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The effect of drinking water quality on the health and longevity of people-A case study in Mayang, Hunan Province, China

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Abstract. Drinking water is an important source for trace elements intake into human body. Thus, the drinking water quality has a great impact on people's health and longevity. This study aims to study the relationship between drinking water quality and human health and longevity. A longevity county Mayang in Hunan province, China was chosen as the study area. The drinking water and hair of local centenarians were collected and analyzed the chemical composition. The drinking water is weak alkaline and rich in the essential trace elements. The daily intakes of Ca, Cu, Fe, Se, Sr from drinking water for residents in Mayang were much higher than the national average daily intake from beverage and water. There was a positive correlation between Ni and Pb in drinking water and Ni and Pb in hair. There were significant correlations between Cu, K in drinking water and Ba, Ca, Mg, Sr in the hair at the 0.01 level. The concentrations of Mg, Sr, Se in drinking water showed extremely significant positive relation with two centenarian index 100/80% and 100/90% correlation. Essential trace elements in drinking water can be an important factor for local health and longevity.

1. Introduction

Trace elements can not be manufactured by human body itself, and they must be taken from the natural environment. Water is a major source of trace elements necessary for the growth of biological organisms. The composition of trace elements in water has a significant impact on human health. Changes in drinking water and groundwater sources can lead to significant changes in health risk related with trace elements [1].

Insufficient or excessive trace elements in water can lead to the occurrence of certain diseases. Liu XJ et al. found that the concentrations of Cu, Fe, Sr, Ti and V in the water samples from area with high incidence of gastric cancer were significantly higher than those in the area with low incidence of gastric cancer [2]. Another research on the relationship between the concentration of trace elements in drinking water and gastric cancer showed that Se and Zn can significantly prevent the development of gastric cancer [3]. Kikuchi H. et al. studied the relationship between the levels of trace elements in water and age-adjusted incidence of colon and rectal cancer, and the results showed that the incidence of colon cancer and rectal cancer was significantly related with the concentration of Au, Mg, Na, P, Sn,

Sr in water [4]. Studies on the relationship between Se and I in soil, water, and rice in an endemic thyroid area in Sri Lanka and the incidence of thyroid disease have shown that low incidence of thyroid disease in northern arid areas is associated with higher I concentrations in local drinking water [5]. In arid and semi-arid areas, the incidence of thyroid disease increases due to drinking deep groundwater with high iodine concentration [6]. P C Ferreira et al have shown that too high concentration of Al in water can increase the risk of neurological disorders in the older persons [7]. Research on the Ca concentration in the drinking water from a high incidence area of esophageal cancer showed that low Ca concentration in drinking water may be one reason for the high incidence of esophageal cancer, and Ca has a certain inhibitory effect on the occurrence of esophageal cancer [8]. Another research on the relationship between drinking water quality and the incidence of Kashin-Beck disease showed significantly higher concentrations of Cu and K and significantly lower concentrations of Al, Fe, Se in a Kashin-Beck disease endemic area than those in the non-disease areas [9]. Studies on the Cu concentration in the water and human health have shown that the acute exposure to Cu in drinking water can cause nausea and vomiting, and the chronic exposure of Cu in drinking water can affect the liver in the sensitive the population [10].

China has the phenomenon of regional health and longevity. From 2000 onwards, China started to evaluate and nominate the longevity county throughout the country. So far, 13 longevity counties have been nominated. To become a longevity county, an area should meet certain standards. The three basic assessment criteria for longevity county are: representativity of longevity, i.e. the number of centenarians in 100000 shall reach the international standard of 7/1000000; the integrity of longevity, i.e. the average life expectancy in the region should be at least 3 years higher than the national average; the sustainability of longevity, i.e. people over 80 years old should account for 1.4% of the total population. Mayang is one of the longevity counties that are nominated by the Chinese government.

High-quality water environment is an extremely important factor for the formation of a longevity region. Currently only random research have been conducted on the relationship between drinking water quality and the regional longevity phenomenon in China. The drinking water in the longevity area of Dujiangyan City in Sichuan province is from the densely vegetated Aba forest, and the concentration of harmful elements in the water is especially low. The spring water from Aba Dagu glacier is the world's oldest water, and has small water molecular group, low deuterium, high dissolved oxygen, a variety of natural mineral elements, weak alkaline, no pollution, no degradation, the vitality of life, and meet the needs of human nutrition and health standards for drinking water [11]. Research on the drinking water from another longevity region Yunlong county in Yunnan province showed that the spring water contained six macro elements Ca, K, Mg, Na, P, S and 8 trace elements Cu, Cr, Fe, Zn, Mn, Mo, Se, Sr [12]. Drinking water from Changxing Island, another longevity region, has slightly higher concentration of Mn and Fe, which is conducive to longevity [13].

In order to interpret the effect of drinking water quality on local health and longevity, a longevity county Mayang was selected as the study area in this study. The drinking water samples and hair samples of local centenarians was collected and tested the concentrations of macro and microelements. The drinking water quality was evaluated. The correlation coefficients between the elements in drinking water quality and hair and the correlation coefficients between the drinking water quality and different longevity and centenarian indices were analyzed and discussed in this manuscript.

2. Study area

Mayang County is located in the northwest of Huaihua City, western part of Hunan Province (figure 1). It is located between the Wuling Mountain and Xuefeng Mountain, with a total area of 1568 square kilometers and a total population of 3.73 million. Mayang belongs to subtropical monsoon climate zone. It has a mild climate, four distinct seasons, adequate light and heat, and abundant rainfall. It has an average yearly temperature of 17.1 ℃ , an average relative humidity of 78%, annual average sunshine of 1294.1 hours, and an average frost-free period of 297 days. The highest elevation is 1405 meters at the south Xihuang Mountain, and the lowest elevation is 130 meters at Maojiatan. Mayang has high life expectancy. According to the latest statistics, the average life expectancy in Mayang is

75.6. According to the fifth census, the county has 48320 people who are more than 60 years old, accounting for 13% of the total population; 5430 people at the age of 80-99 years old, accounting for 1.46% of the total population; 41 people who are hundred or more than hundred years old, accounting for 11/100,000 of the total population. All the indicators are well above the longevity standard specified by the United Nations Population Organization and China. It was formally named as a longevity region in China in December 2007 by the Chinese Society of Gerontology.
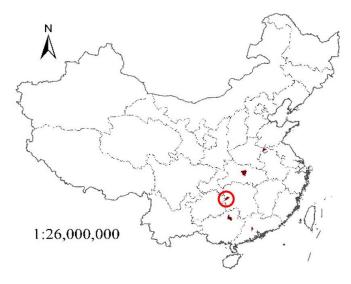

Figure 1. Study area.

3. Materials and methods

3.1. Water sampling and analysis

The drinking water samples were collected according to the distribution of centenarians in the county. As well water is the main drinking water sources for the local people. On average, there is a well in each centenarian's home. The drinking water samples were collected with a mineral water bottle in the centenarian's home. The pH of the sample was measured directly after the collection of the water samples by a hand-held pH meter. Afterwards 10 drops of 1: 1 HNO_3 were added to each sample to prevent the adsorption of soluble metal ions to the inner wall of the bottle and to reduce the microbial activity after sampling. The samples were immediately sent to the laboratory and stored in the refrigerator at 4°C until analysis. A total of 23 water samples were collected.

The concentrations of elements Al, Ba, Ca, Cd, Co, Cr, Cu, Fe, K, Li, Mg, Mn, Mo, Na, Ni, P, Pb, Se, Si, Sr, V, Zn in the water samples were analyzed with ICP-MS and ICP-AES according to the standard method GB/T 2050.6-2006. The concentration of F in the water samples was determined with a national standard F ion-selective electrode method GB/T 2050.5-2006.

3.2. Hair samples sampling and analysis

The occipital hair samples from the selected centenarians were collected with a clean stainless steel scissor. The collected samples were stored in a clean paper bag. A total of 17 hair samples were collected from the centenarians.

The hair samples were pretreated and digested according to the methods developed by K S Rao et al [14]. The hair samples were soaked in 1% detergent (volume percentage) for 24 hours. The oil and grease were removed by stirring several times during the soaking. The samples were washed with pure water afterwards until no foam, then rinsed with ultrapure water for 2 to 3 times. The washed samples were placed on clean filter papers and air dried for two days. Then the hair was cut it to 2mm with Teflon scissors, put into a clean paper bag and stored in a dry place until analysis.

0.2 g of hair sample was weighed into a 100ml glass beaker and added 1.0 mL H_2O_2 and 5.0ml superpure HNO_3. The glass beaker was placed on the hot plate for digestion. The temperature of the digestion was set from low to high. The temperature was controlled between 140-180℃. The digestion will continue until the liquid became light yellow and the residue was less than 0.5 mL. Then the beaker was taken away from the hot plate and cooled to room temperature. The residue was transferred from the beaker into a tube and diluted with 1% HNO_3 to 15 ml. The concentrations of elements Al, Ba, Ca, Fe, K, Mg, Mn, Mo, Na, P, Sr, V and Zn in the mixture were analyzed by ICP-OES [14], and the concentrations of Cd, Co, Cr, Cu, Li, Ni, Pb, Se were determined by ICP-MS [15].

3.3. Quality control
To control the analysis quality, 3 national standard samples were tested simultaneously together with each batch of samples. In addition, several random parallel samples were selected to test for each batch of samples. The standard sample for water samples is GBW08607 and the standard sample for hair sample is GBW09101b. To reduce system error, 2-3 blank samples were set for each batch of samples.

3.4. Statistical analysis
All the statistical analyses in this study are conducted by SPSS 13.0 for windows.

4. Results

4.1. The water quality in Mayang

Table 1. The water analysis results and national and WHO guideline values.

	Mayang	National standard		WHO Guideline values	
		Value	CR (%)	Value	CR (%)
pH	7.21	6.5-8.5	100	6.5-9.5	100
F (mg/L)	0.072		–	≤1.5	100
Ba (mg/L)	0.196	≤0.7	100		–
Cd (mg/L)	ND	≤0.005	100	≤0.003	100
Co (mg/L)	ND	≤1	100		–
Cr (mg/L)	ND	≤0.05	100	≤0.05	100
Cu (mg/L)	0.018	≤1	100	≤2	100
Fe (mg/L)	0.074	≤0.3	93.33	≤2	100
Mn (mg/L)	ND	≤0.1	100	≤0.4	100
Mo(mg/L)	ND	≤0.07	100	≤0.07	100
Na (mg/L)	15.70	≤200	100	≤200	100
Ni (mg/L)	0.004	≤0.02	100	≤0.07	100
Pb(mg/L)	ND	≤0.01	100	≤0.01	100
Se (μg/L)	0.872	≤10	100	≤10	100
Zn(mg/L)	0.009	≤1	100	≤3	100

Note: ND denotes "not detected"; CR denotes "compliance rate".

The average value of the tested parameters in the drinking water samples from Mayang was compared with China's national drinking water standard GB5479-1985 and WHO guideline values [16]. The results are shown in table 1. All the tested items are in line with China's national drinking water standards and WHO guidance values. The drinking water has an average pH of 7.21, which is between 7 and 8 and weak alkaline. Research showed that weak alkaline mineral water is conducive to human health, which can enhance blood circulation and cell metabolism, reduce the production of acidic substances, neutralize gastric acid, eliminate acidosis, and increase the pH of the stomach acid to meet the normal body needs [17]. Weak alkaline water has an almost same pH as human blood, which can maintain the blood vessels of the elderly soft and not hardened, the blood pressure low, and the pulse normal [18]. Alkaline ionized water improves the hyperacidity and abnormal intestinal fermentation [19]. The appropriate mineral elements and trace element content is also an important factor in promoting human health.

Since the existence of the extreme values (either extremely high or low values) may obscure the true range of the element, the probability that the measured sample falls within the range of China's national drinking water standard and WHO guideline value was further calculated. The results are also shown in table 1. Except Fe, which has a very small percentage out of the standard, all the other tested parameters are 100% in line with the national standard and the WHO standard. The drinking water quality is good in Mayang. This may be an important factor for local longevity.

4.2. The effect of element concentrations in drinking water on local health and longevity
The elements in drinking water can get into the human body through the daily dietary intake. Thus, the element concentration in drinking water has an important impact on the corresponding element content in the human body.

4.2.1. Effect of drinking water quality on daily element intake of residents. The elderly in Mayang drink local water in the long-term. Drinking water is an important source of daily elements intake for local people. The daily element intake from drinking water for the residents of Mayang was calculated using the USEPA reference value, and the daily drinking water consumption was 2.00 L [20]. The daily element intake from drinking water can be calculated with the following formula:

$$I_i = C_i * D$$

Where I_i is the daily intake of element i from drinking water, unit mg; C_i is the concentration of element i in drinking water, unit mg/L; D is the amount of water that people consume every day and it is a constant 2.00 L.

The daily element intake from drinking water for the residents in Mayang was calculated and compared with the national average daily intake from beverage and water [21]. The results were shown in table 2. The daily intakes of Ca, Cu, Fe, Se, Sr from drinking water for residents in Mayang were higher than the national average daily intake from beverage and water. The drinking water in Mayang was rich in these elements. Local residents can get enough elements for normal human body needs just by drinking 2 L of water every day.

Table 2. Daily element intake from drinking water for the residents in Mayang.

Element	Daily intake amount	National average daily intake from beverage and water
Ba (mg)	0.37	0.064
Ca (mg)	134.21	30.8
Cr (ug)	-	3.2
Cu (mg)	0.04	0.01
Fe (mg)	0.11	0.1
K (mg)	8.78	10.2

Mg (mg)	31.96	16.3
Mn (mg)	-	0.18
Mo (ug)	-	3
P (mg)	0.08	3
Sr (mg)	1.13	0.18
Zn (mg)	0.007	0.18
Se (ug)	1.77	0.5

4.2.2. Correlation of elements in drinking water and hair. The economic conditions are relatively backward in Mayang and the centenarians normally live in the place where they were born throughout their whole life. As water is an important source for various macro and microelements in human body, the concentrations of elements in drinking water have an important impact on the concentration of corresponding elements in human hair.

There are other sources for human exposure to these macro and micro elements, such as different hair care products shampoos, hair conditioners, hair dryers, etc. As all the hair samples are from centenarians living in the villages. Their living style is quite old fashioned. They use shampoos to wash hair sometimes, but not quite often. They normally don't use hair conditioners, hair dryers etc. Therefore, the effect of these hair care products on element concentration in hair is not taken into account in this study.

The correlation coefficients between the concentrations of elements in drinking water and in human hair were calculated using town as a statistical unit. There are totally 12 towns taken into statistics. The results were shown in table 3. The corresponding descriptive statistics were listed in table 4. There was a positive correlation between Ni and Pb in drinking water and Ni and Pb in hair, with a correlation coefficient of 0.392 and 0.567 respectively. There were significant correlations between Cu, K in the drinking water and Ba, Ca, Mg, Sr in the hair at the 0.01 level. The K, Ca and Mg exhibit the same characteristics in the hair [22]. Sr rarely exists as independent minerals. Sr normally exists in the Ca containing minerals in isomorphic forms due to the similar geochemical properties of Sr and Ca [23]. The results indicated that the element concentrations in drinking water will affect the concentrations of corresponding elements in the hair to a certain extent. Drinking water is an important source for the trace elements in hair.

Table 3. The correlation coefficients between elements in drinking water and elements in hair.

Water \ Hair	Ba	Ca	Cu	Fe	K	Mg	Ni	Pb	Sr	Se
Ba	-	-0.351	**0.788****	0.167	-	-	0.311	0.222	-	-
Ca	-	-0.486	**0.866****	0.152	-	-	0.384	0.273	-	-
Cu	0.090	0.375	0.076	0.134	-0.142	0.494	-	-	0.400	0.400
Fe	-	0.044	-0.184	-	-0.069	-	-	-	-	-
K	0.051	-0.080	-0.002	-	-0.279	-	0.137	-	-	-
Mg	-	-	**0.958****	0.404	-	-	0.472	0.272	-	-
Ni	0.296	0.403	-0.204	0.316	0.219	0.485	**0.392**	-	0.571	0.393
Pb	-	-0.043	0.146	0.189	-0.264	0.332	-	**0.567**	0.397	0.208
Sr	-	-	**0.899****	0.200	-	-	0.510	0.329	-	-
Se	-	-0.308	0.411	-	-0.350	-	-	0.359	-	-

Note: ** Indicates a significant correlation at p = 0.01 level;
* Indicates a significant correlation at p = 0.05 level

Table 4. The statistical results of element concentrations in drinking water and human hair (Take town as the statistical unit).

	Min	Max	Mean	SD
Hair Ba	0.95	6.85	3.93	1.74
Hair Ca	884.9	2847.8	1929	605.1
Hair Cu	3.52	7.99	5.26	1.28
Hair Fe	7.91	41.54	16.75	9.97
Hair K	0.85	64.77	25.09	17.20
Hair Mg	83.71	296.33	194.4	60.74
Hair Mn	0.141	1.484	0.382	0.379
Hair Ni	0.940	17.211	5.298	4.783
Hair Pb	2.069	7.198	5.301	1.550
Hair Sr	0.106	0.563	0.378	0.111
Hair Se	0	0.52	0.19	0.13
Water Ba	2.29	95.54	58.88	30.13
Water Ca	0.017	0.020	0.019	0.001
Water Cu	0	0.19	0.04	0.06
Water Fe	0.46	14.71	3.31	4.34
Water K	0.47	29.25	12.52	9.71
Water Mg	0.003	0.005	0.004	0.001
Water Mn	0	0.004	0.002	0.001
Water Ni	0.018	1.622	0.425	0.549
Water Pb	0.038	1.117	0.571	0.340
Water Sr	0.95	6.85	3.93	1.74
Water Se	884.9	2847.8	1929	605.1

Note: SD is the standard deviation; The concentrations of elements in hair is in the unit of mg/kg; For drinking water, all the elements are in the unit of mg/L, except; Se which is in the unit of μg/L.

4.2.3.   The correlation between element concentrations in drinking water and longevity index. In order to further analyze the relationship between concentrations of elements in drinking water and local longevity, the correlation coefficients between concentrations of macro and microelements in drinking water and different longevity population index in Mayang were calculated with town as the statistical unit. The longevity population index calculated in this study include: the proportion of people over 80 years old in people over 60 years old (80/60%); the proportion of people over 90 years old in people over 60 years old (90/60%); the proportion of people over 100 years old in people over 80 years old (100/80%); the proportion of people over 100 years old in people over 90 years old (100/80%) (100/90%).

The distribution of the aged population and longevity level in a region are mainly affected by social factors such as the birth rate, mortality rate, economic level and medical level. Centenarians, as a group of very special people, may be affected by different factors other than that of people in other age range. Therefore the population index are subdivided into two categories: longevity index, which mainly reflects the longevity level of a region, including 80/60% and 90/60%; and the centenarian

index, which mainly reflects the level of super-longevity in a region, including 100/80% and 100/90%. The correlation coefficients between concentrations of elements in drinking water and different population indices were shown in table 5.

The concentrations of Mg, Sr, Se in drinking water showed extremely significant positive relation with two centenarian index 100/80% and 100/90% and very weak negative correlation with the two longevity index 80/60% and 90/60% (table 5). The concentrations of K and Ca in drinking water also showed a high positive relationship with the two centenarian index 100/80% and 100/90%. Centenarians, as a special group of people, were significantly related with the concentrations of trace elements in drinking water. This illustrates that high-quality water environment is an extremely important factor for the emergence of a large number of centenarians in this region.

Table 5. The correlation coefficient between concentrations of elements in drinking water and different population indices.

Concentrations in water	80/60%	90/60%	100/80%	100/90%
Ba	0.334	0.296	0.436	0.329
Ca	0.079	-0.050	0.471	0.494
Cu	0.290	0.468	-0.314	-0.420
Fe	0.329	0.271	0.292	0.273
K	0.105	-0.292	0.361	0.491
Mg	-0.204	-0.166	**0.710****	**0.717****
Ni	0.322	-0.153	-0.168	0.062
Pb	-0.013	-0.052	-0.227	-0.253
Sr	-0.344	-0.411	**0.643***	**0.749****
Se	-0.006	-0.169	**0.717****	**0.731****

Note: ** Indicates a significant correlation at $p = 0.01$ level; * Indicates a significant correlation at $p = 0.01$ level.

5. Discussion

The chemical analysis results on the drinking water samples from local region showed that the water is weak alkaline and high quality. The water is rich in elements Ca, Cu, Fe, Se and Sr. The daily intake of these elements from drinking water is higher than the national average intake from beverage and water. The concentrations of Mg, Se and Sr had an extremely significant positive relationship with the two centenarian index 100/80% and 100/90%.

The concentration of Ca in drinking water has a direct impact on mineral contents in bone, and drinking water with high Ca concentration in the long-term is conducive to human health [24]. Research have shown that the concentration of Ca in drinking water have significant preventive effects on rectal cancer, gastric cancer, breast cancer and acute myocardial injury [25-29].

Iron Fe is an important trace element in the body. The deficiency of Fe can cause severe chronic diarrhea [30]. In addition, because of diarrhea, gastrointestinal loss of trace element will increase.

Selenium has antioxidant effects and can prevent excessive peroxide damage to the body. In the meantime, selenium can also protect the vision and the blood vessels. Selenium is the main anti-cancer element in the immune system and can directly kill tumor cells. Selenium and Se compounds are considered the most potent anticancer agent for prostate cancer [31]. Selenium can also prevent and treat cardiovascular disease. Drinking water that is rich in Se in the long term can enhance body's immunity to different diseases and thus is conducive to prolong lifespan.

Strontium is a component of human skeletal and teeth. It can promote bone growth and development. It can compete with Na in the intestine [32]. It can reduce Na absorption in the intestinal tract to a certain extent and reduce the negative effect of Na on health and longevity [33]. Strontium can prevent high blood pressure, prevention and treatment of diabetes, high blood cholesterol gallstone and other diseases.

6.　Conclusion

Element content in natural environmental media has an important impact on the element intake into human body. Of the different environmental medium, drinking water is an important source for element intake. The drinking water in longevity county Mayang is weak alkaline and rich in the essential trace elements, and has low concentrations of heavy metals. The drinking water is of high quality according to WHO and China national drinking water standard. The daily intakes of Ca, Cu, Fe, Se, Sr from drinking water for residents in Mayang were much higher than the national average daily intake from beverage and water. There are significant positive correlations between element concentrations in drinking water and in hair of local centenarians. The concentrations of Mg, Sr, Se in drinking water showed extremely significant positive relation with two centenarian index 100/80% and 100/90% correlation. High drinking water quality is an important factor for the formation of local longevity phenomenon.

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