

# Relationships between distributions of longevous population and trace elements in the agricultural ecosystem of Rugao County, Jiangsu, China

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**Abstract** Soil, plant, and water, as well as trace elements they contain, can influence human health through the food chain. A survey was conducted on distributions of trace elements in soils, plants, and drinking water in Rugao County, Jiangsu Province, China, an agricultural area with a high level of centenarians and nonagenarians. The ratio of people over 90 years old per 100,000 inhabitants (90-rate) based on village (about 4,000 residents in 4 km<sup>2</sup>) was correlated with trace elements in soil, drinking water, and rice by means of correlation analysis and/or principal component analysis. Although the average 90-rate in the whole area was as high as 277, the rates were not uniform across the entire region. The 90-rate in the area of loamy and strongly-developed Anthrosols and Cambosols was about 330, significantly higher than the 255 in the areas of sandy and strongly-developed Cambosols and of clayey and weakly-developed Cambosols. The concentrations of available Se, B, Ni, and Mo in soils of the area with the high 90-rate were markedly greater than those in

the area with the low 90-rate. This was demonstrated by highly positive correlations between the 90-rate and available Se ( $r = 0.33$ ), B ( $r = 0.21$ ), Ni ( $r = 0.17$ ) and Mo ( $r = 0.17$ ) at the  $p < 0.01$  level and high loadings of available Se (0.851), B (0.535), Ni (0.594) and Mo (0.394) in the longevous factor. Similar relationships between the available elements in soils and elements in water and rice were found. These results suggest that: (1) the available forms of elements in soil were more crucial to elemental bio-availability in the ecosystem and human health than total elements in soil; and (2) the element association above might have affected the 90-rate positively and could be an important environmental geochemical factor influencing the longevity of humans.

**Keywords** Longevity · Rugao County of Jiangsu Province, China · Soil, water and rice · Trace elements

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## Introduction

Health and long-life are desirable for human beings, and the life-span of a population is an important index in determining the health status of the population. Although a real mechanism of human longevity cannot be fully explained by current science and technology, it is commonly recognized that the longevity of a person is probably related to

genetics, lifestyle and the environment (Gonos 2000; Cicconetti et al. 2002). Among these factors, genetics and lifestyle have been studied extensively for a long time. For example, the aging mechanism of human cells and genes controlling the aging rate has been studied at the molecular level using human genetics and molecular biology methods, resulting in important discoveries in this field (Bodnar et al. 1998; Zhang and He 1999; Cournil and Kirkwood 2001; Perls et al. 2002; Vijg and van Orsouw 2002; Perls and Terry 2003). Based on investigations of traditions, diets, and psychological factors, lifestyle has been found to be related to human longevity (Yang 1994; Recepto et al. 1996; IMSC 1997; Mao et al. 1997; Cicconetti et al. 2002; Stathakos et al. 2005). Although these findings have explained some phenomena related to human longevity, it is difficult to explain the phenomenon that a longevous population is, for example, sometimes collectively distributed in a certain area (Yang 1994; IMSC 1997; Gong 1998). Meanwhile, few studies have been conducted to determine the relationship between human longevity and the environment.

Human beings are intimately united with the natural environment since their subsistence, health, and development depend intensively on the environment (Tan 1994; Lin et al. 2004). The ancient Chinese noticed, recorded and explained the relationship between human health and the environment as early as 3,000 years ago (Gong 1998). Hamilton et al. (1973) reported a similarity of element abundance between the human body and the earth crust rock, suggesting an intimate relationship between humans and their natural environment. Soil is a key component of the environment because it influences the quality of water, plants and atmosphere through material cycling, and further affects human health through food chains (Oliver 1997; Lin et al. 2004). Most essential trace elements originate from soils and the levels of elements in soil greatly affect those in water and plants and even human health. For example, relationships have been established between selenium (Se)-deficiency in soil and endemic Kashin-beck and Keshan diseases in China (Gong and Luo 1992; Gong and Huang 1994; Lin et al. 2004), as well as cardio-vascular diseases and cancer (Jackson 1986; Oliver 1997; Lin et al. 2004).

Since the 1990s, studies have begun on the geochemical relationship between human longevity

and the environment (Liang et al. 1994; Tan 1994; Luo 1995; Li et al. 1999; Qiu et al. 2000; Chen 2001). Li et al. (1999) found that  $\text{H}_2\text{SiO}_3$  concentration in spring water and Se in soils was greater in a longevous village than those of a non-longevous area in Shangdong Province, China. They also discovered that Se in diets consumed by people in the longevous village were greater than in non-longevous areas. Qiu et al. (2000) reported that the greater contents of Cr, Zn, Th, Ca and Mg in soils in the districts of Hetian in Xinjiang, China, with a high level of centenarians than in background levels might have contributed to human longevity in the area. Although the findings in a local area or from limited samples were, to some extent, helpful in understanding the relationship between human health and the environment, they were not irrefutable due to their lack of a systematically regional geochemical investigation and research on the relationship between the density of longevous people and elements in soils, water, and plants.

Rugao County in the Jiangsu Province of China is one of the well-known longevous areas with a high rate of over-90-year-old per 100,000 inhabitants (90-rate). The objectives of this study were: (1) to determine the spatial distribution of the 90-rate in the area; (2) to evaluate the relationship between the 90-rate and soil types distributed in the area; and (3) to determine the statistical relationships between the 90-rate and selected elements and elemental associations in the soil, plants, and water. The findings of this study may be helpful in understanding the influence of soil and its environment on health and longevity of populations and possibly improving the quality of human life.

## Materials and methods

### Study site

Rugao county, Jiangsu province, China ( $32^{\circ}00' - 32^{\circ}30'N$ ,  $120^{\circ}20' - 120^{\circ}50'E$ ) is located in a humid monsoon climate in a northern subtropical zone. The average annual temperature is  $14.6^{\circ}\text{C}$  and precipitation is 1,059.7 mm. The county covers  $1,593 \text{ km}^2$  and has a population of 1.45 million. The topography of the county is fairly flat as it is located in an alluvium plain of the Yangtze River

Delta Region, and there is little difference in climate within the county. However, diverse soil types have developed due to diverse parent materials. Paleo-alluvium with sandy textures from the Yangtze River and Huai River are distributed in the central and western parts and Paleo-alluvium with loamy textures are in the northern parts of the county (Fig. 1). Lacustrine deposits with loamy texture were developed on the alluvium in the eastern and northwestern parts. Neo-alluvium with loamy-clay texture appears in the southern part along the banks of the Yangtze River (OSSRC 1987). Nine soil series in two soil orders, Cambosols and Anthrosols (Table 1), were identified according to the diagnostic horizons and characteristics determined by CRGCST (2001) and Gong et al. (2003). Corresponding to the soil parent materials, sandy Cambosols such as Motou, Guoyuan and Taoyuan soils and loamy Cambosols such as Dongchen soil are distributed on the paleo-alluvium in the western, central, and northeastern parts of the county. Loamy Cambosols and Anthrosols are distributed as Banjing and Baipu soils on the lacustrine deposit in the northwestern and eastern parts. Loamy and Clayey Cambosols are

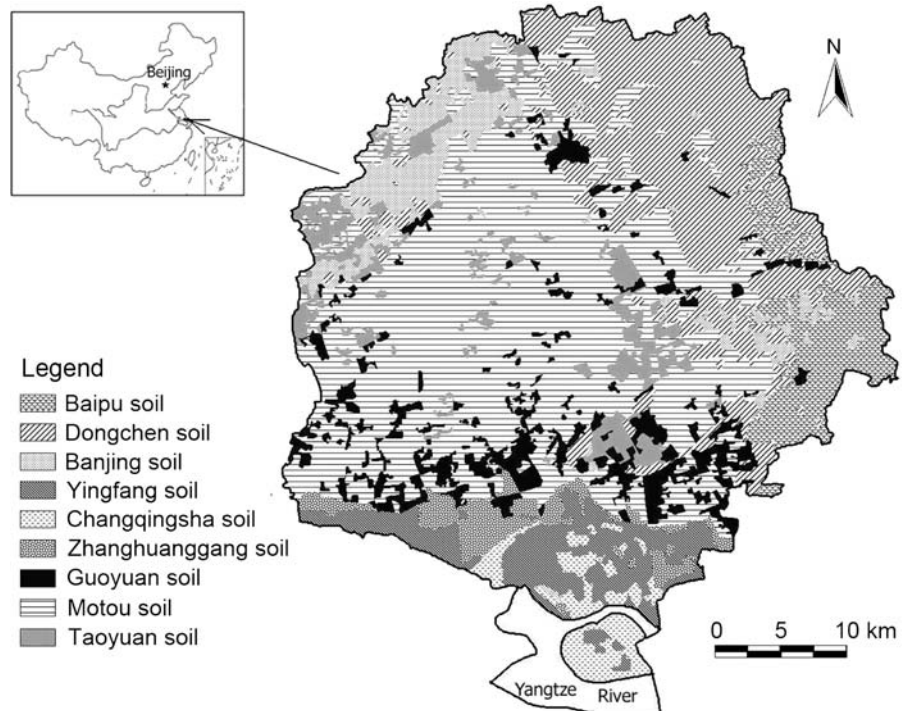
distributed as Zhanghuanggang and Yingfang soils and Changqingsha soils on the neo-alluvium in the southern part (Fig. 1). Selected physico-chemical properties are listed in Table 1.

Although the yearly rotation of corn (*Zea mays*) and wheat (*Triticum aestivum*) was dominant in the central and western areas before the 1990s, the rotation of rice (*Oryza sativa*) and wheat has become the dominant plating system since then. Furthermore, barley (*Hordeum jubatum*), canola (*Isatis tinctoria*), horsebean (*Vicia faba* L.), pea (*Pisum sativum*), and sesame (*Sesamum indicum*) in the summer harvest season and peanut (*Arachis hypogaea*), soybean (*Glycine max*), and sweet potato (*Ipomoea batatas*) in the autumn harvest season are planted in certain areas.

Data collection

Total population and the over-90-year-old population came from the 2002 census conducted by the county government. The rate of over-90-year-old per 100,000 habitants (90-rate) was calculated on the basis of village level with a population of about 4,000 and an area of 4 km<sup>2</sup>.

Fig. 1 Soil map of Rugao County



**Table 1** Soil taxonomy and their physical and chemical properties of the soils in Rugao County

Series	Subgroup	pH	OM		Sand (≥45 μm) (Vol. %)	Silt (2–45 μm)	Clay (<2 μm)
				Free carbonate (g kg <sup>-1</sup> )			
Baipu	Typic Hapli-Stagnic Anthrosols	7.98	20.0	13.2	25.43	64.85	9.72
Dongchen	Anthrostatic Dark-Aquic Cambosols	8.25	16.3	12.7	34.07	57.77	8.17
Banjing	Anthrostatic Dark-Aquic Cambosols	8.21	17.0	8.4	30.80	60.43	8.77
Yingfang	Calcaric, Ochri-Aquic Cambosols	8.40	17.8	57.5	27.48	62.30	10.23
Changqingsha	Calcaric, Ochri-Aquic Cambosols	8.40	17.8	66.2	26.60	63.02	10.55
Zhanghuanggang	Calcaric, Ochri-Aquic Cambosols	8.40	16.9	53.6	32.38	58.64	8.98
Guoyuan	Typic, Haplic-Ustic Cambosols	8.33	14.5	21.0	36.76	56.30	6.80
Motou	Calcaric, Ochri-Aquic Cambosols	8.33	14.0	21.3	43.58	49.78	5.90
Taoyuan	Calcaric, Ochri-Aquic Cambosols	8.28	15.8	24.4	33.78	58.24	7.98

### Sampling

A total of 203 surface soil samples (0–20 cm in depth) covering different soil series and agricultural management systems were evenly collected in the county using a stainless-steel auger. Each soil sample was a mixture of 5 sub-samples collected within 100 m<sup>2</sup>. The longitude and latitude of each sampling site was recorded using a handheld global positioning system (GPS). Soil samples were air-dried at room temperature and sieved (<2 mm) for the analysis of physical and chemical properties and available elements. To determine total element concentration in soil, dried soil samples were sieved through a 0.15-mm particle size. The soils sieved to 2 mm were measured for pH in 1:2.5 soil/water suspension, and also measured for organic matter (OM) (Lu 1999), free carbonates (Lu 1999), and particle size distribution (Beuselinck et al. 1998).

A total of 97 rice samples, an important diet component in the county, were taken on the soil sampling sites where rice was cultivated. Each rice grain sample was randomly taken from a 100-m<sup>2</sup> land area when rice was mature and at harvest. The rice grain was washed in tap water, followed by several rinses in distilled water, and then dried in an oven at 50°C for 24 h. After the rice hull was threshed, the grain, an edible part of rice, was ground with a stainless-steel grinder to <0.15-mm particle size for chemical analysis.

Eleven and 12 drinking water samples from local wells were collected in the areas of Baipu and Motou

soils, respectively, using a plastic container. Well water is the main source of drinking water in local areas. Two sub-samples of 1 l water each were obtained at every sampling well. About 5 ml of concentrated HCl was immediately added to one of the sub-samples for the determination of trace elements, and the other sub-sample was kept fresh for analysis of F and B. All water samples were immediately transported to the laboratory and kept in a refrigerator at 4°C. The determination of all trace elements except F and B was conducted within 2 days.

### Chemical analysis

Water-extractable B, F and Se were employed as bio-available forms (Chen et al. 1984; Dhillon and Dhillon 1991). Soil was extracted with ionized water at a ratio of 1:5 soil:water in a hot-water bath for 1 h. The extract was analyzed for B by a colorimetric method (Lu 1999), F by an F-selective electrode, and Se by atomic fluorescence spectrophotometry. Diethylenetriamine-pentaacetic acid (DTPA) extraction was used to measure the availability of Cu, Zn, Fe, Mn, Ni, and Co in the soils (Lindsay and Norvell 1978). Soil samples were extracted with DTPA solution at a ratio of 1:2 soil:DTPA for 30 min, and the concentrations of metals in the extract were measured by inductively coupled plasma-atomic emission spectroscopy (ICP-AES). Oxalic acid-ammonium oxalate extraction was used to measure the availability of Mo. Soil samples were extracted with 0.2 M ammonium oxalate–0.1 M oxalic

acid solution at a ratio of 1:10 soil:solution for 8 h. The concentration of Mo in the solution was determined colorimetrically (Lu 1999). Total concentrations of Cu, Zn, Fe, Mn, Ni, and Co in soils were directly determined by X-ray fluorescence (XRF) spectrometry. Quality control and assurance was performed using standard reference materials (Institute of Geophysical and Geochemical Exploration, Geological Survey of China). The reference materials were Cambosols (GBW07414) for available Cu and Zn and Argosols (GBW07403) for total metals in soils. The analysis of the Cambosols by the method used showed that the soil contained  $0.79 \pm 0.19 \mu\text{g g}^{-1}$  and  $0.47 \pm 0.04 \mu\text{g g}^{-1}$  of DTPA-Cu and Zn compared with the certified values of  $0.82 \pm 0.12 \mu\text{g g}^{-1}$  and  $0.66 \pm 0.18 \mu\text{g g}^{-1}$ . The analysis of the Argosols by the XRF showed that the soil contained  $12.4 \pm 0.4 \mu\text{g Cu g}^{-1}$ ,  $29.0 \pm 3.2 \mu\text{g Zn g}^{-1}$ ,  $21.4 \pm 0.1 \text{ mg Fe}_2\text{O}_3 \text{ g}^{-1}$ ,  $274 \pm 8 \mu\text{g Mn g}^{-1}$ ,  $12 \pm 0.2 \mu\text{g Ni g}^{-1}$ , and  $5.1 \pm 0.4 \mu\text{g Co g}^{-1}$  compared with the certified values of  $11.4 \pm 1.6 \mu\text{g Cu g}^{-1}$ ,  $31 \pm 4 \mu\text{g Zn g}^{-1}$ ,  $20.0 \pm 0.7 \text{ mg Fe}_2\text{O}_3 \text{ g}^{-1}$ ,  $304 \pm 21 \mu\text{g Mn g}^{-1}$ ,  $12 \pm 2 \mu\text{g Ni g}^{-1}$ , and  $5.5 \pm 1.0 \mu\text{g Co g}^{-1}$ . The results of all determinations for reference materials fluctuated within the allowed ranges compared to the certified values.

Concentrations of metals and B in rice without hull were determined by ICP–AES and that of Se by AFS after digestion with the concentrated  $\text{HNO}_3$  and  $\text{HClO}_4$ . The reference material for performing quality control and assurance of the elements in plants from the Institute of Geophysical and Geochemical Exploration, Geological Survey of China, was poplar leaves (GBW07604). The analysis of the poplar leaves showed that the leaves contained  $9.1 \pm 0.6 \mu\text{g Cu g}^{-1}$ ,  $35 \pm 7 \mu\text{g Zn g}^{-1}$ ,  $236 \pm 19 \mu\text{g Fe g}^{-1}$ ,  $43 \pm 4 \mu\text{g Mn g}^{-1}$ ,  $1.7 \pm 0.3 \mu\text{g Ni g}^{-1}$ ,  $0.41 \pm 0.07 \mu\text{g Co g}^{-1}$ , and  $49 \pm 7 \mu\text{g B g}^{-1}$  compared with the certified values of  $9.3 \pm 0.5 \mu\text{g Cu g}^{-1}$ ,  $37 \pm 1 \mu\text{g Zn g}^{-1}$ ,  $274 \pm 10 \mu\text{g Fe g}^{-1}$ ,  $45 \pm 2 \mu\text{g Mn g}^{-1}$ ,  $1.9 \pm 0.2 \mu\text{g Ni g}^{-1}$ ,  $0.42 \pm 0.02 \mu\text{g Co g}^{-1}$ , and  $53 \pm 4 \mu\text{g B g}^{-1}$ . The determined Se concentration in the leaves was  $128 \pm 14 \text{ ng g}^{-1}$  compared with the certified values of  $140 \pm 10 \text{ ng g}^{-1}$ . The concentration of metals in drinking water was measured by ICP–MS (mass spectrometry) and those of Se, B, and F by AFS, colorimetric method, and F-selective electrode, respectively.

## Data processing

Using GIS software, the administration map at the village level of the county was digitized and each polygon corresponding to a village was assigned a value of the 90-rate to generate a spatial distribution map of the 90-rate. The soil map reported by OSSRC (1987) was also digitized. The 90-rates on different soil series were obtained by averaging the 90-rate values of all polygons within the polygons of soil series through overlaying the 90-rate distribution map at the village level on the soil map.

The concentrations of available and total elements at all sampling sites were interpolated using the kriging to generate the spatial distribution maps (cell size 100 m) of the available and total elements. These kriged maps were individually summarized by village level on the raster version administrative map (cell size 100 m) to obtain the average value of concentration of each available and total element in each village. These average values were linked to the attribute table adhered to the 90-rate distribution map through village name so that a matrix including the 90-rate and the concentrations of available and total elements on the basis of village level was generated. With this matrix, correlation and principal component analysis were performed to determine the relationships between the 90-rate and available forms and total concentrations of elements. The kriged maps of elements were also individually summarized by soil series on the raster version of the soil map (cell size 100 m) to obtain the average value of concentration of each available and total element in each soil.

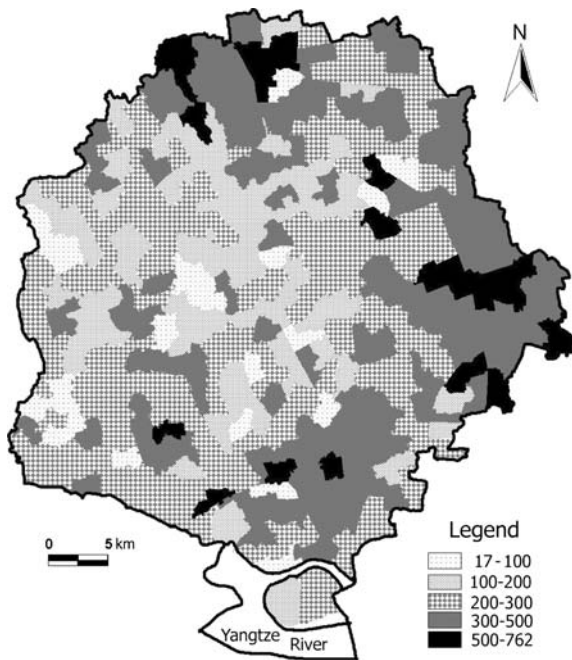
Analysis of variance was performed using the general linear model (GLM). Mean separations were performed using Duncan's Multiple Range Test to test the differences of the 90-rate and the available elements among different soil series.

## Results

### Spatial distribution of the 90-rate and the relationship to soils

The average 90-rate of the whole county was about 277. However, the 90-rate at the village level in different areas was not uniform. The 90-rates in the



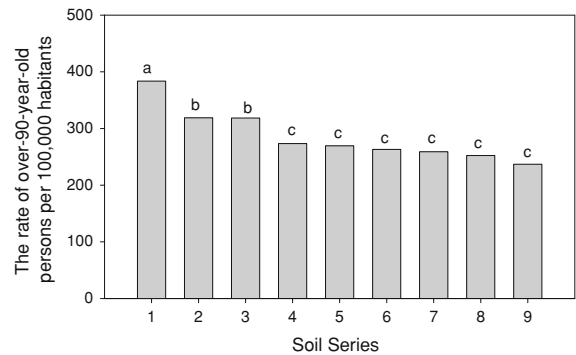


**Fig. 2** Spatial distribution of the rate of over-90-year-old persons per 100,000 inhabitants on the village basis in Rugao County

northern and eastern parts of the county were generally high and those in the southern, central and western parts tended to be lower (Fig. 2). The highest 90-rate was found in the area of Baipu soils with a value of 383.6 (39% higher than the average level of the whole county), followed by significantly lower values of the 90-rates ( $p < 0.05$ ) in the areas of Dongchen (318.9) and Banjing (318.6) soils, then lower values in the areas of Yangfang (273.4), Changqingsha (269.4), Zhanghuanggang (263.1), Guoyuan (259.1) and Motou (252.2) soils ( $p < 0.05$ ). The lowest 90-rate was in the area of Taoyuan soil with 237.0 (14% as low as the average level (Fig. 3).

#### Spatial distribution of elements in soils

The distribution of the available form of elements in soils was classified into three patterns in terms of similarity to the distribution of the 90-rate. At first, the distribution of available elements such as Se, Zn, B, Ni, and Mo showed a similar pattern to the distribution of the 90-rate with high concentrations in eastern and northeastern areas and low concentrations in the central, western and southern areas (Fig. 4a, Se



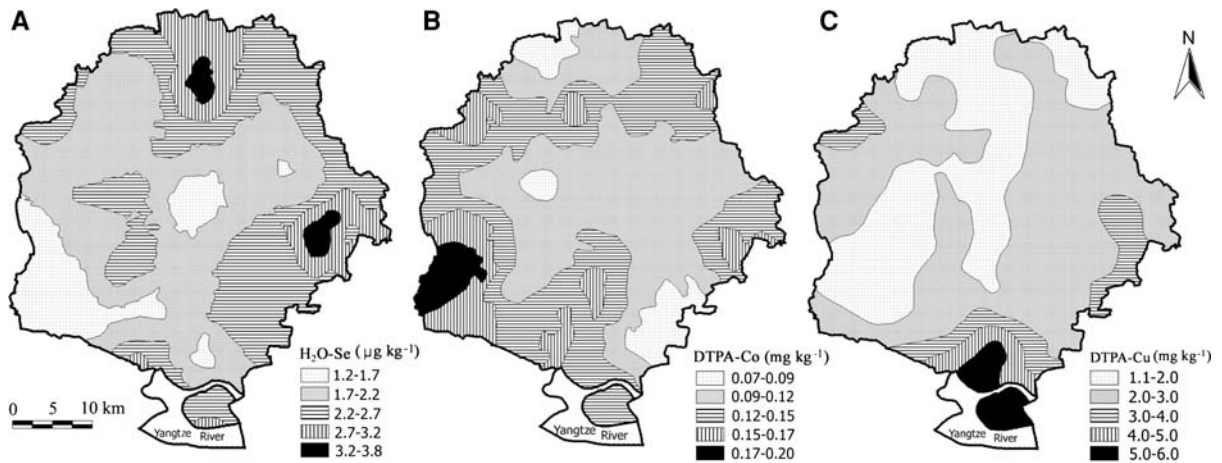
**Fig. 3** The 90-rate on different soil series. 1. Baipu soil, 2. Dongchen soil, 3. Banjing soil, 4. Yingfang soil, 5. Changqingsha soil, 6. Zhanghuanggang soil, 7. Guoyuan soil, 8. Motou soil, 9. Taoyuan soil. Different letters over bars denote significant difference between soil series ( $p < 0.05$ ) by Duncan's multiple range tests

as an example). The second distribution pattern of the available elements such as Mn and Co indicated a reverse pattern to the distribution of the 90-rate and low concentrations in northern and eastern areas and high concentrations in central, western and southern areas (Fig. 4b, Co as an example). The third pattern, including Cu, F, and Fe, showed no similarity to the pattern of the 90-rate. The concentration of DTPA–Cu, for example, was high in the southern area and decreased in the northern area (Fig. 4c). Likewise, the concentrations of  $H_2O$ –Se and B, DTPA–Zn and Ni, and oxalate–Mo in Baipu, Dongchen and Banjing soils were significantly higher than those in Yingfang, Guoyuan and Motou soils (Table 2).

For total concentration of elements, the spatial distribution maps of total Se, Cu, Zn, Mn, Fe, Ni and Co revealed no similarity to the 90-rate distribution and no significant relationships between them (data not shown). We believe that relationships between the 90-rates and the available elements in soils must be significantly more important than those between the 90-rate and total elements in soils. Therefore, we discontinued the analysis of total Se, F and B in soils.

#### Relationships between the 90-rate and the available elements in soils

The 90-rates had significant positive correlations with available elements such as  $H_2O$ –Se, B and F, DTPA–Ni and Zn, and oxalate–Mo. The correlation



**Fig. 4** Spatial distribution patterns of the selected available trace elements. (a) Se, (b) Co, (c) Cu

**Table 2** Concentrations of selected available trace elements in different soil series

Soil series	Sample no.	Se ( $\mu\text{g kg}^{-1}$ )	(mg $\text{kg}^{-1}$ )								
			F	B	Fe	Mn	Cu	Zn	Ni	Co	Mo
Baipu	15	2.56a	4.75a	1.04a	28.9bc	13.9ab	2.70d	0.97a	0.16a	0.13a	0.18ab
Dongchen	45	2.48ab	4.66a	1.03a	33.1a	13.3bcd	2.39e	0.94a	0.13c	0.12a	0.19a
Banjing	15	2.36bc	4.67a	0.99b	34.3a	13.6bc	2.65d	0.98a	0.14b	0.13a	0.17ab
Yingfang	10	2.16d	4.85a	0.89e	29.4bc	14.4a	4.03b	0.81bc	0.11e	0.13a	0.21a
Changqingsha	8	2.10d	4.72a	0.82f	28.1c	14.4a	4.75a	0.82b	0.11e	0.13a	0.20a
Zhanghuanggang	14	2.04d	4.86a	0.92cd	32.0ab	13.7b	3.36c	0.80c	0.11e	0.12a	0.18ab
Guoyuan	19	2.09d	4.42b	0.89de	31.9ab	13.0cd	2.20e	0.81c	0.12d	0.13a	0.18ab
Motou	62	2.22cd	4.44b	0.93c	34.3a	12.7d	2.35e	0.87b	0.12d	0.12a	0.16b
Taoyuan	15	2.13d	4.38b	0.92cd	33.1a	12.6d	2.20e	0.87b	0.12de	0.12a	0.17ab

Values in same column for different soil series followed by a different letter are significantly different ( $p < 0.05$ ) by Duncan’s multiple range test

coefficients were 0.33 for  $\text{H}_2\text{O-Se}$ , 0.21 for  $\text{H}_2\text{O-B}$ , 0.15 for  $\text{H}_2\text{O-F}$ , 0.17 for  $\text{DTPA-Fe}$ , 0.17 for  $\text{DTPA-Ni}$ , and 0.17  $\text{DTPA-Mo}$  at the  $p < 0.01$  significant level (Table 3). These results, however, do not validate an intrinsic linkage of the 90-rates and available elements because significant correlations ( $p < 0.05$ ) were observed among 33 out of 45 available element pairs (Table 3). The high frequency of correlations indicates that pairs of the 90-rate and elements without intrinsic linkage can reach significant correlations as well (Brejda et al. 2000). A principal component analysis can group all variables into factors based on their correlation patterns (Shama 1996; Brejda et al. 2000). In our case, an intrinsic elemental association related to the 90-rate

would be distinguished on the basis of the factor containing a high loading of the 90-rate.

Each of the first four factors had eigenvalues greater than 1 (Table 4) and was retained for interpretation (Shama 1996). The order in which factors were interpreted was determined by the magnitude of their eigenvalues. The first factor (F1) had a high positive loading for B, F, Fe, Mn, Zn, and Co (Table 4), which could be a soil texture factor because the soils with high availability of these elements were all loamy or clayey Cambosols or Anthrosols (Tables 1 and 2). The second factor (F2) had a high positive loading for the 90-rate and would, therefore, be termed the longevous factor. Meanwhile,  $\text{H}_2\text{O-Se}$  and B,  $\text{DTPA-Ni}$ , and oxalate-Mo

**Table 3** Correlation coefficients between the 90-rate and concentrations of selected available trace elements

	90-Rate	B	F	Se	Fe	Mn	Cu	Zn	Ni	Co
B	0.21**									
F	0.15**	0.54**								
Se	0.33**	0.44**	-0.02							
Fe	0.17**	0.18**	0.38**	0.28**						
Mn	-0.02	0.16**	0.58**	-0.21**	0.31**					
Cu	0.10	0.01	0.20**	0.04	0.21**	0.37**				
Zn	0.08	0.55**	0.07	0.47**	0.31**	0.25**	-0.09			
Ni	0.17**	0.09	-0.11*	0.39**	-0.12*	-0.51**	-0.01	-0.30**		
Co	-0.15**	-0.08	0.21**	-0.37**	0.32**	0.53**	0.16**	0.14**	-0.43**	
Mo	0.17**	0.04	-0.01	0.23**	0.41**	-0.23**	0.19**	-0.07	0.11**	-0.04

\*  $p = 0.05$ \*\*  $p = 0.01$ **Table 4** Results of principal component analysis of the 90-rate and soil available elements

Variable	F1	F2	F3	F4
90-Rate	0.177	<b>0.490</b>	0.208	0.222
B	0.592	<b>0.535</b>	-0.314	0.226
F	0.705	0.009	0.106	0.521
Se	0.148	<b>0.851</b>	-0.137	-0.115
Fe	0.691	0.259	0.287	-0.344
Mn	0.772	-0.444	0.004	0.222
Cu	0.345	-0.052	0.619	0.179
Zn	0.556	0.295	-0.598	-0.349
Ni	-0.430	<b>0.594</b>	0.217	0.345
Co	0.515	-0.570	0.109	-0.268
Mo	0.077	<b>0.394</b>	0.637	-0.491
Eigenvalue cumulative %	2.858	2.438	1.460	1.139
	25.982	22.164	13.270	10.353

High positive loadings in the second factor (F2) are shown in bold

also had high positive loadings (0.394–0.851). Compared to the correlation matrix between the 90-rate and the available elements (Table 3), the close relationships between the 90-rate and H<sub>2</sub>O–F and DTPA–Fe were excluded from the longevous factor, indicating that intrinsic elemental associations related to the 90-rate should only include the high availability of Se, B, Ni, and Mo in the soil environment. In the fourth factor, H<sub>2</sub>O–F had just a high loading (Table 3). Owing to the factor being out of the scope of this study, we will not discuss it here.

**Table 5** Concentrations of selected trace elements in rice grain on different soil series

Soil series	Se ( $\mu\text{g kg}^{-1}$ )	B ( $\text{mg kg}^{-1}$ )	Fe	Mn	Cu	Zn	Ni
Baipu	<b>130</b>	5.0	185	142	11.6	23.3	12.2
Dongchen	<b>123</b>	5.4	201	158	13.6	21.1	10.7
Banjing	<b>103</b>	5.8	196	135	15.2	22.7	11.6
Yingfang	36	5.2	278	145	11.9	23.0	14.7
Changqingsha	28	4.1	100	123	7.0	17.9	3.6
Zhanghuanggang	36	5.7	271	165	20.6	23.5	16.1
Guoyuan	53	9.7	294	142	15.8	26.2	12.9
Motou	103	5.8	215	148	13.4	22.0	12.2
Taoyuan	26	5.2	291	163	17.9	21.9	17.6

Significant high values are shown in bold

#### Spatial distribution of elements in crops and ground water

Since rice grain is the main food source in local area, its composition could affect the human health and longevity. The concentrations of most of the studied elements in rice grain are listed in Table 5. As expected, a similar spatial distribution of Se in rice grain to those of the soils or 90-rate was found (Table 5). The Se concentration in the rice grain on Baipu soil in eastern area, on Dongchen soil in northeastern, and on Banjing soil in northwestern areas were significantly higher than those in the soils in southern, central, and western areas. However, unexpectedly, the concentration of other metal



**Table 6** Concentrations of selected elements in wells consumed by local people

	Se ( $\mu\text{g l}^{-1}$ )	F ( $\text{mg l}^{-1}$ )	B	Cu ( $\mu\text{g l}^{-1}$ )	Cr	Ni	Mo	Co
Baipu soil area	0.286	0.368	0.588	6.34	51.52	11.54	0.22	1.74
Motou soil area	0.240	0.272	0.415	6.18	43.77	11.36	0.26	1.80
Significance	*	**	***	**	**	ns	ns	ns

\* and \*\* denote significant differences of elemental concentrations between two soils at  $p = 0.05$  and  $0.01$  by  $T$ -test, respectively; *ns* not significant

elements in rice grain did not have similar spatial distribution to those in the soils.

The well water between the Baipu soil area (high 90-rate area) and Motou soil area (low 90-rate area) revealed to be the significant differences in the concentrations of some trace elements (Table 6), indicating that the concentrations of the elements including Se, B, and Ni mentioned above in the drinking water in high 90-rate area were greater than those in the low 90-rate area. However, Mo in the drinking water had no significant difference between the two areas.

**Discussion**

Generally, longevity is attributed to genetics (Cournil and Kirkwood 2001; Perls et al. 2002; Perls and Terry 2003). In Rugao County, most longevous people in a local area may come from different families without any genetic relationship to one another. On the other hand, there are no significant differences in traditions, lifestyles and diet habits in the rural area of the county where 86% of longevous people live. Most of these longevous people live in the same place where they were born. They seldom emigrated out of their villages or towns, and rarely had material exchange from other places. Therefore, we suggest that the soil, as a key component in the environment, might have played an important role in human health and longevity. Soil influences components such as the trace elements in food and drinking water and further human health and longevity through the food chain.

With regards to soil properties, those soils with a high 90-rate were loamy Cambosols or Anthrosols. They were well-developed and had low pH and free carbonate content due to leaching in the process of soil genesis (Table 1). Undoubtedly, the fine texture,

low pH and low free carbonate content in soils benefit the availability of some nutrient elements (Liu 1996) such as B, Se, Ni, and Mo (Table 2). Sandy Cambosols with low 90-rates lack such advantages. Free carbonate content and pH of those soils are significantly higher (Table 1) and the available elements are lower than those of loamy Cambosols (Table 2). Although the Cambosols distributed in the southern area also had a fine texture, even finer than the loam Cambosols and Anthrosols in the eastern area, those soils have a high soil pH, free carbonates (Table 1) and fewer available elements (Table 2) due to the weak development in a short history of soil genesis. The 90-rate on that part of area was also relatively low (Fig. 3). These characteristics of these soils significantly affected the components in water and crops and their distributions (Tables 5 and 6). As for the inconsistency of some trace element contents between crops and soils, it may be due to the foliar spray of trace element fertilizers containing metal nutrients, such as B, Zn, Fe, and Mo, when local rice cultivation was conducted. In contrast, Se was not present in the trace element fertilizer and appeared to be consistently distributed in the soils. This actually indicates a clue to the effect of soil geochemical background on human health through the food chain.

Essential trace elements play an important role in the biochemical reactions of the human body as components of enzymes, hormones, vitamins and nucleic acids (Plant et al. 1996; Nielsen 2000). The abundance and association of these elements originating mostly from soils significantly affect human health and life-span through transferring elements from soils through crops and water to the food chain in terms of their available forms. However, most published results regarding the relationship between longevity and soil environment (Li et al. 1999; Qiu et al. 2000) have reported high concentration of total

elements in soils. Those studies did not, to some extent, totally reflect intrinsic geochemical relationships between longevity and elements in the environment. Therefore, when similar work is carried out in the future, it will be very important to study the distribution of the available forms of elements in soils and the effect of soil properties, such as pH, organic matter content, free carbonate content, and soil texture on the chemical behaviors of those elements (Kabata-Pendias and Pendias 1992; Liu 1996).

Although the essential elements play an important role in human health, the functionality of elements depends on the magnitude of elemental concentrations and the balance between elements in the environment (Gong and Huang 1994; Oliver 1997; Lin et al. 2004). If concentrations of trace elements are above or below the relatively narrow critical ranges, endemic diseases may occur (Gong and Luo 1992; Gong and Huang 1994). For example, Se deficiency could cause Keshan, Kashin-beck and cardio-vascular diseases (Oliver 1997; Lin et al. 2004). Only if the concentrations of the trace elements are within the critical ranges could the tissues and their functions within the human body operate normally and extend life-spans. In our case, it is possible that trace elements, such as Se, B, Ni and Mo, with key biochemical functions in human health (Miao et al. 1997; Nielson 1998, 2000; Yan et al. 1999; Lin et al. 2004) might be just within the range of the critical values in the longevous areas. In addition, synergism and antagonism among trace elements in the human body are of great importance to human health (Miao et al. 1997; Nielson 1998; Yan et al. 1999). The association of elements likely has a synergistic effect that further enhances some functions of anti-aging during the process of life over a long period of time in this specific environment. What we would emphatically point out is that all these assumptions are, to some extent, speculative and need to be verified by further exploration of the mechanisms of the relationship between essential elements and longevity of human beings through multidisciplinary collaboration.

## Conclusions

There was a significant relationship between the spatial distribution of longevous populations and soil

series and their elemental available forms, indicating an intrinsic linkage between human health or longevity and environment to a certain extent. We can conclude the following from this study. First, the available forms of elements in soils exhibit a closer relationship to the 90-rate in spatial distribution than do total elements in the soil. The availability of elements depends mainly on soil physical and chemical properties such as pH, OM, free carbonate, and texture, while total elements are dominantly related to the geochemical background, including parent material and their sources. Consequently, we should pay more attention to the available forms of elements in soil and soil properties affecting elemental availability than to the total elements in soils. In fact, the composition of foods and dinking water had strong correlations to elemental availability in their corresponding soils. Second, human health and longevity does not appear to be related to a single element, but rather multi-elements or association of elements in soils and environment. We may extrapolate that the specific associations of elements in the environment, e.g., the association of Se, B, Ni, and Mo in our case, have an intimate relationship to human health and longevity. Finally, availability of elements and elemental association in the soil and its ecosystem would be emphasized when the studies on the relationship between soil ecosystems and human health are conducted.

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