Distribution and transfer of Se in soil of Hainan Province

Zhe Hao1,2,3, Yonghua Li4,a, Xinqing Zou 1,3,5 and Lihong Chen2

1 School of Geographic and Oceanographic Sciences, Nanjing University, Nanjing 210093, China
2 Key Laboratory of Engineering Oceanography, Second Institute of Oceanography, SOA, Hangzhou 310012, China
3 Collaborative Innovation Center of South China Sea Studies, Nanjing University, Nanjing 210093, China
4 Key Laboratory of Land Surface Pattern and Simulation, Institute of Geographical Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China
5 Key Laboratory of Coast and Island Development (Nanjing University), Ministry of Education, Nanjing 210093, China

a Corresponding author: yhli@igsnrr.ac.cn

Abstract. Soil plays an important role to human health. Selenium is an essential nutrient for health. Se in soil will affect human health mainly by transferring to rice and other crops, and then to human body through the food chain. So it’s necessary to analyse distribution of Se concentration in soil and its bioaccumulation ability from soil to rice. In this study, concentrations of soil Se ranged from 108.41-618.23μg/kg by counties. The average value was 343.90μg/kg, which was higher than soil background. It indicated that soil in Hainan was loaded with selenium. Soil in northeast contains more Se than that in southwest and Se content in natural soil was significant higher than cultivated soil. Positive correlations were seen between soil Se, rice Se and C/100,000. The transfer ability of Se varies in counties.

1. Introduction
As the material basis which biology relies on to survive, soil plays a nonnegligible role to human health. Soil affects water quality, plants, the atmosphere, and further human health through the food chain [1]. Studies have shown distribution similarities between longevity index and some elements in soil like Se and Zn in China [2], demonstrating that longevity has correlation with soil environment [3].

Selenium is an essential nutrient, and adequate amounts are required for optimal health [4]. It acts as a potent antioxidant protecting cells from oxygen free radicals and thus can slow the aging process [5-6]. Moreover, adequate concentrations of Se might increase the lifespan of centenarians, which are a representative group for healthy aging [7]. Se in soil can affect health mainly by transferring to rice and other crops, and then to human body through the food chain. So it’s necessary to analyse distribution of Se concentration in soil and its bioaccumulation ability from soil to rice.

Hainan Province is an island famous for its longevity and was recognized by the International Expert Committee on Population Aging and Longevity as a “World Longevity Island” on August 27, 2014 [8-9]. According to the demographic database of the sixth Chinese census, there are 1162
centenarians in Hainan Island and their prevalence per 100,000 people (C/100,000) is 18.75 (China NBS), with both values ranking highest in China (Fig. 1) [7]. It’s worth investigating Se concentration and its potential effect on longevity of Hainan.

This paper analyzed distribution of Se in soil of Hainan Province. The bioaccumulation factor, as well as relationships between soil Se, rice Se and longevity index were also discussed. It will help provide data support and theoretical basis for identify contribution of Se (especially soil Se) to human health.

![Figure 1. Distribution of centenarians per 100,000 people in China and Hainan Island](image)

2. Materials and method

2.1 Study area

Hainan is a province at the southern tip of China with an area of 35,100 km², a latitude of 18°10′ to 20°10′ North and a longitude from 108°37′ to 111°05′ East. The climate is tropical monsoon with an average annual rainfall of 1600–2500 mm and average annual temperature of 23–25°C [10].

2.2 Sample collection and analytical methods

Population data were collected from the Chinese demographic database of the sixth census [11]. Samples of rice were also collected and the analytical methods and results had already been published [9].

Samples of natural and cultivated soil were collected from all 18 counties in Hainan Province. They were sealed in plastic bags and immediately transported to the laboratory. After grinding, sieving and drying, approximately 0.0500 g soil from each sample was placed in a 50 mL beaker and digested with 4 mL concentrated nitric acid and 1 ml concentrated perchloric acid. Samples were then carefully evaporated to near dryness on an electric heating plate at 100-120°C until the soil turned grayish white. Then 2 ml of concentrated hydrochloric acid was added for reduction. The residue was transferred to a 10 mL polyethylene bottle and diluted to the volume for later analysis. Se concentration was determined by hydride generation atomic fluorescence spectrometry.

2.3 Statistical methods

All statistical analyses were performed using SPSS 16.0 for Windows (IBM, Chicago, IL, USA). The statistical significance was set at p < 0.05. In addition, ArcGIS version 10.0 (Esri, Redlands, CA, USA) software was used to generate distribution maps of longevity indexes and element concentration. Microsoft Excel was used to draw histograms.
2.4 Equation of bioaccumulation factor

The bioaccumulation factor for Se was calculated in order to assess the extent by which Se occurs in rice and associated soil. Se concentration of cultivated soil was chosen in this equation for it had more direct impact on rice. This was calculated by the equation:

\[ \text{BAF} = \frac{C_{\text{rice}}}{C_{\text{cultivated soil}}} \]

3. Results

3.1 Concentration of Se in Hainan Province

Table 1 shows the mean concentration of Se in soil samples by county. Se concentrations showed significant regional difference in Hainan Province, they were ranging from 108.41-618.23μg/kg, and the average value was 343.90μg/kg. The highest values presented to Haikou, Wanning and Lingao, while the lowest values to Dongfang, Ledong and Changjiang. It showed that soil in northeast contained more Se than in southwest (Fig.2). Values of most counties as well as the average value were much higher than the background value of soil Se (Table 1 and Fig.3). It indicated that soil in Hainan was loaded with selenium, which may contribute to its residents’ health and high percentage of centenarians.

| Region     | Soil  | Natural soil | Cultivated soil | p    |
|------------|-------|--------------|-----------------|------|
| Baisha     | 414.80| 577.95       | 297.70          | 0.000|
| Baoting    | 399.65| 344.71       | 463.34          | 0.001|
| Changjiang | 189.68| 171.43       | 209.88          | 0.011|
| Chengmai   | 314.06| 481.59       | 280.74          | 0.000|
| Danzhou    | 229.08| 256.35       | 204.70          | 0.000|
| Ding'an    | 376.28| 360.47       | 392.77          | 0.000|
| Dongfeng   | 108.41| 87.15        | 134.86          | 0.035|
| Haikou     | 618.23| 663.10       | 576.40          | 0.005|
| Ledong     | 121.42| 110.06       | 133.95          | 0.000|
| Lingao     | 507.84| 547.36       | 471.18          | 0.001|
| Lingshui   | 286.29| 315.17       | 260.06          | 0.001|
| Qionghai   | 439.85| 453.43       | 426.69          | 0.005|
| Qiongzhong | 449.79| 538.50       | 375.69          | 0.001|
| Sanya      | 201.59| 212.33       | 191.40          | 0.003|
| Tunchang   | 349.44| 322.26       | 378.92          | 0.029|
| Wanning    | 555.25| 629.39       | 489.85          | 0.000|
| Wenchang   | 421.94| 426.77       | 417.16          | 0.003|
| Wuzhishan  | 206.51| 264.54       | 167.02          | 0.013|
| Average    | 343.90| 375.70       | 326.24          |      |
| Max        | 618.23| 663.10       | 576.40          |      |
| Min        | 108.41| 87.15        | 133.95          |      |
| Background value | 216.00 |        |         |      |
3.2 Comparison of Se concentration in natural soil and cultivated soil

The comparison of Se concentrations between natural soil and cultivated soil was also listed in Table 1. Se concentrations of natural soil were ranging from 87.15-663.1 0μg/kg, and the average value was 375.70μg/kg; Se concentrations of cultivated soil were ranging from 133.95-576.40μg/kg, with the average value of 326.24μg/kg. The average value of Se concentration in natural soil is higher than that in cultivated soil. In order to make the comparison clearer and more visual, histogram was draw as Fig. 3. Except in Baoting, Changjiang, Ding’an, Dongfang, Ledong and Tunchang, Se contents in natural soil were significant higher than in cultivated soil (p<0.05). It indicated that cultivated land had caused Se element loss. High level of Se content wasn’t caused by cultivation, but benefited from high background value in Hainan soil. By contrast in our related research, for most of heavy metals, which were considered as harmful to human health, their contents in natural soil were significant lower than in cultivated soil (p<0.05). It indicated that cultivated land had caused heavy metal to increase. Both these results turned out that quality of natural soil was better than cultivated soil in Hainan, and Hainan had a good soil environment as a whole.

3.3 Relationships between soil, rice and C/100,000

In order to explore the potential influence of soil Se on human health, correlation analysis was used to evaluate the relationships between soil, rice and C/100,000 (Table 2). Positive correlations were seen
between these three factors. Although the correlations were not statistically significant, it can infer that content of Se in soil has a positive effect on that in rice, and they all contribute to the high level of C/100,000 of Hainan province.

Table 2. Correlation coefficients between soil, rice and C/100,000

|            | C/1000000 | Cultivated soil | Rice |
|------------|-----------|----------------|------|
| C/1000000  | 1         |                |      |
| Cultivated soil | 0.270 | 1 | |
| Rice      | 0.464 | 0.117 | 1 |

Se concentration of rice [9] and the BAFs were listed in Table 3. Values of BAF varied among different counties. They were ranging from 0.06-0.66, and the average value was 0.15. Chengmai ranked the highest value of BAF while Lingao had the lowest value. The BAF reflected the transfer ability of Se from soil to rice, and maybe the reflection of its affect on human health. Higher BAF presented better potential for rice to accumulate Se from soil. However, it's a complex process and needs further studies.

Table 3. BAF of Se from soil to rice

| Region          | Cultivated soil (μg/kg) | Rice (μg/kg) | BAF  |
|-----------------|-------------------------|--------------|------|
| Baisha          | 297.70                  | 21.24        | 0.07 |
| Baoting         | 463.34                  | 44.11        | 0.10 |
| Changjiang      | 209.88                  | 31.91        | 0.15 |
| Chengmai        | 280.74                  | 185.68       | 0.66 |
| Danzhou         | 204.70                  | 30.86        | 0.15 |
| Ding'an         | 392.77                  | 56.57        | 0.14 |
| Dongfang        | 134.86                  | 35.83        | 0.27 |
| Haikou          | 576.40                  | 64.57        | 0.11 |
| Ledong          | 133.95                  | 41.59        | 0.31 |
| Lingao          | 471.18                  | 28.41        | 0.06 |
| Lingshui        | 260.06                  | 33.92        | 0.13 |
| Qionghai        | 426.69                  | 46.29        | 0.11 |
| Qionghai        | 375.69                  | 35.62        | 0.09 |
| Sanya           | 191.40                  | 44.85        | 0.23 |
| Tunchang        | 378.92                  | 35.24        | 0.09 |
| Wanning         | 489.85                  | 65.43        | 0.13 |
| Wenchang        | 417.16                  | 57.92        | 0.14 |
| Wuzhishan       | 167.02                  | 30.87        | 0.18 |
| Average         | 326.24                  | 49.50        | 0.15 |
| Max             | 576.40                  | 185.68       | 0.66 |
| Min             | 133.95                  | 30.87        | 0.06 |

4.Conclusions
This paper analyzed the distribution of Se in soil of Hainan Province by counties. Concentrations were ranging from 108.41-618.23μg/kg. The average value was 343.90μg/kg, which was much higher than background value of soil Se. It indicated that soil in Hainan was loaded with selenium, which may contribute to residents' health and high percentage of centenarians. Soil in northeast contains more Se than that in southwest. Se content in natural soil was significant higher than in cultivated soil. Cultivated land may cause loss of Se. Content of Se in soil has a positive effect on that in rice, and they all contribute to the high level of C/100,000 of Hainan province. Values of BAF varied among different counties. They were ranging from 0.06-0.66, and the average value was 0.15.
Acknowledgment
This work was supported by the National Natural Science Foundation of China [grant numbers 41601560 & 41671499] and the Strategic Priority Research Program of the Chinese Academy of Sciences [grant number XDA19040303].

References
[1] C.F. Mills.  Geochemical aspects of the aetiology of trace element related diseases. Geological Society London Special Publications, 113(1): 1–5(1996).
[2] B. Huang , Y.C. Zhao, W.X. Sun, R.Q. Yang, Z.T.Gong, Z. Zou, F. Ding, J.P. Su. Relationships between distributions of longevous population and trace elements in the agricultural ecosystem of Rugao County, Jiangsu, China. Environ Geochem Health 31(3):379–390 (2009).
[3] Y. Liu, Y.H. Li, J.P. Yu, H.R. Li, W.Y. Wang, L.S. Yang. Effects of Soil Trace Elements on Longevity Population in China. Biol. Trace. Elem. Res. 153: 119-126 (2013).
[4] L. V. Papp, J. Lu, A. Holmgren, K. K. Khanna. From selenium to selenoproteins: Synthesis, identity, and their role in human health. Antioxidants & Redox Signaling, 9, 775-806 (2007).
[5] I. M. J. Hamilton, W. S. Gilmore, J. J. Strain. Marginal copper deficiency and atherosclerosis. Biological Trace Element Research, 78, 179-189(2000).
[6] K. Yoshizawa, W. C. Willett, S. J. Morris, M. J. Stampfer, D. Spiegelman, E. B. Rimm, E. Giovannucci. Study of prediagnostic selenium level in toenails and the risk of advanced prostate cancer. J. Natl. Cancer I., 90, 1219-1224 (1998).
[7] Z. Hao, Y.H. Li, Y. Liu, H.R. Li, W.Y. Wang, J.P. Yu. Hair elements and healthy aging: a cross-sectional study in Hainan Island, China. Environ Geochem Health. 1-13 (2015).
[8] Xinhua. China Exclusive: Hainan declared as "World Longevity Island" (2014).
[9] Z. Hao, Y. Liu, Y. Li, W.J. Song, J. P. Yu, H.R. Li, W.Y. Wang. Association between Longevity and Element Levels in Food and Drinking Water of Typical Chinese Longevity Area. J Nutr Health Aging, 20, 9, 1-7(2016).
[10] W. Jiang, Q. Y. Hou, Z. F. Yang, T. Yu, C. Zhong, Y. Yang, Y.R. Fu.. Annual input fluxes of heavy metals in agricultural soil of Hainan island, China. Environ. Sci. Pollut R., 21, 7876-7885 (2014).
[11] Tabulation of the 2010 population census of China (2010)
[12] http://www.stats.gov.cn/tjsj/pcsj/rkpc/6rp/indexch.htm. Accessed October 23rd (2013).