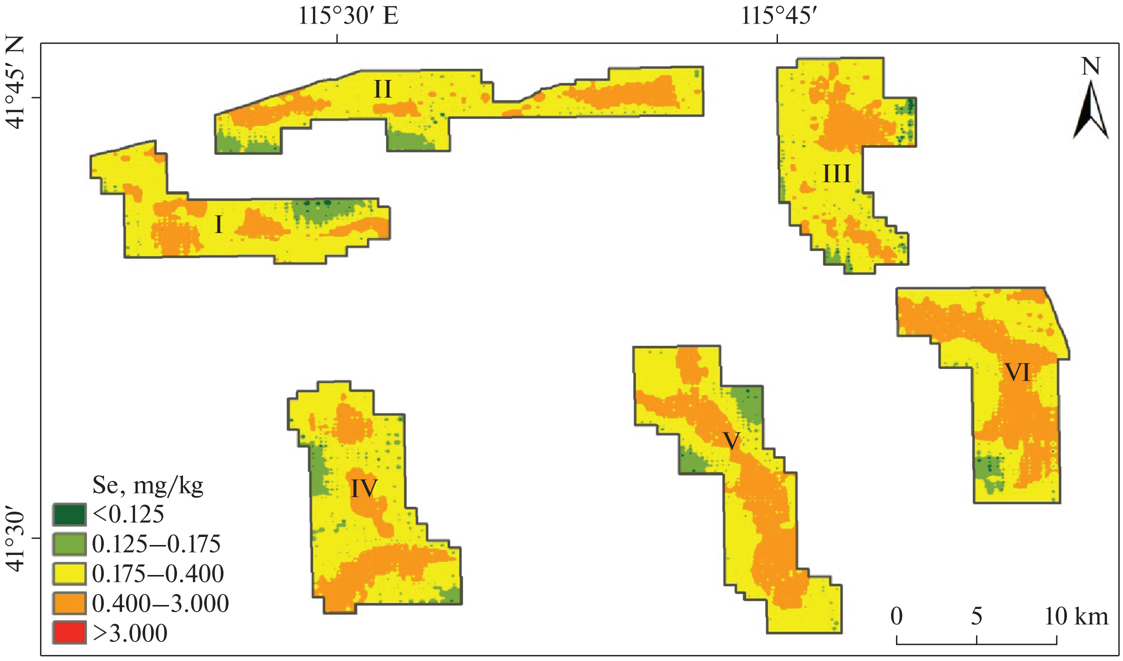

Fig. 2. Distribution of surface soil Se in the study area.

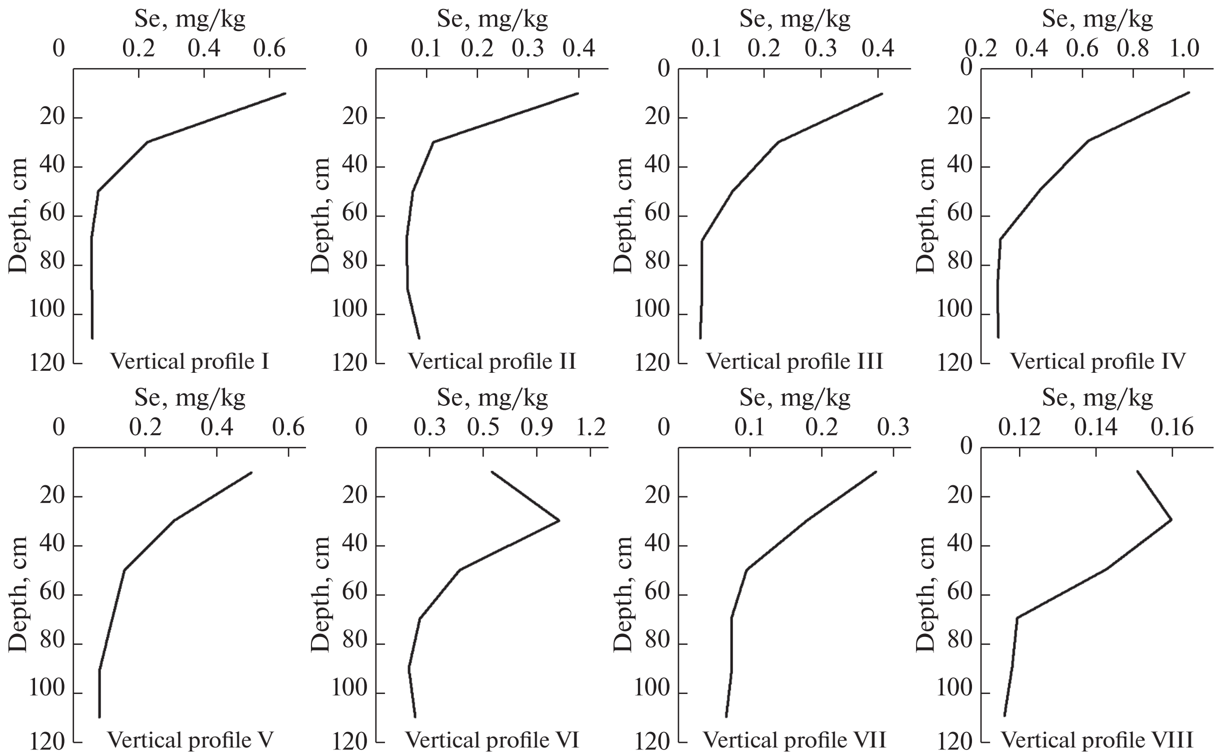

Fig. 3. Changes of Se content in the soil vertical profile.

(correlation coefficient of 0.875). C_{org} is a major component of organic matter and is generally regarded as an important factor affecting soil Se content (Ermakov and Jovanovic, 2010; Roca-Perez et al., 2010; Yamada et al., 2009). Selenite (+4) and selenate (+6), which can be adsorbed and fixed by organic matter, dominate Se speciation in soil (Weng et al., 2011). Selenite is strongly adsorbed and has low mobility, and selenate sorption in soil is weaker (El-Sayed et al., 2020). The presence of higher levels of C_{org} helps to create anoxic

Table 6. Correlation matrix of Se, soil environment factor, and topographical parameters

	Se	pH	C_{org}	S	Fe_2O_3	Al_2O_3	H	Slope	Aspect
pH	0.309**	–	–	–	–	–	–	–	–
C_{org}	0.857**	0.155**	–	–	–	–	–	–	–
S	0.869**	0.300**	0.904**	–	–	–	–	–	–
Fe_2O_3	0.697**	0.131**	0.836**	0.683**	–	–	–	–	–
Al_2O_3	–0.025	–0.054**	0.094**	–0.097**	0.460**	–	–	–	–
H	–0.072**	–0.379**	–0.090**	–0.207**	–0.046**	0.024	–	–	–
Slope	–0.153**	–0.169**	–0.146**	–0.166**	–0.111**	–0.006	.115**	–	–
Aspect	0.01	–0.002	0.002	0.004	–0.004	0.001	–0.005	0.066**	–
TWI	0.108**	0.125**	0.089**	0.106**	0.080**	0.012	–0.088**	–0.326**	–0.001

** $p < 0.01$; H: elevation; TWI: topographic wetness index.

Table 7. The statistical characteristics of surface soil pH

Area		Num.	Minimum	Median	Maximum	Mean	STD	CV
Study area		3853	5.33	8.52	10.37	8.47	0.57	0.07
Subarea	I	470	6.15	8.59	10.00	8.57	0.55	0.06
	II	572	6.08	8.57	10.37	8.63	0.63	0.07
	III	601	5.91	8.51	10.00	8.46	0.54	0.06
	IV	706	5.37	8.55	10.07	8.47	0.49	0.06
	V	786	5.33	8.37	9.46	8.26	0.59	0.07
	VI	718	6.51	8.52	9.90	8.51	0.50	0.06
Stratum	Q_h	2858	5.37	8.59	10.37	8.60	0.47	0.06
	Q_pm	904	5.33	8.33	9.92	8.12	0.64	0.08
	J_3y	26	7.45	8.40	8.77	8.21	0.39	0.05
	J_3z	65	6.72	7.71	8.63	7.75	0.47	0.06
Soil type	Meadow chestnut soil	15	8.01	8.58	9.46	8.65	0.37	0.04
	Calcareous regosol	6	8.32	8.56	8.75	8.55	0.18	0.02
	Alkaline chestnut soil	218	7.90	8.74	10.37	8.79	0.36	0.04
	Chestnut soil	1437	5.33	8.41	10.27	8.28	0.63	0.08
	Gley meadow soil	1582	5.91	8.56	10.07	8.55	0.44	0.05
	Calcareous meadow soil	180	6.61	8.24	9.16	8.11	0.46	0.06
	Saline meadow soil	415	6.43	8.78	10.04	8.80	0.53	0.06
Land use type	Village	29	7.20	8.33	9.92	8.28	0.50	0.06
	Dry land	1089	5.33	8.43	9.80	8.28	0.58	0.07
	Other grassland	536	6.27	8.52	9.59	8.41	0.54	0.06
	Other garden	39	8.06	8.82	9.86	8.88	0.52	0.06
	Other woodland	172	6.53	8.12	9.36	8.03	0.59	0.07
	Artificial grassland	19	6.29	8.24	9.01	8.21	0.68	0.08
	Irrigated land	241	5.91	8.42	9.43	8.34	0.45	0.05
	Natural grassland	1653	5.50	8.67	10.37	8.69	0.47	0.05
	Forest land	75	6.91	8.36	9.22	8.17	0.52	0.06

Num.: number of samples; STD: standard deviation; CV: coefficient of variation.

Table 8. The statistical characteristics of surface soil C_{org} (%)

Area		Num.	Minimum	Median	Maximum	mean	STD	CV
Study area		3853	0.10	2.12	15.90	2.59	1.89	0.73
Subarea	I	470	0.39	2.43	8.14	2.52	1.43	0.57
	II	572	0.16	1.53	8.02	2.03	1.39	0.68
	III	601	0.11	2.65	9.98	2.88	1.67	0.58
	IV	706	0.10	1.55	8.27	1.85	1.15	0.62
	V	786	0.22	2.05	11.90	2.83	2.09	0.74
	VI	718	0.18	2.65	15.90	3.28	2.49	0.76
Stratum	Q_h	2858	0.16	2.60	15.90	3.01	1.92	0.64
	Q_pm	904	0.10	1.14	14.80	1.41	1.10	0.78
	J_3y	26	0.54	1.12	2.62	1.22	0.48	0.39
	J_3z	65	0.38	0.96	4.56	1.33	0.94	0.71
Soil type	Meadow chestnut soil	15	0.57	4.47	6.91	4.01	1.98	0.49
	Calcareous regosol	6	0.95	1.23	2.51	1.39	0.59	0.42
	Alkaline chestnut soil	218	0.16	1.81	6.88	2.10	1.15	0.55
	Chestnut soil	1437	0.11	1.56	11.90	2.20	1.81	0.82
	Gley meadow soil	1582	0.10	2.50	15.90	2.86	1.99	0.70
	Calcareous meadow soil	180	0.69	2.56	10.60	3.15	1.99	0.63
	Saline meadow soil	415	0.38	2.80	10.20	2.99	1.57	0.52
Land use type	Village	29	0.55	1.51	3.46	1.52	0.68	0.44
	Dry land	1089	0.24	1.39	6.00	1.63	0.93	0.57
	Other grassland	536	0.13	2.18	9.55	2.45	1.59	0.65
	Other garden	39	1.23	2.75	5.56	2.96	1.37	0.46
	Other woodland	172	0.33	1.39	7.85	1.61	1.02	0.63
	Artificial grassland	19	0.25	0.95	3.50	1.19	0.85	0.71
	Irrigated land	241	0.28	1.87	9.20	2.08	1.19	0.57
	Natural grassland	1653	0.10	3.09	15.90	3.54	2.15	0.61
	Forest land	75	0.22	1.12	4.17	1.18	0.66	0.56

Num.: number of samples; STD: standard deviation; CV: coefficient of variation.

zones facilitating Se reduction and immobilization (Li et al., 2017; Wang et al., 2018). Figure 4a shows that soil Se content increased initially with increasing C_{org}, reached a peak at C_{org} content between 5.61 and 7.08%, and then decreased, which is consistent with the study of Liu et al. (2021). The result shows that soil C_{org} have a certain limited effects on soil Se content.

The geochemical affinity of Se and S is similar because of similarity in ion radius, lattice energy coefficient, and ion potential (Savard et al., 2006). Selenium can replace S in sulfide minerals, resulting in widespread presence of Se in natural sulfide minerals (Song et al., 2019). It is shown in Fig. 4b, that the effect of S on soil Se content is similar to that of C_{org}. The soil Se content increased with increasing S content, reached a peak, and then decreased, indicating that S have an important impact on soil Se content.

Iron oxides have large surface area and abundant binding sites (Matos et al., 2017), strong adsorption and fixation ability for soil Se (Muller et al., 2012; Peak, 2006). As shown in Fig. 4c, soil Se content increased with increasing Fe_2O_3 content, indicating that Fe_2O_3 was an important factor affecting the soil Se content.

Topography. Topography is an important factor of soil Se distribution (Liu et al., 2021). Elevation and slope are the parameters of topographic relief which can indirectly affect soil Se distribution by causing redistribution of minerals, water and energy (Tan et al., 2002; Wang and Zhang, 1996). TWI is the parameter describing soil humidity: the higher the TWI value, the higher the soil moisture (Kaiser and McGlynn, 2018). Besides, soil moisture can indirectly affect soil Se distribution by affecting soil pH, soil aer-

Table 9. The statistical characteristics of surface soil S (mg/kg)

Area		Num.	Minimum	Median	Maximum	Mean	STD	CV
Study area		3853	78.00	533.00	5555.00	670.25	503.56	0.75
Subarea	I	470	134.00	607.00	3197.00	740.75	522.84	0.71
	II	572	153.00	465.00	2722.00	578.11	380.59	0.66
	III	601	87.70	602.00	5555.00	703.82	472.16	0.67
	IV	706	119.41	406.69	1971.27	518.36	338.07	0.65
	V	786	127.00	485.50	3320.00	657.15	468.17	0.71
	VI	718	78.00	616.00	4386.00	833.11	684.66	0.82
Stratum	Q_h	2858	78.00	636.00	5555.00	778.64	521.74	0.67
	Q_pm	904	87.70	297.50	2918.00	371.26	280.78	0.76
	J_3y	26	162.44	272.46	581.86	302.22	116.74	0.39
	J_3z	65	147.78	251.50	611.00	279.87	100.25	0.36
Soil type	Meadow chestnut soil	15	251.00	1119.00	1797.00	1040.33	485.04	0.47
	Calcareous regosol	6	259.00	302.00	410.00	315.50	54.52	0.17
	Alkaline chestnut soil	218	165.00	525.00	2546.00	623.74	337.48	0.54
	Chestnut soil	1437	90.50	383.00	5555.00	562.22	468.65	0.83
	Gley meadow soil	1582	78.00	606.00	4665.00	764.23	559.84	0.73
	Calcareous meadow soil	180	197.00	428.50	2059.00	562.36	344.07	0.61
	Saline meadow soil	415	154.00	679.50	2722.00	776.80	434.35	0.56
Land use type	Village	29	153.45	368.02	1090.00	413.25	204.98	0.50
	Dry land	1089	119.41	349.00	1634.00	402.09	201.57	0.50
	Other grassland	536	78.00	548.00	3106.00	657.72	467.27	0.71
	Other garden	39	336.00	736.00	3197.00	957.74	700.23	0.73
	Other woodland	172	119.00	305.69	1525.00	361.63	227.25	0.63
	Artificial grassland	19	130.00	234.29	1177.00	350.03	292.98	0.84
	Irrigated land	241	128.00	440.73	4665.00	508.68	357.00	0.70
	Natural grassland	1653	90.50	791.00	5555.00	928.20	563.51	0.61
	Forest land	75	124.00	264.18	961.00	297.61	156.33	0.53

Num.: number of samples; STD: standard deviation; CV: coefficient of variation.

ation, and redox state (Sajedi et al., 2012; Shao et al., 2018; Xu et al., 2018). Table 6 shows that the correlation between surface soil Se content and H, slope, aspect, and TWI was weak in the study area, which indicated that the influence of topography on soil Se distribution is not strong.

Soil type. The Se contents of seven soil types in the study area were different (Table 12). The highest Se content (0.66 mg/kg) was found in meadow chestnut soil. Calcareous meadow soil, gley meadow soil, and saline meadow soil also have relatively high Se contents (above 0.4 mg/kg), reaching the Se-rich level

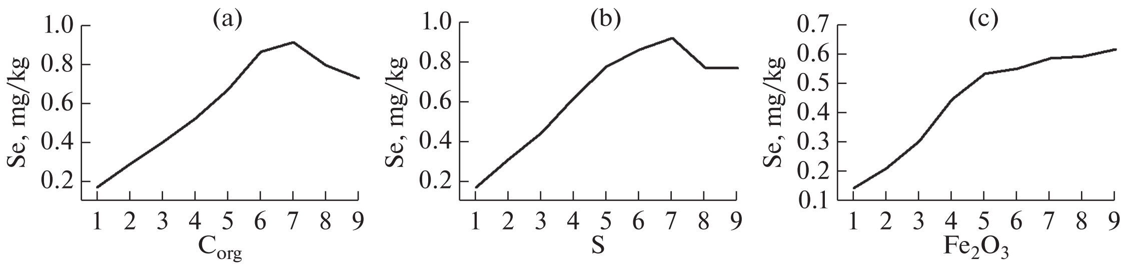

Fig. 4. Relationships between soil Se content and C_{org} (a), S (b), and Fe_2O_3 (c).

Table 10. The statistical characteristics of surface soil Fe_2O_3 (%)

Area		Num.	Minimum	Median	Maximum	Mean	STD	CV
Study area		3853	0.94	3.13	8.22	3.13	0.84	0.27
Subarea	I	470	1.06	3.24	5.21	3.06	0.74	0.24
	II	572	1.05	2.77	4.74	2.89	0.66	0.23
	III	601	1.00	3.46	8.22	3.30	0.88	0.27
	IV	706	1.37	2.90	5.43	2.92	0.66	0.22
	V	786	1.45	3.21	7.10	3.33	0.99	0.30
	VI	718	0.94	3.27	6.41	3.23	0.88	0.27
Stratum	Q_h	2858	0.94	3.34	8.22	3.32	0.81	0.24
	Q_pm	904	1.00	2.46	5.54	2.57	0.66	0.26
	J_3y	26	1.56	2.66	3.63	2.66	0.51	0.19
	J_3z	65	1.48	2.40	4.65	2.60	0.74	0.28
Soil type	Meadow chestnut soil	15	2.11	3.50	3.89	3.31	0.53	0.16
	Calcareous regosol	6	2.22	2.44	3.66	2.63	0.52	0.20
	Alkaline chestnut soil	218	1.20	2.90	4.39	2.90	0.62	0.21
	Chestnut soil	1437	1.05	2.83	7.10	2.95	0.84	0.29
	Gley meadow soil	1582	0.94	3.22	8.22	3.17	0.80	0.25
	Calcareous meadow soil	180	1.84	3.84	7.01	3.92	0.96	0.25
	Saline meadow soil	415	1.43	3.50	5.37	3.44	0.72	0.21
land use type	Village	29	1.81	2.69	4.02	2.70	0.56	0.21
	Dry land	1089	1.37	2.75	5.79	2.88	0.76	0.26
	Other grassland	536	1.00	3.05	5.91	3.01	0.76	0.25
	Other garden	39	2.34	3.31	4.93	3.41	0.59	0.17
	Other woodland	172	1.28	2.74	5.54	2.79	0.84	0.30
	Artificial grassland	19	1.37	2.31	3.32	2.36	0.53	0.22
	Irrigated land	241	1.38	2.79	6.37	2.98	0.83	0.28
	Natural grassland	1653	0.94	3.45	8.22	3.44	0.82	0.24
	Forest land	75	1.42	2.30	4.05	2.41	0.63	0.26

Num.: number of samples; STD: standard deviation; CV: coefficient of variation.

(Tan, 1989). Meadow chestnut soil is a subclass of chestnut soil. Among all the subclasses of chestnut soil, meadow chestnut soil has a higher moisture content (Li, 1990). When soil humidity is high, inorganic Se in soil mainly exists in the form of selenite (+4), which is easily adsorbed by C_{org} and clay minerals and remains in soil (Jayaweera and Biggar, 1996; Sajedi et al., 2012). Calcareous meadow soil, gley meadow soil, and saline meadow soil are a subclass of meadow soil, which occurs mainly in areas with high groundwater levels. The soil humidity is high, and the content of soil organic matter is high and can be more than 5% (Li, 1990). As mentioned above, high soil moisture and organic matter content are favorable conditions for Se enrichment in soil.

Land use type. There are 9 land use types in the study area. The main vegetation types are crops, grass, and trees. The main crop types are naked oats, flax, and rye. The types of grass include achnatherum splendens, dandelion, and plantain. The main tree types are include pine and cypress. Among all the land use types, the soil Se content of other garden, natural grassland, and other grassland was greater than 0.4 mg/kg (Table 13). The distribution area of other garden was small and very dispersed (Fig. 1e), while natural grassland and other grasslands, as the main land use types in the study area, were very consistent with the spatial distribution of Se-rich areas (Figs. 1e, 2). Land use types involving changes in phytocoenosis will have a strong impact on soil properties, especially on soil organic matter (Sevink et al., 2005; Smith, 2008). Grassland is an important input source of soil carbon, which is conducive to maintaining the content of soil organic matter (Smith, 2008). Organic matter has a strong adsorption capacity, and a large portion of soil Se (40–50% of total Se) is combined with it (Gustafsson and Johnsson, 1994; Oram et al., 2008; Qin et al., 2012). Therefore, the high content of organic matter in natural grassland and other grassland promoted soil enrichment in Se.

Table 11. The statistical characteristics of surface soil Al_2O_3 (%)

Area		Num.	Minimum	Median	Maximum	Mean	STD	CV
Study area		3853	6.39	11.13	16.12	11.12	1.23	0.11
Subarea	I	470	8.12	11.41	16.12	11.40	1.01	0.09
	II	572	6.97	11.09	13.50	10.97	1.07	0.10
	III	601	6.39	11.22	13.99	11.20	1.14	0.10
	IV	706	8.04	10.65	14.45	10.79	1.09	0.10
	V	786	7.37	11.44	15.02	11.36	1.28	0.11
	VI	718	6.44	11.02	15.98	11.03	1.49	0.13
Stratum	Q_h	2858	6.39	11.14	16.12	11.12	1.27	0.11
	Q_pm	904	7.41	11.04	14.81	11.07	1.12	0.10
	J_3y	26	9.18	11.15	12.79	11.11	0.94	0.08
	J_3z	65	9.37	11.58	14.17	11.58	1.12	0.10
Soil type	Meadow chestnut soil	15	9.76	10.60	12.26	10.75	0.81	0.08
	Calcareous regosol	6	9.44	10.37	12.64	10.62	1.14	0.11
	Alkaline chestnut soil	218	7.30	10.61	13.30	10.72	0.99	0.09
	Chestnut soil	1437	7.37	11.12	14.45	11.10	1.19	0.11
	Gley meadow soil	1582	6.39	11.02	16.12	11.02	1.21	0.11
	Calcareous meadow soil	180	8.43	12.36	15.02	12.31	1.03	0.08
	Saline meadow soil	415	6.97	11.34	14.41	11.25	1.34	0.12
Land use type	Village	29	9.48	10.83	13.23	11.14	1.09	0.10
	Dry land	1089	8.34	11.37	15.02	11.40	1.12	0.10
	Other grassland	536	7.17	10.96	13.96	10.99	1.10	0.10
	Other garden	39	8.37	11.35	13.29	11.17	1.06	0.09
	Other woodland	172	8.83	11.48	14.81	11.44	1.22	0.11
	Artificial grassland	19	8.31	10.04	11.74	10.04	0.77	0.08
	Irrigated land	241	7.53	11.25	15.72	11.33	1.19	0.11
	Natural grassland	1653	6.39	10.98	16.12	10.93	1.31	0.12
	Forest land	75	8.82	10.62	13.12	10.84	1.07	0.10

Num.: number of samples; STD: standard deviation; CV: coefficient of variation.

In (a), (b), (c), the abscissa represents the element content gradient; the specific content value of each gradient is the same as in Table 2; each inflection point in the figure represents the average Se content under a certain element content gradient.

Table 12. Selenium content in different soil types (mg/kg)

Soil type	Num.	Minimum	Median	Maximum	Mean	STD	CV
Chestnut soil	1437	0.06	0.21	2.60	0.34	0.31	0.91
Meadow chestnut soil	15	0.17	0.69	1.34	0.66	0.35	0.53
Alkaline chestnut soil	218	0.08	0.29	1.33	0.35	0.20	0.57
Calcareous meadow soil	180	0.14	0.35	1.57	0.43	0.27	0.63
Gley meadow soil	1582	0.06	0.34	3.74	0.46	0.40	0.87
Saline meadow soil	415	0.11	0.37	2.25	0.44	0.25	0.57
Calcareous regosol	6	0.16	0.18	0.24	0.19	0.03	0.16

Num.: number of samples; STD: standard deviation; CV: coefficient of variation.

Table 13. Selenium content in different land use types (mg/kg)

Land use type	Num.	Minimum	Median	Maximum	Mean	STD	CV
Irrigated land	241	0.09	0.25	2.03	0.30	0.21	0.70
Dry land	1089	0.08	0.21	1.55	0.26	0.16	0.62
Other garden	39	0.17	0.42	2.16	0.56	0.44	0.79
Forest land	75	0.09	0.16	0.70	0.18	0.10	0.56
Other woodland	172	0.07	0.18	1.43	0.24	0.18	0.75
Natural grassland	1653	0.06	0.41	3.74	0.54	0.41	0.76
Artificial grassland	19	0.09	0.13	0.32	0.17	0.08	0.47
Other grassland	536	0.07	0.32	2.08	0.41	0.31	0.76
Village	29	0.12	0.21	0.49	0.22	0.09	0.41

Num.: number of samples; STD: standard deviation; CV: coefficient of variation.

Table 14. The analysis of factor detector results

Factors	*q* statistic	*p* value	Proportion	Factors	*q* statistic	*p* value	Proportion
Stratum	0.094	0.000	5.9%	H	0.032	0.000	2.0%
pH	0.063	0.000	3.9%	Slope	0.018	0.000	1.2%
C_{org}	0.460	0.000	28.9%	Aspect	0.002	0.618	0.1%
S	0.468	0.000	29.4%	TWI	0.004	0.149	0.3%
Fe_2O_3	0.226	0.000	14.2%	Soil type	0.030	0.000	1.9%
Al_2O_3	0.048	0.000	3.0%	Land use type	0.144	0.000	9.1%

H: elevation; TWI: topographic wetness index; Proportion: proportion of explanatory ability for different factors.

Driving Factors of Soil Se Distribution

The spatial distribution of surface soil Se in the study area was affected by many factors, but the influence degree of each factor is uncertain. Hence, the driving factors of Se distribution were revealed by the aid of GeoDetector. Based on the theory of spatial stratified heterogeneity, GeoDetector can quantify the influence of soil parent rock, soil physicochemical properties, main elements in soil, topography, soil type, and land use type on the distribution of soil Se and the effect of interaction of different factors on the distribution of soil Se (Wang and Xu, 2017).

The analysis of factor detector results showed that (Table 14) among all the influencing factors, S and C_{org} had the strongest effect on the distribution of soil Se, and their explanatory ability was 29.4% and 28.9%, respectively, which is consistent with the results of Spearman correlation analysis. Besides, Fe_2O_3 and land use type also had a high influence, with q value above 0.1 and explanatory ability of 14.2 and 9.1%, respectively. The q values of other factors were lower than 0.1, with explanatory ability from 0.1 to 5.9%, showing that they had a minor impact on soil Se distribution.

The analysis of interaction detector results shown in Table 15 indicated that there were two types of interaction between two factors (X1, X2): two-factor enhancement ($q(X1 \cap X2) > \mathrm{Max}(q(X1), q(X2))$ and nonlinear enhancement ($q(X1 \cap X2) > q(X1) + q(X2)$), indicating that the influence of two factors on soil Se distribution will be enhanced when they work together. The interaction of S and C_{org} with other factors was significant, which indicated that S and C_{org} were very important influencing factors of soil Se distribution. Although Al_2O_3 and Fe_2O_3 have some similar characteristics, such as large surface area and rich binding sites (Matos et al., 2017), the influence ability of Al_2O_3 on soil Se distribution is very low, and the q value was only 0.048 (Table 14). However, when Al_2O_3 and Fe_2O_3 work together, the influence of the two factors on soil Se distribution will be enhanced. More specifically, the value of q ($Al_2O_3 \cap Fe_2O_3$) was 0.477 (Table 15), which indicates that the interaction of Fe_2O_3 and Al_2O_3 had an important effect on soil Se distribution.

In summary, the analysis of GeoDetector results showed that soil parent rock, soil physicochemical properties, main elements in soil, topography, soil type, and land use type had certain impacts on soil Se distribution, and S and C_{org} were the main driving factors. The interaction of Fe_2O_3 and Al_2O_3 also had an important effect on soil Se distribution. Therefore, the formation of 116.8 km^2 Se-rich soils in the study area was most affected by S and C_{org} in the soil. The previ-

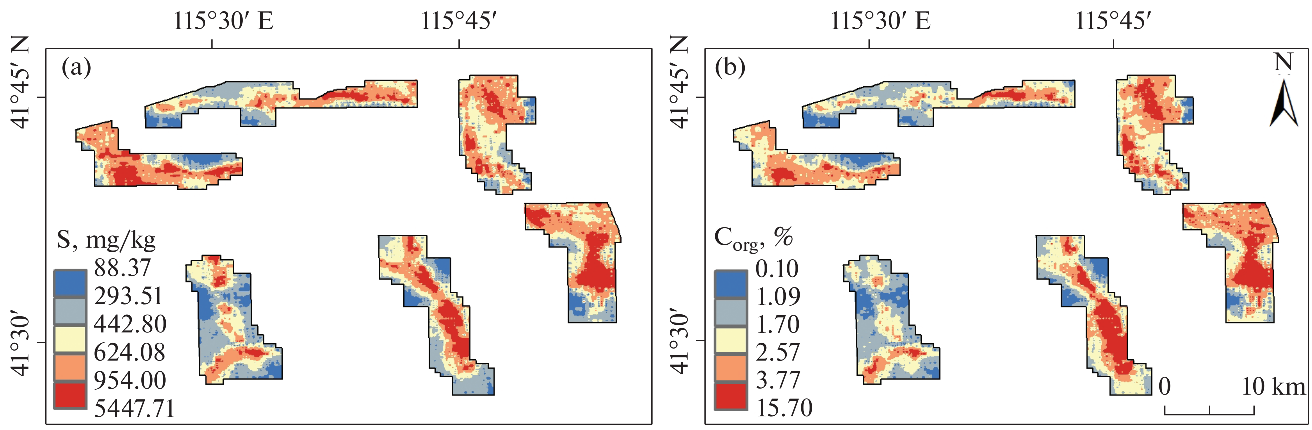

Fig. 5. Distribution of surface soil S (a) and C_{org} (b) in the study area.

ous analysis has shown that the soil Se content had a strong positive correlation with S and C_{org}, and the correlation coefficients were 0.869 and 0.857, respectively. In addition, the distribution map of element contents (Fig. 5) shows that the regions of high S, C_{org}, and Se strongly overlap, indicating that S and C_{org} were closely related to the existence of Se-rich areas.

CONCLUSIONS

(1) The Se contents of surface soil in the study areas were 0.06–3.74 mg/kg, with a mean of 0.4 mg/kg. This is similar to the mean global value, but higher than that of China and Hebei. Moreover, the average Se contents of 6 subareas were between 0.34 mg/kg and 0.49 mg/kg and tended to increase from north to south.

(2) The surface soil Se content in the study area was dominated by Se-sufficient and Se-rich. The area of Se-rich was about 116.8 km^2, accounting for 29.05% of the total area. The Se-rich domains in the 6 subareas were from 12.3 to 27.17 km^2 and increased from north to south.

(3) Soil parent rocks were the initial sources of soil Se, but their effects on soil Se content and distribution were limited. The Se content of surface soil had a strong positive correlation with C_{org}, S, and Fe_2O_3, but a weak correlation with topographic parameters. Additionally, various soil types and land use types, including meadow chestnut soil, calcareous meadow soil, gley meadow soil, saline meadow soil, natural grassland, and other grassland, have a strong promoting effect on soil enrichment in Se.

(4) The influence of different factors on the distribution of soil Se was quantified by GeoDetector. It was found that S and C_{org} were the main driving factors. Their influence on soil Se distribution was enhanced when they were superimposed with other

Table 15. The analysis of interaction detector results

	Stratum	pH	C_{org}	S	Fe_2O_3	Al_2O_3	H	Slope	Aspect	TWI	Soil type	Land use type
Stratum	0.094	–	–	–	–	–	–	–	–	–	–	–
pH	0.141	0.063	–	–	–	–	–	–	–	–	–	–
C_{org}	0.466	0.495	0.460	–	–	–	–	–	–	–	–	–
S	0.473	0.505	0.529	0.468	–	–	–	–	–	–	–	–
Fe_2O_3	0.246	0.275	0.509	0.502	0.226	–	–	–	–	–	–	–
Al_2O_3	0.143	0.164	0.537	0.515	0.477	0.048	–	–	–	–	–	–
H	0.127	0.100	0.504	0.522	0.283	0.106	0.032	–	–	–	–	–
Slope	0.101	0.077	0.467	0.474	0.238	0.072	0.051	0.018	–	–	–	–
Aspect	0.098	0.078	0.484	0.493	0.243	0.069	0.045	0.024	0.002	–	–	–
TWI	0.097	0.075	0.487	0.500	0.240	0.068	0.051	0.025	0.028	0.004	–	–
Soil type	0.102	0.097	0.494	0.490	0.255	0.097	0.086	0.052	0.041	0.043	0.030	–
Land use type	0.180	0.238	0.476	0.482	0.302	0.201	0.200	0.158	0.152	0.156	0.167	0.144

factors. The interaction of Fe_2O_3 and Al_2O_3 also had an important effect on soil Se distribution, while the influence of other factors was low.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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