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Background concentrations of elements in surface soils and their changes as affected by agriculture use in the desert-oasis ecotone in the middle of Heihe River Basin, North-west China

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Abstract

The concentrations of twenty four chemical elements in the surface layer of natural desert soils and the cultivated farmland soils were measured at a desert-oasis ecotone in the middle of Heihe river basin, north-west China. Background values were estimated for (a) major elements (Si 335.3 g kg^{-1}, Al 49.4 g kg^{-1}, Fe 19.1 g kg^{-1}, Ca 29.4 g kg^{-1}, Mg 8.9 g kg^{-1}, K 20.1 g kg^{-1}, Na 17.5 g kg^{-1} and P 0.338 g kg^{-1}), (b) heavy metals and non-metals (Cr 55.8 mg kg^{-1}, Mn 404.8 mg kg^{-1}, Ni 17.7 mg kg^{-1}, Cu 5.1 mg kg^{-1}, Zn 33.7 mg kg^{-1}, Pb 15.5 mg kg^{-1} and As 5.2 mg kg^{-1}) and (c) other trace elements (Ti 2.0 mg kg^{-1}, V 55.3 mg kg^{-1}, Co 5.7 mg kg^{-1}, Rb 82.4 mg kg^{-1}, Sr 232.9 mg kg^{-1}, Y 14.7 mg kg^{-1}, Zr 194.9 mg kg^{-1}, Nb 7.8 mg kg^{-1} and Ba 720.6 mg kg^{-1}). After natural desert soil was cultivated for agricultural use, significant changes in element concentrations occurred under tillage, irrigation and fertilisation management. Compared to natural soil, the for the levels of Si, K, Na, Sr, Zr and Ba decreased, and no changes were observed for Rb, while the values of the other 17 elements increase in agricultural soil from 1.2 to 3.5 times. However, their absolute concentrations are still low, suggesting that the arable soil in this region remains comparatively a clean soil. The increased silt, clay and organic carbon content, under long-term irrigation, enriched the fine-grained materials, and application of fertilisers and manure contributed to the accumulation of most elements in arable soil. The accumulation of elements in agricultural soil increased with increasing cultivation years and extent of soil development.

Keywords: Background concentrations; Desert soil; Land cultivation; Agricultural use; Desert-oasis ecotone

1. Introduction

Background concentrations of elements in soil may reflect basic information and interrelationships within a given period and spatial scale (Chen, 2005). As a reference level for estimating the degree and extent of soil contamination, the estimation of background values is crucial for establishing soil environmental quality standards, assessing the impacts of agricultural use of solid wastes, and the long-term application of fertilisers and pesticides on soil environmental quality, as well as guiding soil micro-nutrients application (Chen et al., 2004).

Background concentrations of elements in soil are highly dependent on the mineralogical composition of the parent material and on the weathering processes that have led to its formation (Tack et al., 1997; De Temmerman et al., 2003), but also on soil particle size, clay and organic matter content (Salminen and Tarvainen, 1997; Tack et al., 1997, Tume et al., 2006). Consequently, the natural concentration of elements in soil varies widely, making it inappropriate to use universal background levels for assessing the extent and risks of trace metal contamination in a specific soil type (Horckmans et al., 2005). Therefore, although natural background concentrations in soil have been investigated in many countries and have laid the foundations for understanding natural element variation and in assessing soil contamination, such as Poland (Anderson et al., 1994) and many countries in Europe (Salminen et al., 2005; De Vos et al., 2006), the USA (Holmgren et al., 1993; Bradford et al., 1996; Ma et al., 1997) and China (Chen et al., 1991), it is still necessary to estimate local background concentrations and

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spatial distribution characteristics of elements in soil, and the factors affecting their evolution in a specific area, since local element concentrations in a specific soil type may exceed or be lower than listed ranges.

Anthropogenic activities, such as agricultural practices, can strongly influence element concentrations in soil (De Temmerman et al., 2003; Ikem et al., in press). Mineral fertilisers, primarily phosphate fertilisers, and animal manure, can increase the levels of certain elements in soil. Moreover, addition of sewage sludge and some types of compost may cause the enrichment of heavy metals in soil (De Temmerman et al., 2003). The impact of agricultural activities on the accumulation of elements, especially heavy metals in arable soil is of great concern, because of the potential transfer of heavy metals through crops to animals and humans.

The oasis in the middle of Hexi Corridor region, located in Gansu province, north-west China, is an important area for grain production. In recent years, this region has become one of the main planting areas of wine-making grape, ketchup-making tomato, and vegetables, due to its typical desert climatic conditions. Application of large amounts of chemical fertilisers and pesticides contributed to the high yields of these crops. However, little information is available about soil environmental quality in this region. On the other hand, it is one of the main sandy desertification areas induced by wind action and one of the source regions of sandstorms in North China (Research Group of Study on Combating Desertification/Land degradation in China, 1998). A better understanding of the concentration and distribution of elements in soil may provide a reference for determining the source region of sandstorms. The objective of the present study is to estimate the background concentration levels in the surface layer of desert soil and to examine the changes of elements in soil, following land cultivation and, subsequently, agricultural use, and finally to discuss the influence of agricultural practices on the soil environment.

2. Materials and methods

2.1. Study area description

The study area, covering the marginal oasis and adjacent desert area of Gaotai and Linze counties in the middle of Hexi Corridor region of Gansu province, is located between 39°18′–39°25′N and 99°34′–100°37′E, with an altitude ranging from 1330–1420 m. The area is classified as a typical temperate desert and a desert-oasis ecosystem (Fig. 1). The landscape consists of the relatively flat Gobi desert, covered by gravels and the undulate denudation terrain of sand dunes. The vegetative cover is 5%–15% in the Gobi desert, and the main plant species consists of some sub-shrubs, including *Nitraria sphaerocarpa* (Maxim.) and *Reaumria soongorica* (Pall. Maxim.), and a few annual desert species, such as *Suaeda glauca* (Bge.) and (*Sillium mongolicum* Rgl.). There is *Nitraria sibirca* and *Phragmites communis* (Trin.) population, distributed in the inter-dune lowland of the residual desert. The marginal oasis belongs to young oasis, which is exploited in recent decades. This region has a typical temperate desert climate: dry and hot in summer, cold in winter, ample sunshine, very little precipitation, strong winds, and frequent drifting sands. The annual mean air temperature is about is 7.6 °C, with an absolute maximum and minimum of 39.1 °C, and −27 °C respectively. The normal annual precipitation is 117 mm. Mean annual pan-evaporation is around 2390 mm, twenty times greater than the annual precipitation. The frost-free season lasts

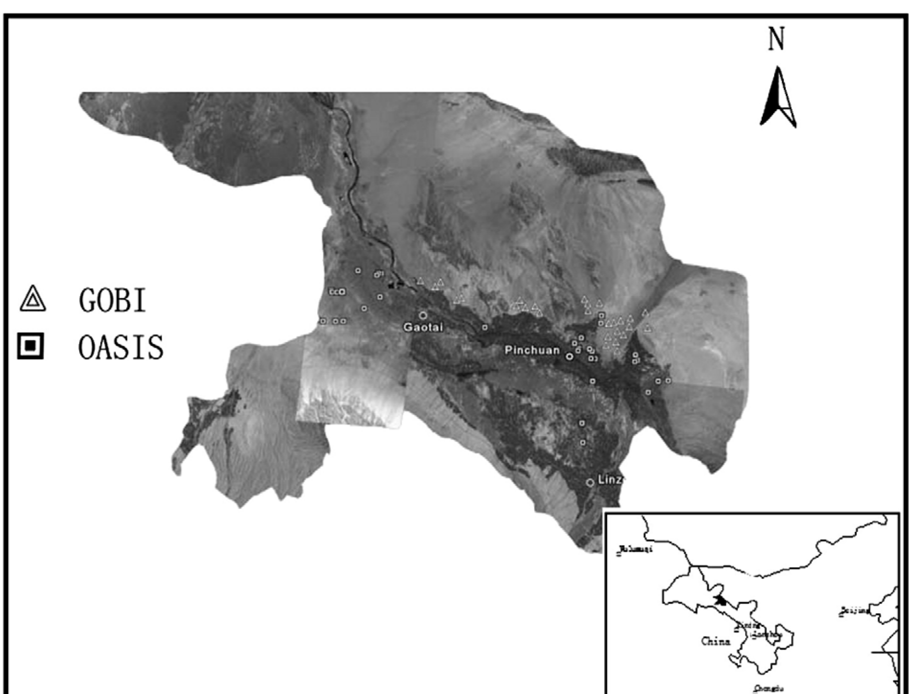

Fig. 1. Study location map and soil sample sites.

165 days on average. Accumulated temperature of ≥10 °C is about 3088 °C. Mean annual wind velocity is 3.2 m s^{-1}. Gales with velocity of >17 m s^{-1}, occur 15 or more days per year (Su et al., 2007a). The zonal soil at the marginal part of the oasis is Calci-Orthic Aridosols, derived from diluvial–alluvial materials according to Chinese Soil Taxonomy. Due to long-term encroachment of drift sand from Badanjilin Desert and deposition of aeolian sand, Ari-Sandic Primosols developed in some areas. After the original Ari-Sandic Primosols and Calci-Orthic Aridosols were cultivated for a short period, their surface horizon still shows typical characteristics of desert soil. But, under a long-term application of sediment-rich irrigation water, fertilisation and cultivation they develop into Siltigi–Orthic Anthrosols. A small part, along the bank of Heihe River with shallow groundwater depth is covered by Ustic Cambosols, which has a high salt content and is susceptible to salinisation. Soil on newly reclaimed land at the marginal part of the oasis has very low organic matter content and loose sandy structure (Su et al., 2007b). Soil erosion by wind is very serious, especially in spring, and is one of the source regions of sandstorms in north China. The staple crops of this area are maize and spring wheat, but the planting of ketchup-making tomato and seeded corn is gradually increasing in recent years.

2.2. Soil sampling

In late September of 2005 two groups of samples surface soil samples (0–10 cm) were collected from the Gobi desert (Fig. 1). The first group of 37 surface soil samples were taken randomly by a hand auger. Each sampling site was away from the edge of the oasis by at least 1000 m, where the soil is less disturbed or minimally affected by human activities. The second group of 49 soil samples were collected from the farmlands with a different land cultivation history along Gaotai and Linze marginal oasis near the desert. Also, the agricultural soil samples were taken by hand auger. Both the desert and farmland soil samples are composites taken from 5 sites within a 20 m×20 m area. Soil samples were placed in cleaned plastic bags and transported to the laboratory.

2.3. Sample preparation and total element determination

Samples were air-dried, and crushed using a rubber hammer to pass a 2-mm nylon sieve. 10 g of sieved soil samples (<2 mm) was fractioned by natrium hexametaphosphate and ultrasonic dispersion in water and the particle-size distribution and specific surface area were measured using a Malvern Laser Particle Instrument. Soil pH and electrical conductivity (EC) were measured in a soil–water suspension (1:1 and 1:5 soil–water ratio, respectively). Part of the <2 mm fraction was further ground to pass a 0.1 mm sieve for chemical analysis. Soil organic carbon (SOC) was determined by dichromate oxidation of Walkley–Black; total nitrogen (total N) was measured by a micro-Kjeldhal procedure and total phosphorous by UV-2450 spectrophotometer after H_2SO_4–$HClO_4$ digestion (Institute of Soil Sciences, 1978).

For the determination of element concentrations, soil samples were ground in an agate mortar and passed through a 0.10 mm sieve, then powder pellets were made and the analysis was carried out using the X-ray fluorescence spectrometry.

2.4. Statistical methods

All statistical analyses were performed using SPSS 11.5. Descriptive statistics (minimum, maximum, median, arithmetic mean, geometric mean, and coefficient of variation, CV) were calculated. Analysis of variance was used to assess significant differences of element concentrations among soil samples from different cultivation periods. Simple linear correlation analysis was used to relate element concentrations to soil properties and among elements themselves.

3. Results

3.1. Soil properties

The selected physical and chemical properties of the soil samples are summarised in Table 1. The natural desert soil samples showed high sand content with an average of 78.5% in

Table 1
Characteristics of some selected soil properties

Land use	Arable soil				Desert soil
Soil type	Ustic Cambosols	Siltigi–Orthic Anthrosols	Tilled Calci-Orthic Aridosols	Tilled Calci-Orthic Aridosols	Calci-Orthic Aridosols
Sample number	4	7	20	18	37
Cultivation history, (yr)	>50	>50	20~30	5~13	0
Sand 2–0.05 mm (%)	16.3±2.6 e	39.8±8.4 d	50.2±6.1 c	64.4±8.7 b	78.5±3.9 a
Coarse silt 0.05–0.02 mm (%)	18.6±1.0 a	15.0±4.7 ab	16.1±3.8 a	10.4±3.4 c	7.2±3.4 cd
Fine silt 0.02–0.002 mm (%)	47.4±1.6 a	33.1±3.7 b	22.7±4.7 c	17.9±4.6 cd	10.6±3.6 e
Clay<0.002 mm (%)	17.6±3.5 a	12.1±2.1 b	11.0±1.6 b	7.3±5 c	4.7±0.5 d
Organic carbon (g kg^{-1})	10.51±0.42 a	8.18±1.33 b	5.05±2.20 c	4.25±1.61 c	0.79±0.31 d
Total nitrogen (g kg^{-1})	1.37±0.18 a	0.83±0.11 b	0.62±0.16 c	0.55±0.15 c	0.17±0.04 d
Electrical conductivity (EC)	205.8±40.8 a	130.0±60.3 b	136.0±76.1 b	92.0±63.5 c	146.2±65.6 b
pH (H_2O)	8.90±0.15 a	8.61±0.10 a	8.60±0.26 a	8.66±0.27 a	8.91±0.22 a
Total salt (g kg^{-1})	1.20±0.19 a	0.89±0.28 b	0.84±0.40 b	0.62±0.09 c	0.59±0.32 c

Data in each line are subject to variance analysis and the same letter in each line indicates no significance at 0.05 level.

Table 2
Statistical characteristics of element concentrations of natural desert soils, $n=37$

Element	Unit	Min.	Max.	Median	AM [a]	C.V.%	GM [b]	BCEC [c]
Si	g kg^{-1}	318.0	353.4	334.2	335.5	2.8	335.3	
Al	g kg^{-1}	46.2	51.2	49.7	49.4	2.9	49.4	66.2
Fe	g kg^{-1}	14.9	23.6	19.6	19.3	11.0	19.1	29.4
Ca	g kg^{-1}	22.2	39.1	30.5	29.8	11.5	29.4	15.4
Mg	g kg^{-1}	5.0	13.4	9.7	9.2	18.7	8.9	7.8
K	g kg^{-1}	18.0	22.3	19.8	20.0	4.9	20.1	18.6
Na	g kg^{-1}	16.0	19.7	17.6	17.5	5.1	17.5	10.2
Ti	mg kg^{-1}	1.1	2.8	2.0	2.0	17.9	2.0	3.8
P	mg kg^{-1}	275.3	441.7	334.8	341.8	11.3	338.4	
V	mg kg^{-1}	38.6	86.6	27.0	56.7	15.2	55.3	82.4
Cr	mg kg^{-1}	27.1	87.6	55.9	58.0	17.9	55.8	61.0
Mn	mg kg^{-1}	300.7	520.7	412.2	409.8	12.4	404.8	583.0
Co	mg kg^{-1}	2.1	11.0	6.2	6.3	23.6	5.7	12.7
Ni	mg kg^{-1}	9.4	26.3	19.5	18.3	18.6	17.7	26.9
Cu	mg kg^{-1}	1.0	10.2	6.6	6.1	28.4	5.1	22.6
Zn	mg kg^{-1}	22.5	46.3	34.5	34.3	14.5	33.7	74.2
Pb	mg kg^{-1}	10.6	19.9	16.1	15.7	12.1	15.5	26.0
As	mg kg^{-1}	1.4	9.1	5.5	5.6	20.9	5.2	11.2
Rb	mg kg^{-1}	75.0	88.2	82.5	82.4	3.5	82.4	111.0
Sr	mg kg^{-1}	219.9	254.7	231.4	233.0	3.8	232.9	167.0
Y	mg kg^{-1}	9.7	18.2	15.6	14.9	12.6	14.7	22.9
Zr	mg kg^{-1}	107.3	295.2	193.2	200.7	16.6	194.9	256.0
Nb	mg kg^{-1}	5.9	10.0	8.2	7.9	13.0	7.8	
Ba	mg kg^{-1}	602.3	874.0	720.8	423.7	7.9	720.6	469.0

[a] Arithmetic mean.
[b] Geometric mean.
[c] Background concentration of elements in soils of China.

the 0–10 cm surface layer, due to long-term wind erosion and aeolian sand accumulation. After desert soil is cultivated, the sand content decreases with increasing period of cultivation, because of the long-term irrigation with sediment-rich river water, and fertilisation. However, the soil particle composition was still dominant in the fine sand fraction of the Tilled Calci-Orthic Aridosols with cultivation history of less than 30 years. Under the long-term agricultural use, the fine sand content in the surface layer significantly decreased, and the Tilled Calci-Orthic Aridosols developed towards the Siltigi–Orthic Anthrosols. Whereas, the dominant fraction was fine silt for Ustic Cambosols, which occurs along the bank of Heihe River and developed from sediment materials with a long-term history of agricultural use. All soil samples were low in clay, ranging from 4.7% to 17.6%.

The average soil organic carbon and total nitrogen concentration in the 10–20 cm layer of natural desert soil is 0.79 g kg^{-1} and 0.17 g kg^{-1} respectively. The cultivation of desert soil and its subsequent agricultural use, caused a significant increase of organic carbon and total nitrogen concentrations with increasing number of cultivation years.

The pH value in all soil samples was over 8.5. The Ustic Cambosols have the highest EC value and total salt content. But, the EC value is higher in desert soil than the cultivated Calci-Orthic Aridosols and Siltigi–Orthic Anthrosols.

3.2. Background concentrations of elements in soil

In the present study, background concentrations were determined by analysing desert soil samples, which were unaffected, or at least minimally affected, by human activities. The descriptive statistics for 37 desert soil samples are tabulated in Table 2. The median is very close to the arithmetic and geometric mean for all 24 elements, indicating a similar statistical distribution pattern for different elements in desert soil samples. The CV value is 20.9%–28.4% for Cu, Co and As, and is less than 5% for Si, Al, K, Sr and Rb; for the remaining 18 elements the CV varies from 10% to 20%. The relatively small variability and the narrow range between minimum and maximum values for all elements show that the statistical dispersion of element concentrations is narrow. This suggests that the different desert soil types are derived from a single and uniform parent material.

Many studies adopt the geometric mean as the background value elements in soil (Chen et al., 2004; Bech et al., 2005;Tume et al., 2006), because it is assumed to reflect well the concentration trend of element distribution (Chen et al., 2004; Tume et al., 2006). The estimated background values of 24 elements are as follows: (a) major elements (Si 335.3 g kg^{-1}, Al 49.4 g kg^{-1}, Fe 19.1 g kg^{-1}, Ca 29.4 g kg^{-1}, Mg 8.9 g kg^{-1}, K 20.1 g kg^{-1}, Na 17.5 g kg^{-1} and P 0.338 g kg^{-1}); (b) heavy metals and non-metals (Cr 55.8 mg kg^{-1}, Mn 404.8 mg kg^{-1}, Ni 17.7 mg kg^{-1}, Cu 5.1 mg kg^{-1}, Zn 33.7 mg kg^{-1}, Pb 15.5 mg kg^{-1} and As 5.2 mg kg^{-1}), and (c) other trace elements (Ti 2.0 mg kg^{-1}, V 55.3 mg kg^{-1}, Co 5.7 mg kg^{-1}, Rb 82.4 mg kg^{-1}, Sr 232.9 mg kg^{-1}, Y 14.7 mg kg^{-1}, Zr 194.9 mg kg^{-1}, Nb 7.8 mg kg^{-1} and Ba 720.6 mg kg^{-1}).

Potassium, Na, Ca, Mg, Ba, and Sr have higher geometric mean values than national averages, and other elements have values less than the national averages (Chen et al., 1991).

Table 3
Statistical characteristics of element concentrations of agricultural soils converted from desert soils, $n=49$

Element	Unit	Min.	Max.	Median	Arithmetic mean	Geometric mean	C.V. %
Si	g kg^{-1}	241.3	335.3	306.4	301.5	300.3	8.51
Al	g kg^{-1}	44.5	82.2	57.5	58.2	57.8	13.84
Fe	g kg^{-1}	18.9	42.6	26.8	27.8	27.3	17.70
Ca	g kg^{-1}	24.1	60.3	34.0	36.6	35.3	26.62
Mg	g kg^{-1}	9.1	51.7	15.3	17.0	26.8	39.28
K	g kg^{-1}	14.6	25.2	17.4	17.8	17.7	11.85
Na	g kg^{-1}	9.9	17.1	13.3	12.8	12.8	12.30
Ti	mg kg^{-1}	2.0	4.4	2.9	3.0	2.9	17.57
P	mg kg^{-1}	323.8	986.6	601.6	611.4	598.2	23.59
V	mg kg^{-1}	48.8	109.2	74.5	74.2	73	18.86
Cr	mg kg^{-1}	52.4	112.4	83.7	82.9	81.2	15.12
Mn	mg kg^{-1}	378.3	772.1	530.7	539.0	531.9	15.70
Co	mg kg^{-1}	3.3	17.8	10.7	10.5	9.8	32.63
Ni	mg kg^{-1}	22.9	47.4	31.9	32.8	32.2	17.69
Cu	mg kg^{-1}	7.7	36.9	17.7	18.8	17.9	33.02
Zn	mg kg^{-1}	34.2	85.2	53.5	54.8	53.6	21.82
Pb	mg kg^{-1}	13.0	32.9	17.5	18.7	18.3	20.68
As	mg kg^{-1}	3.7	18.7	10.2	10.1	9.7	26.84
Rb	mg kg^{-1}	67.6	130.7	79.9	83.4	82.8	14.31
Sr	mg kg^{-1}	137.3	456.7	190.4	205.5	199.5	29.39
Y	mg kg^{-1}	12.3	23.6	18.1	18.3	18.1	13.99
Zr	mg kg^{-1}	17.3	219.4	159.8	161.8	154.7	18.63
Nb	mg kg^{-1}	7.4	13.4	10.2	10.3	10.2	13.55
Ba	mg kg^{-1}	437.0	587.7	515.4	511.6	511.4	6.73

3.3. Changes and characteristics of elements following cultivation of desert soil

The descriptive statistics for 24 elements in arable soil converted from desert soil are tabulated in Table 3. Apart from the changes in soil particle composition and organic carbon content, significant changes in the concentrations of chemical elements occurred, following the cultivation of desert soil. In comparison with the uncultivated desert soil, except for Rb, the mean concentration of Si, K, Na, Sr, Zr and Ba show a variable decrease in arable soil, whereas, the mean concentrations of the other 17 elements have an obvious increase. The increase ranges from 3–3.5 fold (Cu and Mg) to 1.2 (Al, Ca and Pb). Although the mean concentrations of Cr, Zn, Co, Ni, and As increased by 46%–87% following cultivation, they are still at a low level, compared with their respective national background values (Chen et al., 1991). The CV and range of element concentrations increased in arable soil in comparison to desert soil, due to the differences of land use history and management. The median, arithmetic and geometric means are very close to each other, suggesting that it is derived from the same parent material with an overall similar chemical composition (Table 2).

3.4. Differences in element concentrations in different soil types

Element concentrations vary greatly in different soil types, depending on their cultivation history (Table 4). The Ustic Cambosols, which occur in the lower area at the bank of Heihe River, and are developed from sediments with a long-term history of agricultural use, show the highest element concentrations, except for Si, K, Na, Zr, and Ba. Whereas the surface horizon of Calci-Orthic Aridosols, with a relatively short-term period of agricultural use, still shows typical characteristics of desert soil. But, desert soil developed into Siltigi–Orthic Anthrosols, following a long-term application of sediment-rich irrigation water, fertilisation and cultivation, has notable differences in element levels. Apart from Si, K, Na, Zr, and Ba, the concentration of major elements (Ca, Mg and P), and trace elements (Cr, Zn, Co, Ni, Cu, Mn and As) are significantly increased with increasing cultivation years. Within a short cultivation period (5–13 years), the concentrations of 13 elements (Fe, Ca, Mg, K, Ti, Cu, Zn, As, Sr, Zr, and Ba) had significant changes relative to desert soil. Following the cultivation for 20–30 years, significant changes occurred in the concentrations of most elements, except for K, Cr and Y, as compared to desert soil. However, significant differences were observed in the concentration of only 5 elements (Ti, P, Mg, Rb and Sr) between Siltigi–Orthic Anthrosols and Tilled Calci-Orthic Aridosols with 20–30 cultivated years. This indicated that significant changes in most elements occurred within the 30 years of cultivation period, and the extent of increase or decrease of most element concentrations reduced following the cultivation of 30 years.

Table 4
Comparison of element concentrations among soils with different cultivation years

Land use	Arable soil				Desert soil
Soil type	Ustic Cambosols	Siltigi–Orthic Anthrosols	Tilled Calci-Orthic Aridosols	Tilled Calci-Orthic Aridosols	Calci-Orthic Aridosols
Sampling number	4	7	20	18	37
Cultivated year (a)	>50	>50	20~30	5~13	0
Si g kg^{-1}	252.5±5.1 c	296.4±21.6 b	293.5±20.3 b	323.2±9.0 a	335.3±9.8 a
Al g kg^{-1}	67.8±0.6 a	57.9±6.3 bc	61.5±8.9 ab	52.6±3.6c	49.4±1.5 c
Fe g kg^{-1}	36.6±0.7 a	27.6±2.4 b	29.5±4.6b	23.97±2.4 c	19.3±2.6 d
Ca g kg^{-1}	57.7±2.6 a	38.3±10.7 bc	38.6±5.6 b	28.9±4.4 d	29.8±4.5 c
Mg g kg^{-1}	25.4±0.9 a	22.9±13.0 a	17.1±3.4 c	12.8±1.9 d	9.2±2.5 d
K g kg^{-1}	19.9±0.2 a	17.3±1.6 bc	18.5±2.6 ab	16.8±1.2 c	20.1±1.1a
Na g kg^{-1}	11.5±0.2 c	13.1±1.8 bc	12.3±1.1 c	13.6±1.7 b	17.5±1.0 a
Ti g kg^{-1}	3.8±0.1 a	2.9±0.3 c	3.2±0.5 b	2.5±0.3 d	2.0±0.5 d
P mg kg^{-1}	842.1±175.4 a	733.9±142.6 a	608.3±95.0 b	516.0±110.1 c	341.8±50.1d
V mg kg^{-1}	95.6±11.3 a	76.5±11.5 b	77.1±12.5 b	65.3±10.2 c	56.7±13.2 c
Cr mg kg^{-1}	100.6±7.6 a	88.0±3.8 ab	81.6±11.7 b c	78.4±12.9 c	58.0±15.7 c
Mn mg kg^{-1}	687.0±18.9 a	551.3±45.8 b	570.6±69.2 b	466.4±45.9 c	409.8±64.6 c
Co mg kg^{-1}	15.7±1.8 a	11.8±3.1 b	10.9±2.6 b	8.5±3.2 c	6.3±2.6 c
Ni mg kg^{-1}	45.9±1.3 a	34.5±4.6 b	33.0±3.6 b	29.1±4.0 c	18.3±4.9 c
Cu mg kg^{-1}	31.3±1.4 a	20.5±2.2 b	20.2±5.4 b	13.9±2.9 c	6.1±2.9 d
Zn mg kg^{-1}	72.5±2.3 a	60.7±7.6 b	58.6±10.7 b	44.4±6.1 c	34.3±6.7 d
Pb mg kg^{-1}	23.9±2.4 a	17.8±4.0 bc	19.4±4.5 b	17.2±1.8 c	15.7±2.4 c
As mg kg^{-1}	12.3±2.1 a	10.7±1.0 b	10.8±2.6 b	8.5±2.7 c	5.6±1.9 d
Rb mg kg^{-1}	95.0±1.1 a	80.9±9.1 b	88.2±14.5 a	76.5±5.0 b	82.4±3.1 b
Sr mg kg^{-1}	304.4±29.3 a	269.6±99.5 a	183.5±26.1 c	183.0±28.2 c	233.0±9.8 b
Y mg kg^{-1}	22.4±1.7 a	17.8±1.3 bc	19.4±2.0 b	16.3±1.8 bc	34.9±2.3 bc
Zr mg kg^{-1}	159.5±3.0 b	154.4±11.5 b	169.4±24.9 b	156.9±41.3 b	200.7±49.0 a
Nb mg kg^{-1}	12.2±0.4 a	10.2±0.6 b	10.7±1.6 b	9.5±0.9 bc	7.93±1.3 c
Ba mg kg^{-1}	513.1±19.7 bc	521.7±53.5 bc	495.3±29.8 c	525.6±26.8 b	723.7±69.3 a

Data in each line are subject to variance analysis and the same letter in each line indicates no significance at 0.05 level.

Table 5
Correlations between element concentrations and soil properties

	Silt	Clay	Particle specific area	SOC	Total salt	pH
Si	−0.767**	−0.796**	−0.798**	−0.606**	−0.369**	−0.037
Al	0.503**	0.614**	0.574**	0.548**	0.073	0.112
Fe	0.657**	0.722**	0.709**	0.576**	0.275	0.117
Ca	0.843**	0.763**	0.814**	0.448**	0.599**	−0.038
Mg	0.638**	0.624**	0.648**	0.502**	0.388**	−0.076
K	0.284*	0.442**	0.378**	0.446**	−0.104	0.149
Na	−0.641**	−0.355*	−0.499**	−0.054	−0.590**	0.168
Ti	0.746**	0.687**	0.717**	0.465**	0.345*	0.039
P	0.721**	0.622**	0.672**	0.651**	0.336*	−0.216
V	0.530**	0.590**	0.551**	0.541**	0.283*	0.054
Cr	0.313*	0.429**	0.409**	0.411**	0.233	0.082
Mn	0.740**	0.750**	0.762**	0.565**	0.270	0.046
Co	0.500**	0.632**	0.598**	0.579**	0.184	−0.056
Ni	0.630**	0.689**	0.677**	0579**	0.327*	0.135
Cu	0.752**	0.795**	0.790**	0.594**	0.317*	0.138
Zn	0.698**	0.729**	0.748**	0.611**	0.276	0.088
Pb	0.196	0.337*	0.290*	0.478**	0.370	0.103
As	0.562**	0.531**	0.565**	0.331*	0.233	−0.034
Rb	0.343*	0.482**	0.432**	0.452**	−0.029	0.154
Sr	0.450**	0.583**	0.548**	0.608**	0.234	0.005
Y	0.676**	0.621**	0.644**	0.399**	0.427**	−0.045
Zr	−0.002	−0.118	−0.069	−0.189	0.066	−0.102
Nb	0.557**	0.510**	0.536**	0.539**	0.152	−0.144
Ba	−0.355**	−0.198	−0.289*	0.105	−0.362**	0.108

*Correlation is significant at the 0.05 level.
**Correlation is significant at the 0.01 level.

3.5. Correlation analysis for concentrations of element in soils

3.5.1. Correlation between element concentrations and soil properties

Element concentrations in soil were strongly affected by soil texture and fertility. The linear correlation coefficients (Table 5) show that most elements are positively correlated with clay, silt, organic carbon and particle specific area, except for Si, Na, Pb, Zr and Ba. This indicates that the increased organic carbon and fine particle-size materials in soil, following cultivation and agricultural use, contributed mostly to the accumulation of most elements. There was no significant correlation between element concentrations and pH. Total salt content is significant positively correlated with Ca, Mg, Y, Ti, P, V, Ni and Cu, while it is negatively correlated with Si, Na and Ba.

3.5.2. Correlation between major and trace elements

The eight trace elements Cr, Mn, Co, Ni, Cu, Zn, Pb and As display negative correlations with Si (Table 6), but they have a significant positive correlation with Al and Fe. There are no significant correlations between Pb and P, Ca and Mg, and between K and Cr. While, Na shows significant negative correlations with Mn, Cu and As. Iron and Al show strong positive correlations with most trace elements.

4. Discussion

Background concentrations of elements in soil are highly dependent on the mineralogical composition of the parent material and on the weathering processes that have led to its formation (Buckman and Brady, 1970; Chen et al., 1991;

Table 6
Correlations between the concentrations of several trace metal elements and selected major elements

	Si	P	Al	Fe	Ca	Mg	K	Na
Cr	−0.381**	0.367**	0.235	0.448**	0.399**	0.363**	−0.037	−0.087
Mn	−0.928**	0.643**	0.878**	0.962**	0.726**	0.608**	0.653**	−0.305*
Co	−0.689**	0.510**	0.645**	0.689**	0.538**	0.465**	0.462**	−0.087
Ni	−0.675**	0.551**	0.541**	0.721**	0.619**	0.465**	0.318*	−0.246
Cu	−0.922**	0.643**	0.802**	0.934**	0.778**	0.687**	0.557**	−0.348*
Zn	−0.890**	0.655**	0.861**	0.922**	0.667**	0.606**	0.656**	−0.288*
Pb	−0.484**	0.240	0.654**	0.542**	0.196	0.138	0.722**	0.151
As	−0.686**	0.366**	0.616**	0.685**	0.565**	0.512**	0.471**	−0.415**

*Correlation is significant at the 0.05 level.
**Correlation is significant at the 0.01 level.

Alloway, 1997; Tack et al., 1997; Kabata-Pendias and Pendias, 2001; De Temmerman et al., 2003). The more developed a soil, the less may be the influence of parent materials on element contents (Zhang et al., 2002). In the present study area, soils are derived from diluvial–alluvial materials, and the surface layer of soil was strongly affected by aeolian transportation of sand. The study area is considered as one of the source regions of sandstorms in north China. Soil erosion by wind is serious in winter and spring. As clay and silt contents are important in controlling the level and distribution of element concentrations in soil, the loss of fine fractions by wind erosion can exert a remarkable impact on element concentrations in the surface layer of desert soil.

Under the extremely arid climate, the vegetation cover is very low, and the influences of chemistry and biota on soil development are relatively minor. Desert soil types show the typical characteristics of the soil-forming parent materials from diluvial–alluvial and aeolian sand. The accumulation of soluble salts in the surface desert soil, under strong evaporation, contributed to the high contents of Ca, Mg, Na and K and some alkaline elements, Sr and Ba. While, the levels of other major and trace elements are relatively low. Estimated background concentrations of elements in soil obtained are very close to the results from the Taklamakan desert region, published by Zhao et al. (1994). In comparison with the background values in soil of China (Chen et al., 1991), the concentrations of some trace elements in the studied desert soil types are remarkably lower than the national averages. This may related to the integrate factors such as the abundance of sandy materials and the weak influences of chemistry and biota on soil development in this region. Especially, the concentrations of Zn and Mn, which are beneficial to plants, are only 45.4% and 70.3% of the national average respectively. This may be the main reason of Zn deficiency in corn, following its cultivation in the desert soil of this region. In recent years, Zn fertiliser had began to apply in corn production in this region.

Land use and management exert significant impact on element concentrations in soil (De Temmerman et al., 2003). The results showed that the concentrations of most elements increase significantly, following cultivation of desert soil, and increase with increasing cultivation years, except for Si, K, Na, Zr, and Ba. This is mostly attributed to the increase of fine particle-size materials and organic matter in arable soil, under long-term irrigation with silt-rich river water and fertilisation, which increase the absorbing capacity of soil to chemical elements. Clay and organic carbon contents are generally considered to be important factors in evaluating element concentrations in soil (Tack et al., 1997; Klassen, 1998; Kabata-Pendias and Pendias, 2001). For some elements (As, B, Co, Cu, Mn, Ni, Cr and Zn) there are increasing amounts as a function of increasing clay content (De Temmerman et al., 2003).

The concentration of most elements shows significant positive correlations with clay and organic carbon contents (Table 6), which coincides with results for other regions (Chen, 1992; Tack et al., 1997; Klassen, 1998; De Temmerman et al., 2003). In agricultural areas with arid irrigation, an increase in organic carbon content can enhance the formation of secondary calcium carbonate and its precipitation in the surface layer (Bronick and Lal, 2005). This may be the main reason for the increase of Ca concentrations with increasing organic carbon content. In addition, the application of chemical fertilisers and manure can increase the levels of certain mineral elements in soil (De Temmerman et al., 2003), following cultivation of desert soil. The application of superphosphate fertiliser is common in the study region, and it can contain given amounts of Ca, Cd, Cr, Co, Cu, Pb, Ni, Zn, As and F (Zhou, 2005). These elements can accumulate in soil with the continuous application of superphosphate fertiliser. The concentration of Zn in arable soil increased notably, and is related to the application of Zn fertiliser in this region. There is no significant correlation between element contents and soil pH (Table 6), possibly due to its very high value in soil, and its narrow range (8.60–8.91), having, therefore, little influence on elemental behaviour. In this region, there is a high salt content in soils and carbonates of Ca and Mg are the main component of salt (Su et al., 2007b), which contributed to a significant correlations between salt content and the concentrations of Ca, Mg, and some alkali metal elements Ti and Y.

Correlations were found at different significant levels between several trace elements (Cr, Mn, Co, Ni, Cu, Zn, Pb and As) and several major elements (P, Al, Fe, Ca and Mg) (Table 6). Especially, Fe shows a strong positive correlation with Cr, Mn, Co, Ni, Cu, Zn, Pb and As. Baize and Sterckman (2001) also noted that an almost linear relationship between Fe and trace elements such as Cu, Co, Ni, Pb, and Zn, may exist in a given soil type. The correlation between Fe and trace elements, may be a relevant factor to take into account when determining background concentration levels (Horckmans et al., 2005), and assessing the contamination extent of soil by trace elements, subject to anthropogenic activity (Zhu et al., 2005).

5. Conclusions

The natural desert soil types that were less disturbed by human activities show low background concentrations for most elements, except for Si, K, Na, Mg, Sr, and Ba. The variability of element concentrations in desert soil is relatively low, suggesting development on a relatively uniform parent material.

Significant changes in most element concentrations occurred, following cultivation of desert soil under long-term irrigation and fertilisation. Except for Si, K, Na, Sr, Zr, Ba and Rb, the concentration of the other 17 elements shows a significant increase, and generally increases with increasing cultivation years. Compared with natural desert soil, the average element concentrations in arable soil increased by 1.7 (Al) to 3.5 (Mg) fold. Whereas the concentration of Cr, Zn, Co, Ni and As increased by 46%–87%, following cultivation. However, their absolute levels are still low, suggesting that the arable soil in this region may still be considered as clean soil. The increased fine particle-size fractions and organic carbon, under long-term irrigation and fertilisation, contributed to the accumulation of most elements in arable soil.

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