Acta Geochim (2018) 37(4):571–577
https://doi.org/10.1007/s11631-017-0253-4

ORIGINAL ARTICLE

Are spatial distributions of major elements in soil influenced by human landscapes?

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Received: 6 September 2017 / Revised: 1 November 2017 / Accepted: 20 November 2017 / Published online: 24 November 2017

Abstract The present study attempted to evaluate the influence of human activity on major elements (Na_2O, MgO, Al_2O_3, SiO_2, K_2O, CaO, Fe_2O_3), and to find a method to explore correlations between major elements and human disturbances, according to geospatial theories and methods. The study results indicate that landscapes influence major elements in diverse ways: Al_2O_3 is closely related to road and mine landscapes; strong relationships exist between MgO, Fe_2O_3, CaO, and SiO_2 and roads; Na_2O, SiO_2, and Fe_2O_3 are unrelated to city landscapes; and Na_2O is unrelated to road and mine landscapes.

Keywords Major elements · Spatial distribution · Geographical background · Human landscape · Geographic information system · Remote sensing

1 Introduction

The major elements in virgin soil are generally dependent on the lithology of the parent material and the pedological and geochemical processes of soil formation (Mitchell 1960; Hardy and Cornu 2006). Major element concentrations in soils are influenced by natural factors, such as features of the soil parent material, the processes of weathering and biocycling, and wet and dry atmospheric deposition (Cortizas et al. 2003). Various solutions and chemical indices have been established and applied to the quantitative evaluation of chemical weathering intensity, most of which are based on major element analyses (Qiu et al. 2014). Many studies are based on the assumption that major elements in soil are mainly controlled by natural processes (Taylor and McLennan 1985; Huang and Gong 2001; Zhang 2011; Palma et al. 2013).

However, farming, traveling, mining, industrial production, and human settlements have a critical influence on the geochemical, physical, and biochemical properties of soil, especially on soil elements (Kelepertsis et al. 2001; Caravaca et al. 2002; Takamatsu et al. 2010; Alexakis and Gamvroula 2014; Ye et al. 2014). In the past 20 years, major element distribution in soil subjected to various human disturbances has garnered considerable attention. Li and Thornton (2001) investigated the influence of mining and smelting activities on some major elements (Mn, Fe, Al, Ca, and P) in soils. Popovic et al. (2001) studied the leaching behavior of major elements through coal ash transportation in a power plant. Lucho-Constantino et al. (2005) estimated the distribution and accumulation of major elements in agricultural soils that had been irrigated with raw wastewaters for about 20 years. A comprehensive chemical characterization of 27 fertilizers of different types used in Spain was conducted by Otero et al. (2005) to identify and characterize sources of contamination based on major, minor, and trace element analysis. Reimann et al. (2012) studied the total concentrations of the major elements (Na_2O, MgO, Al_2O_3, SiO_2, K_2O, CaO, TiO_2, MnO, Fe_2O_3, and P_2O_5) in grazing land and agricultural soils, and derived some rules around the influence of human activity on those elements.

Most past research supports the legitimacy of using quantitative geochemical methods according to mathematical statistics to evaluate the influence of human

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activity on soil elements (Cuadrado and Perillo 1997; Villaescusa Celaya et al. 2000; Cevik et al. 2009). Moreover, many studies have demonstrated that element distribution characteristics in soil can be effectively analyzed by geospatial methods (Eze et al. 2010; Bai et al. 2011; Lin et al. 2011; Bastami et al. 2012; Nanos and Martín 2012). The objectives of this paper are to (a) evaluate the influence of human activity on spatial distribution characteristics of major elements, and (b) develop a method for exploring the spatial relationships between major elements and influencing factors based on geospatial theories and methods.

2 Materials and methods

2.1 Location of study area

The study region is 28°55′–30°27′N and 105°20′–106°22′E, in Chongqing Municipality (Fig. 1). We chose this region based on convenience of transportation and for its representative economic status, landscape, ecosystem, and presence of conflict between people and land.

2.2 Data

Mine, road, and building landscapes were delineated using remote sensing image interpretation, with buffering regions averaging 2000 m. Landform, stratigraphy, and soil data were obtained through digitizing a thematic map.

In total, 2314 soil samples were gathered at the study area in 2010. Parameters were tested using Geochemical Survey Specifications, conducted by the Chinese Geological Survey.

Fig. 1 Location of study area in Chongqing, China

2.3 Methods

Na_2O, MgO, Al_2O_3, SiO_2, K_2O, CaO, and Fe_2O_3 spatial distribution were obtained by interpolating soil point samples through spatial analysis (Simanton and Osborn 1980) using ArcGIS software.

Geochemical anomalies were based on regional geochemical background values and Na_2O, MgO, Al_2O_3, SiO_2, K_2O, CaO, and Fe_2O_3 spatial distribution data, in terms of the Geochemical Survey Specifications; one example is shown in Fig. 2. Through the comprehensive analysis of element spatial distributions and regional geochemical background values, geochemical anomalies were identified according to the Specifications of the Multi-purpose Regional Geochemical Survey, executed by the Chinese Geological Survey. When sampling data had a normal distribution, the ranges of regional background values were identified by arithmetic mean (X) with 2 standard deviations (S): $X \pm 2S$. When sampling data had a lognormal distribution, the ranges of regional background values were identified by geometric mean (Xg): $Xg \times Sg^{\pm 2}$. Values that went beyond the change range of backgrounds were considered to be geochemical anomalies. The anomalies were applied to explore these element correlations with

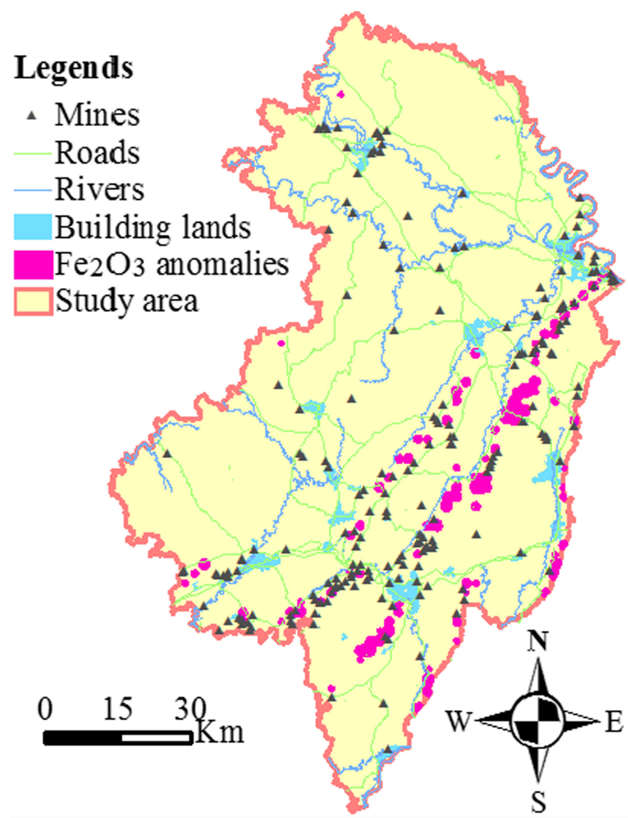

Fig. 2 Distribution of Fe_2O_3 in context of mines, roads, building lands, and rivers

geographical factors and human landscapes, to explore their influence on major element spatial distributions.

The human disturbance factors were then analyzed by a distance decay function and regression methods. Distance decay describes the effect of distance on cultural or spatial interactions, with the effect decreasing as distance increases. The spatial distributions of the elements were derived and the spatial relationships between the elements in soils and human landscapes obtained. To illustrate correlations between element anomalies and landscapes of human disturbances scientifically, the Pearson method was used to calculate product moment correlation coefficients between the element anomaly area ratio and the distance to landscapes of human disturbance (Pearson 1895). Correlation coefficients have a value between + 1 and − 1, where 1 is total positive linear correlation, − 1 is total negative linear correlation, and 0 is no linear correlation.

3 Results and discussion

3.1 Natural background analysis

The ratios of Na_2O, MgO, Al_2O_3, SiO_2, K_2O, CaO, and Fe_2O_3 anomalies in the different soil types, landform types, and geological times were calculated by spatial analysis (Table 1).

Most of the Al_2O_3, CaO, K_2O, MgO, SiO_2, and Fe_2O_3 anomalies were detected in the landforms of *Uplifting Folded Low Mountains* and *Eroded or Denuded Hills*, which cover more than 97% of this region; more than 74% of the anomalies were detected in *Yellow Soil* and *Paddy Soil*; and more than 76% were in the *Late Triassic–Early Jurassic*. Thus, *Uplifting Folded Low Mountains*, *Eroded or Denuded Hills*, *Yellow Soil*, *Paddy Soil*, and *Late Triassic–Early Jurassic* were considered natural backgrounds in further analysis of human disturbance factors. As more than 99% of Na_2O anomalies were in the *Eroded or Denuded Hills*, *Paddy* or *Purple Soils*, and *Middle Jurassic*, these were considered natural background in further analysis of human disturbances for Na_2O.

At the same time, the *Uplifting Folded Low Mountains*, *Yellow Soil*, and *Late Triassic–Early Jurassic* only occupy 8.76%, 7.69%, and 11.83% of the entire study area, respectively. This indicates that Al_2O_3, CaO, K_2O, MgO, SiO_2, and Fe_2O_3 might have been affected by certain natural or human factors. Whether or not the anomalies were caused by human interference requires further analysis.

3.2 Human disturbance analysis

Anomaly distribution data of Al_2O_3, CaO, K_2O, MgO, Na_2O, SiO_2, and Fe_2O_3 and buffer region spatial data were overlapped to calculate the ratios of anomalies falling in each buffer region; an example is shown in Fig. 3. Correlation coefficients between the anomaly area ratio distributions and the distance to human disturbance landscapes were calculated based on the Pearson method (Table 2).

3.2.1 City landscape

The Al_2O_3, CaO, K_2O, and MgO anomaly area distributions of cities continually fluctuated with distance for all landform, soil, and geological formation types, and the regularities were vague, indicating an infirm relationship. However, Al_2O_3 returned a high coefficient and a low P value for *Eroded or Denuded Hills* and *Paddy Soil*; CaO returned a high coefficient and a low P value for all four of these natural background factors; K_2O returend a high coefficient and a low P value for *Eroded or Denuded Hills, Paddy Soil*, and *Late Triassic–Early Jurassic*; MgO returned a high coefficient and a low P value for *Eroded or Denuded Hills* and *Late Triassic–Early Jurassic*. Collectively these results preclude confirmation of correlations between the city landscapes and Al_2O_3, CaO, K_2O, and MgO.

Similarly, the distributions of Na_2O, SiO_2, and Fe_2O_3 anomalies also continually fluctuated with distance from landform, soil, and geological formation types, and with vague regularities. However, correlation coefficients of Na_2O were all below 0.33 and P values all above 0.52, indicating a weak relationship and suggesting that Na_2O was not affected by city landscapes. Low correlation coefficients and high P values of SiO_2 and Fe_2O_3 also reflect a weak relationship and demonstrate that city landscape does not affect SiO_2 and Fe_2O_3. Previous work demonstrated that trace elements presented significantly higher concentrations in urban soils than in control soils, with the highest concentrations correlating with land use type; major elements did not show a similar phenomenon (Khalil et al. 2013).

3.2.2 Road landscape

Al_2O_3, MgO, Fe_2O_3, CaO, and SiO_2 anomalies constantly decreased with distance from roads across landform, soil, and geological formation types, which is consistent with the rule that effects of disturbance decrease further from roads. Moreover, both Al_2O_3 and Fe_2O_3 showed a high coefficient and a low P value for all the landform, soil, and geological formation types (Table 2); the correlation coefficients of MgO were all above 0.96 and their P values below 0.05 for all the natural backgrounds, indicating a strong relationship and demonstrating that Al_2O_3, MgO, and Fe_2O_3 were affected by roads. Similarly, the correlation coefficients of CaO and SiO_2 were all above 0.93 for

Table 1 The proportions of the anomaly area falling in different geographical backgrounds

Geographical background	Ratio of background	Al_2O_3	CaO	K_2O	MgO	Na_2O	SiO_2	Fe_2O_3
Landform								
Uplifting folded low mountains	8.76%	42.14%	64.43%	37.94%	58.18%	0.00%	35.34%	71.00%
Eroded or denuded hills	79.83%	55.45%	34.66%	59.22%	41.32%	99.09%	63.76%	28.91%
Eroded or denuded platforms	2.70%	0.00%	0.00%	0.12%	0.00%	0.91%	0.00%	0.00%
Eroded or denuded low mountains	3.76%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.10%
Other valley floors	4.95%	2.41%	0.91%	2.72%	0.49%	0.00%	0.90%	0.00%
Soil								
Yellow soil	7.69%	44.79%	65.32%	39.34%	65.07%	0.00%	41.96%	64.36%
Paddy soil	41.32%	31.63%	17.42%	35.14%	17.11%	61.95%	33.57%	19.25%
Purple soil	46.68%	11.92%	8.35%	13.71%	9.39%	38.05%	17.73%	2.63%
Lime soil	3.72%	10.65%	8.91%	11.81%	8.43%	0.00%	6.75%	13.76%
Alluvial soil	0.59%	1.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Geology								
Late Triassic–Early Jurassic	11.83%	76.96%	90.70%	84.61%	90.21%	0.00%	79.75%	80.77%
Late Jurassic	30.77%	1.05%	2.22%	0.35%	4.30%	0.00%	13.17%	0.19%
Middle Jurassic	54.24%	15.23%	2.94%	12.11%	1.52%	100.00%	4.05%	2.10%
Early Jurassic	0.05%	0.38%	0.37%	0.63%	0.29%	0.00%	0.71%	0.00%
Holocene	0.92%	0.14%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Middle Triassic	1.09%	2.14%	2.00%	1.26%	0.87%	0.00%	0.79%	13.96%
Early Triassic	0.55%	3.61%	1.77%	1.03%	2.82%	0.00%	1.53%	2.98%
Pleistocene	0.07%	0.07%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Quaternary system	0.48%	2.78%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Ratio of backgrounds is the ratio of the background area to the entire study area

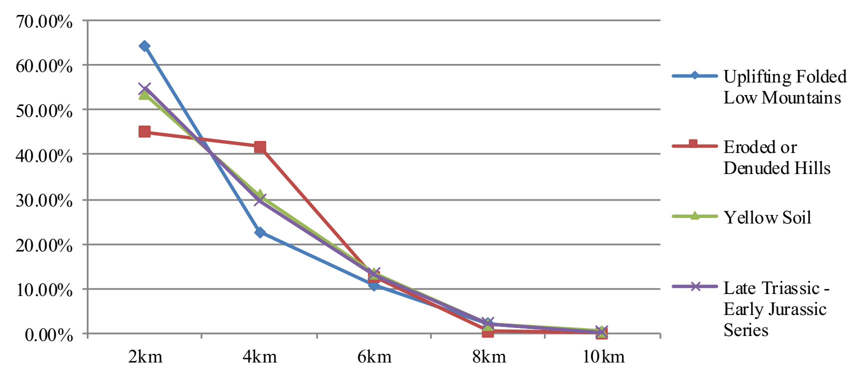

Fig. 3 Distributions of Fe_2O_3 anomalies at different distances to roads under main geographical backgrounds

all the natural backgrounds. The close relationship between Al, Ca, and Mg with roads is supported by previous work (Rybak 2015); these elements originate mainly from windblown road dust (Szczepaniak and Biziuk 2003) or are emitted by traffic (Zechmeister et al. 2006). Furthermore, it has been proven that Al and Fe often originate from the wear of metallic vehicle parts and from road dust resuspension in urban areas (Vuković et al. 2013). In addition, Ca and Fe are considered the most mobile elements and affected by a variety of natural and human factors (Gregorauskiene and Kadunas 2006).

The distribution of K_2O anomalies continually fluctuated with distance in *Yellow Soil*, indicating an infirm relationship. However, the correlation coefficients of K_2O were all above 0.89 and their P values below 0.05 for all the landform, soil, and geological formation types. Thus, correlations between the road landscape and K_2O were unable to be clearly confirmed.

Na_2O anomalies also continually fluctuated with increasing distance for all the landform, soil, and geological formation types and the regularities were vague, indicating another infirm relationship. Low correlation

Table 2 Pearson correlation coefficients between distance to human disturbance landscapes and area ratio distributions of the anomalies

Element	Geographical background	Distance to cities		Distance to roads		Distance to mines	
		Coefficient	*P* value	Coefficient	*P* value	Coefficient	*P* value
Al_2O_3	Uplifting folded low mountains	0.171	0.659	0.897	0.015	0.944	0.001
	Eroded or denuded hills	0.842	0.004	0.924	0.008	0.971	0.000
	Yellow soil	0.374	0.321	0.946	0.004	0.967	0.000
	Paddy soil	0.712	0.031	0.905	0.013	0.952	0.001
	Late Triassic–Early Jurassic	0.611	0.081	0.924	0.008	0.960	0.001
CaO	Uplifting folded low mountains	0.679	0.044	0.946	0.054	0.922	0.009
	Eroded or denuded hills	0.785	0.012	0.991	0.009	0.925	0.008
	Yellow soil	0.673	0.047	0.997	0.003	0.900	0.014
	Late Triassic–Early Jurassic	0.815	0.007	0.970	0.030	0.921	0.009
K_2O	Uplifting folded low mountains	0.526	0.145	0.973	0.005	0.986	0.002
	Eroded or denuded hills	0.860	0.003	0.923	0.025	0.975	0.005
	Yellow soil	0.667	0.050	0.929	0.022	0.992	0.001
	Paddy soil	0.808	0.008	0.898	0.039	0.941	0.017
	Late Triassic–Early Jurassic	0.777	0.014	0.953	0.012	0.962	0.009
MgO	Uplifting folded low mountains	0.594	0.092	0.960	0.040	0.951	0.004
	Eroded or denuded hills	0.714	0.031	0.981	0.019	0.949	0.004
	Yellow soil	0.644	0.061	0.998	0.002	0.944	0.005
	Late Triassic–Early Jurassic	0.785	0.012	0.975	0.025	0.953	0.003
Na_2O	Eroded or denuded hills	0.315	0.542	0.752	0.248	0.229	0.622
	Paddy soil	0.275	0.598	0.868	0.132	0.177	0.704
	Purple soil	0.328	0.525	-0.141	0.859	0.152	0.745
	Middle Jurassic	0.315	0.542	0.752	0.248	0.229	0.622
SiO_2	Uplifting folded low mountains	0.205	0.597	0.931	0.069	0.886	0.045
	Eroded or denuded hills	0.554	0.122	0.992	0.008	0.698	0.190
	Yellow soil	0.447	0.228	0.940	0.060	0.912	0.031
	Paddy soil	0.449	0.226	0.991	0.009	0.782	0.118
	Late Triassic–Early Jurassic	0.627	0.071	0.995	0.005	0.977	0.004
Fe_2O_3	Uplifting folded low mountains	0.510	0.161	0.899	0.038	0.991	0.001
	Eroded or denuded hills	0.590	0.095	0.943	0.016	0.979	0.004
	Yellow soil	0.496	0.175	0.957	0.011	0.898	0.039
	Late Triassic–Early Jurassic	0.524	0.147	0.953	0.012	0.962	0.009

coefficients or high *P* values of Na_2O were observed, indicating an infirm relationship and demonstrating that Na_2O was not affected by the road landscape.

3.2.3 Mine landscape

Al_2O_3 anomaly distributions constantly decreased with distance from mines across landform, soil, and geological formation types, which is consistent with the rule that disturbance decreases further from mines. In addition, correlation coefficients of Al_2O_3 were all above 0.94 and their *P* values below 0.01 for all the landform, soil, and geological formation types (Table 2), indicating a firm relationship and demonstrating that Al_2O_3 was influenced by mine landscapes. A strong correlation between Al and mine landscapes or mining activity has been established by several previous studies (Li and Thornton 2001; Santos et al. 2015; Valente et al. 2016).

The distributions of CaO anomalies continually fluctuated with distance in *Eroded or Denuded Hills* and *Yellow Soil*; K_2O anomalies continually fluctuated with distance in Paddy Soil; MgO anomalies continually fluctuated with distance in *Eroded or Denuded Hills*, Fe_2O_3 anomalies continually fluctuated with distance in *Yellow Soil* and *Late Triassic–Early Jurassic*, all indicating infirm relationships. The correlation coefficients of CaO, K_2O, and Fe_2O_3 were all above 0.89 and their *P* values below 0.05 for all the landform, soil, and geological formation types. The

Table 3 Relationships of the different landscapes and major element distributions in soil

Landscape	Al_2O_3	CaO	K_2O	MgO	Na_2O	SiO_2	Fe_2O_3
City	Uncertain	Uncertain	Uncertain	Uncertain	Unrelated	Unrelated	Unrelated
Road	Close	Close	Uncertain	Close	Unrelated	Close	Close
Mine	Close	Uncertain	Uncertain	Uncertain	Unrelated	Uncertain	Uncertain

correlation coefficients of MgO were all above 0.94 and their *P* values below 0.01 for all the landform, soil, and geological formation types. Duly, correlations between the mine landscapes and CaO, K_2O, Fe_2O_3, and MgO were unable to be clearly confirmed.

The distribution of Na_2O anomalies continually fluctuated with distance across landform, soil, and geological formation types, and the regularities were vague, indicating another infirm relationship. The correlation coefficients of Na_2O were all below 0.23 and the *P* values all above 0.62, demonstrating that Na_2O was not disturbed by the mine landscape.

The spatial distribution of SiO_2 anomalies continually fluctuated with distance in *Uplifting Folded Low Mountains*, *Eroded or Denuded Hills*, *Yellow Soil*, and *Paddy Soil*—an infirm relationship. SiO_2 returned a high coefficient and a low *P* value in *Uplifting Folded Low Mountains*, *Yellow Soil* and *Late Triassic–Early Jurassic* but a high *P* value in *Eroded or Denuded Hills* and *Paddy Soil*. Thus, correlations between the mine landscape and SiO_2 were unable to be clearly confirmed.

A table showing the relationships of the different landscapes and major element distributions in soil is shown in Table 3.

4 Conclusions

Element anomalies are primarily produced by geographical influences or disturbances involving human activities. On the premise of the natural background analysis, the correlations between Na_2O, MgO, Al_2O_3, SiO_2, K_2O, CaO, and Fe_2O_3 anomalies and human disturbance landscapes, i.e., cities, roads, and mines, were explored to show that major elements are influenced by different landscapes in diverse ways. Al_2O_3 had a strong correlation with road and mine landscapes; MgO, Fe_2O_3, CaO, and SiO_2 had a strong correlation with road landscapes that affected these elements significantly; Na_2O, SiO_2, and Fe_2O_3 had a weak relationship with city landscapes; Na_2O had a weak relationship with road and mine landscapes.

This study proves that a response mechanism exploration of major element migration and human disturbance landscape using geospatial theories and methods is practical. However, correlations between Al_2O_3, CaO, K_2O, and MgO and city landscapes; correlations between K_2O and road landscapes; and correlations between CaO, K_2O, MgO, SiO_2, and Fe_2O_3 and mine landscapes could not be determined through the present methods, and will require further work.

Acknowledgements This study was supported by the Youth Science Foundation (Grant Nos. 41101174 and 41301094), the Lead Strategic Project of the Chinese Academy of Sciences (Grant No. XDB03030507), the Hundred Young Talents Program of the Institute of Mountain Hazards and Environment (Grant No. SDSQB-2015-02) and the Open Fund for Key Laboratory of Geoscience Spatial Information Technology of Ministry of Land and Resources (Grant No. KLGSIT2016-01). We felt grateful to Southeast Sichuan Geological Team for offering us the experimental data.

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