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ORIGINAL ARTICLE

Hydrochemical anomaly of drinking waters in some endemic Kashin-Beck disease areas of Tibet, China

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Abstract Kashin-Beck disease (KBD) has been identified in some areas of Tibet, China. In this work, the Sangri, Nimu, Xietongmen and Gongbujiangda counties of Tibet were selected as case study areas to understand the relationship between KBD occurrence and chemical composition of drinking water. 30 drinking water samples were collected in the KBD-affected and KBD-unaffected villages of these four counties, and the hydrochemistry of endemic and non-endemic samples was compared. The results show that HCO_3–Ca, HCO_3–Ca·Na, and HCO_3·SO_4–Ca are the major hydrochemical types of water samples from both KBD-affected and KBD-unaffected villages. Although Se deficiency in environment has been widely regarded as an important cause of KBD, the Se concentrations in the drinking water samples do not correlate with KBD occurrence in the study areas. However, there are significant differences between the concentrations of Al, Fe, Na, Mn, Cd, Co, Cu, Ba and Mo in the endemic drinking water samples and those in the non-endemic samples, indicating that these constituents may be related to the prevalence of KBD in the study areas.

Keywords Kashin-Beck disease · Hydrochemistry · Drinking water · Tibet

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Introduction

Kashin-Beck disease (KBD), also known as "Big Bone Disease", is a disorder affecting the bones and joints of the hands (including fingers), elbows, knees, and ankles of children and adolescents. Individuals stricken with the disease develop chronically stiff or deformed joints, and even short limbs and statures due to necrosis of the growth plates of bones and those of joint cartilage. Endemic KBD occurs mostly in China, southeastern Siberia and North Korea (Sokoloff 1989). China is the most seriously afflicted country in the world. It was reported that there are 13 provinces and 2 autonomous regions with prevalent KBD in China (Tan et al. 2002). The KBD patients in China are mainly farmers who live in remote and rural areas. According to the statistics of 1999, there are about 40 million people living in the KBD areas of China, and the total population of KBD patients is more than 1 million (Yang et al. 2006).

From the 1850s to the 1950s, Russian researchers investigated the prevalence of KBD in Russia (Hinsenkamp 2001). In China, the relevant research studies have been carried out since the 1950s. These studies focused mainly on environmental etiology of KBD, with an emphasis on the relationship between KBD prevalence and selenium levels in eco-environments or human body (Li et al. 1982, 1992; Deng et al. 1999; Guo et al. 1999; Xu et al. 2000; Zhang et al. 2001; Wang et al. 2003; Fan 2005), organic matter concentration in drinking waters (Wu et al. 1987; Peng and Xu 1988; Wang and Feng 1989; Zhang et al. 1990; Wang et al. 1991a, b) and severe contamination of grains by fungi-produced mycotoxin (Bi et al. 2001).

Due to the geographic distribution of the KBD-prevalent areas, there are few studies concerning KBD conducted by western researchers before the 1990s. Since the late 1990s, a group of Belgian researchers made a series of investigations on KBD in Tibet, China. Mathieu et al. (1997, 2001a, b) and Hinsenkamp et al. (2001) carried out clinical–radiological studies on the identification of KBD in Lhasa, Shannan, and Rikaze of Tibet. Pasteels et al. (2001) and Suetens et al. (2001) made histopathological studies of the KBD sufferers in Lhasa of Tibet, and considered that KBD is induced by the peroxidation of chondrocytes as the antioxidant system of human body is impaired. Moreno-Reyes et al. (1998, 2001, 2003) investigated the relationship among the serum selenium concentration, thyroid function, and KBD status in children with ages between 5 and 15 living in the villages around Lhasa, and evaluated the effects of selenium and iodine supplements on KBD control. Chasseur et al. (1997, 2001) and Haubruge et al. (2001, 2003) analyzed the impact of food crop contamination by fungi-produced mycotoxin on the KBD prevalence in Lhasa and Rikaze, and accordingly recommended some prevention and control measures for KBD.

From the above overview of previous work, one notes that much effort has been made to explain the prevalence of KBD in terms of environmental etiology and pathology. However, there are so far only a few systematic studies that have focused on the relationship between KBD occurrence and drinking water chemical composition. The aims of this study are: (1) to investigate the hydrochemistry of major and trace elements in drinking waters in four counties of Tibet as study areas where KBD is prevalent; and (2) to delineate any hydrochemical anomalies of the water samples collected from the study areas. This study will not only be a reference for future etiological studies of KBD, but help to guide the prevention and control of KBD in Tibet and other KBD-afflicted areas.

KBD in Tibet

Tibet is where KBD disease is the most widely distributed, serious and active in China (Institute of Kashin-Beck Disease of Harbin Medical University 2000), and there have been reports of KBD cases in all seven of its administrative divisions (Lhasa, Changdu, Linzhi, Shannan, Rikaze, Naqu and Ali). A survey made in the 1980s indicates that there were 13 KBD counties in Tibet (Wang et al. 1985) (Fig. 1). However, 20 new KBD counties were discovered during an investigation made in the late 1990s (Yang et al. 2003) (Fig. 1). Altogether, KBD disease was present in 379 KBD villages distributed in the above 33 counties (Gong et al. 2004a, b), and the number of individuals diagnosed with KBD was 18,000, equivalent to 0.69% of the total population of Tibet (Zaxi et al. 2003). The number of villages with KBD incidence rates greater than 40% reached 113 and accounted for 30% of the total of KBD villages (Zaxi et al. 2007). Moreover, children and adolescents who were less than 25-year old accounted for 50% of the total KBD patients in Tibet (Gong et al. 2004a). The most serious KBD symptoms, such as shortened limbs and statures, were observed in children 5–10 years of age (Institute of Kashin-Beck Disease of Harbin Medical University 2000).

Sampling and analysis

The study areas selected for this investigation were the Sangri, Nimu, Xietongmen, and Gongbujiangda counties of Tibet. A total of 30 water samples were collected from springs, rivers, and streams that serve as drinking water sources for local residents. In each county, several KBD-affected and KBD-unaffected villages were chosen for drinking water sample collection and analysis. The sampling locations of all water samples were listed in Table 1.

All water samples were filtered through 0.45 μm membranes on site. Samples were collected in 300 ml polyethylene bottles, which had been rinsed with deionized water twice before sampling. For cation analysis, reagent-grade HNO_3 with molar concentration up to 14 M was added to one sample collected at each site to bring the pH below 1. Unstable hydrochemical parameters including water temperature, pH, and electrical conductance (EC) were measured on site using a portable pH/EC/temperature meter. Alkalinity was measured using the Gran titration method (Appelo and Postma 1996). The concentrations of SO_4^{2-}, Cl^-, and NO_3^- were determined on an unacidified sample by Ion Chromatography. Se was analyzed by Atomic Fluorescence Spectrometry, and other chemical constituents by ICP-MS within 2 weeks of sampling. The HCO_3^-, CO_3^{2-} and CO_2 concentrations of all samples were calculated from the measured alkalinity and pH using PHREEQC. The hydrochemical properties and major ion concentrations of all 30 water samples are listed in Table 2, and the trace element concentrations in Table 3.

Results and discussion

Major constituents

The hydrochemical 'type' of all collected water samples was determined from the concentrations of seven major constituents (HCO_3^-, SO_4^{2-}, Cl^-, Ca^{2+}, Mg^{2+}, Na^+, and K^+), and are listed in Table 1. HCO_3–Ca, HCO_3–Ca·Na, or HCO_3·SO_4–Ca are the hydrochemical types of almost all water samples, except for samples GBJD04-A, XTM01 and XTM02 from the KBD-affected villages, which are SO_4–Ca and HCO_3–Ca·Mg type, respectively. In other

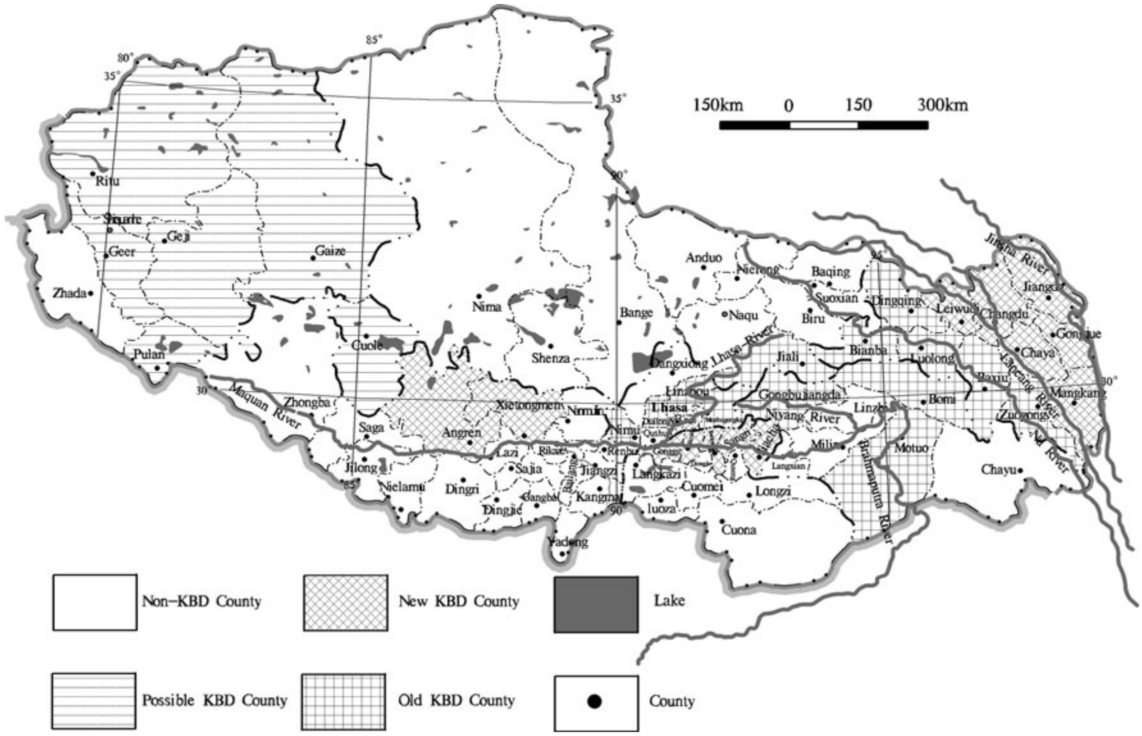

Fig. 1 Geographical distribution of the KBD counties in Tibet

Table 1 Sampling locations and hydrochemical types of water samples collected from the endemic and non-endemic villages of Sangri, Nimu, Xietongmen and Gongbujiangda counties

No.	Sampling location	Type of village	Longitude (°)	Latitude (°)	Elevation (m)	Hydrochemical type
SR01	Biba-III Village, Sangri County	Endemic area	92.034611	29.352056	3,871	$HCO_3 \cdot SO_4$–Ca
SR02	Biba-II Village, Sangri County	Endemic area	92.045111	29.319083	3,734	$HCO_3 \cdot SO_4$–Ca
SR03	Biba-I Village, Sangri County	Endemic area	92.041167	29.291361	3,628	$HCO_3 \cdot SO_4$–Ca
SR06	Zangga Village, Sangri County	Endemic area	92.210278	29.258611	3,581	$HCO_3 \cdot SO_4$–Ca
SR08	Qiamumai Village, Sangri County	Endemic area	92.327500	29.405833	3,946	HCO_3–Ca
SR09	Zengqi Village, Sangri County	Endemic area	92.364444	29.445000	4,105	HCO_3–Ca·Na
SR05	Jiangxiang-I Village, Sangri County	Non-endemic area	91.938861	29.280556	3,603	HCO_3–Ca
SR07	Quguosa Village, Sangri County	Non-endemic area	92.199444	29.336389	3,757	$HCO_3 \cdot SO_4$–Ca
SR10	Banggong Village, Sangri County	Non-endemic area	92.380000	29.483889	4,313	HCO_3–Ca·Na
NM02	Shangang Village, Nimu County	Endemic area	90.267778	29.569167	4,156	HCO_3–Ca
NM03	Old Hedong Village, Nimu County	Endemic area	90.262500	29.551667	4,068	HCO_3–Ca
NM04	Old Nixu Village, Nimu County	Endemic area	90.261111	29.515278	3,942	HCO_3–Ca
NM03-A	New Hedong Village, Nimu County	Non-endemic area[a]	90.266944	29.549167	4,072	HCO_3–Ca
NM04-A	New Nixu Village, Nimu County	Non-endemic area[a]	90.264167	29.520833	3,961	HCO_3–Ca·Na
NM01	Gonglang Village, Nimu County	Non-endemic area	90.274722	29.598889	4,305	HCO_3–Ca
NMS01	Shangang Village, Nimu County	Non-endemic area	90.271389	29.576389	4,201	HCO_3–Ca
NM05	Angang Village, Nimu County	Non-endemic area	90.265556	29.485000	3,917	HCO_3–Ca
NM06	Xumai Village, Nimu County	Non-endemic area	90.263333	29.468056	3,908	HCO_3–Ca·Na
XTM01	Old Lunzhuzi Village, Xietongmen County	Endemic area	88.580639	29.575917	4,158	HCO_3–Ca·Mg
XTM02	Old Duicuo Village, Xietongmen County	Endemic area	88.532972	29.507889	4,037	HCO_3–Ca·Mg

Table 1 continued

No.	Sampling location	Type of village	Longitude (°)	Latitude (°)	Elevation (m)	Hydrochemical type
XTM01-A	New Lunzhuzi Village, Xietongmen County	Non-endemic area[a]	88.577194	29.578000	4,182	HCO_3–Ca·Na
XTM02-A	New Duicuo Village, Xietongmen County	Non-endemic area[a]	88.533750	29.509222	4,036	HCO_3–Ca
XTM03	Renqinze Village, Xietongmen County	Non-endemic area	88.509611	29.487722	4,078	HCO_3–Ca
GBJD01	Old Xinsheng Village, Gongbujiangda County	Endemic area	92.961667	30.024444	3,666	HCO_3–Ca·Na
GBJD02	Nibi Village, Gongbujiangda County	Endemic area	93.022778	30.007222	3,631	HCO_3–Ca
GBJD03	Pang Village, Gongbujiangda County	Endemic area	93.043611	29.999444	3,652	HCO_3–Ca
GBJD04-A	Old Tangding Village, Gongbujiangda County	Endemic area	93.145278	29.934167	3,521	SO_4–Ca
GBJD01-A	New Xinsheng Village, Gongbujiangda County	Non-endemic area[a]	92.951667	30.030833	3,688	HCO_3–Ca
GBJD04	New Tangding Village, Gongbujiangda County	Non-endemic area[a]	93.145000	29.940000	3,501	HCO_3·SO_4–Ca
GBJD05	Jin Village, Gongbujiangda County	Non-endemic area	93.163611	29.917222	3,463	HCO_3·SO_4–Ca

[a] Sampling area is a new non-endemic village whose residents were emigrated from an old endemic village

Table 2 Average, maximum, and minimum values of hydrochemical properties and major constituent concentrations of water samples (in mg/L except for water temperature, *T*, in °C, electrical conductivity, EC, in μS/cm and pH)

Type of sample locations	*T*	pH	EC	HCO_3^-	SO_4^{2-}	Cl^-	NO_3^-	CO_3^{2-}	CO_2	SiO_2	HBO_2	Ca	Mg	Na	K	Al	Fe	Sr	TDS
Endemic villages of Sangri County																			
Average	11.7	7.78	83.4	27.5	11.8	2.2	2.8	0.08	1.16	4.6	0.17	12.3	1.3	2.4	0.7	0.23	0.73	0.06	54.6
Max	18.1	8.07	132.1	42.8	23.3	3.0	3.0	0.10	2.80	5.3	0.38	19.8	2.0	4.3	1.6	0.39	1.08	0.09	85.6
Min	7.1	7.46	56.7	18.5	4.0	1.7	2.6	0.04	0.34	3.4	0.00	7.0	0.9	1.0	0.2	0.06	0.40	0.04	41.2
Non-endemic villages of Sangri County																			
Average	15.6	7.94	145.2	72.5	10.3	2.6	2.7	0.53	1.79	7.3	0.09	21.5	2.1	4.6	1.2	0.08	0.30	0.09	91.5
Max	18.4	8.41	220.2	128.9	21.4	2.9	3.1	0.79	3.09	13.5	0.26	35.5	3.3	5.5	2.1	0.11	0.42	0.16	136.5
Min	13.1	7.57	95.7	38.3	4.8	2.2	2.1	0.08	0.35	3.1	0.00	11.9	1.6	3.4	0.7	0.04	0.18	0.06	63.4
Endemic villages of Nimu County																			
Average	13.4	7.67	52.7	25.5	3.1	2.6	3.1	0.06	1.04	4.2	0.04	8.0	1.3	2.9	1.0	0.45	0.95	0.05	41.4
Max	14.1	7.78	55.1	27.8	3.1	2.6	3.1	0.07	1.24	4.6	0.04	8.8	1.4	2.9	1.1	0.59	1.22	0.05	44.6
Min	12.9	7.57	51.4	24.2	3.1	2.6	3.0	0.04	0.77	3.8	0.03	7.6	1.2	2.8	0.9	0.32	0.74	0.04	39.8
Non-endemic villages of Nimu County																			
Average	15.1	7.70	116.0	61.9	5.2	2.8	3.3	0.25	2.10	5.1	0.15	15.9	1.5	6.0	2.2	0.10	0.34	0.12	75.8
Max	18.4	7.96	178.9	96.5	9.0	3.2	3.6	0.62	2.78	8.8	0.31	22.5	1.9	12.1	3.4	0.30	0.86	0.22	113.2
Min	10.7	7.48	42.9	17.4	2.5	2.6	3.0	0.03	0.76	3.5	0.02	6.1	1.1	2.4	0.7	0.01	0.08	0.04	33.3
Endemic villages of Xietongmen County																			
Average	11.9	8.33	86.7	85.1	8.7	2.7	3.2	1.16	1.10	14.3	0.01	17.8	7.3	3.4	4.5	8.25	14.2	0.08	129.2
Max	12.2	8.64	87.0	104.5	11.6	2.7	3.2	1.64	1.91	14.6	0.01	19.4	9.3	3.6	5.3	8.97	15.2	0.09	142.5
Min	11.6	8.01	86.3	65.8	5.8	2.6	3.2	0.69	0.29	13.9	0.01	16.2	5.4	3.2	3.6	7.53	13.3	0.08	115.9
Non-endemic villages of Xietongmen County																			
Average	14.5	8.20	106.0	53.0	6.4	2.6	3.2	0.57	1.34	6.5	0.29	14.3	2.3	4.7	1.9	0.25	0.44	0.08	71.3
Max	16.1	8.84	125.3	73.0	8.5	2.7	3.3	1.03	3.24	7.3	0.65	17.1	3.4	5.6	2.4	0.46	0.65	0.11	83.3
Min	13.4	7.62	77.5	28.8	3.9	2.6	3.1	0.18	0.08	5.3	0.01	10.0	1.3	4.0	1.3	0.02	0.08	0.06	56.3
Endemic villages of Gongbujiangda County																			
Average	16.6	8.07	54.9	19.6	8.5	2.6	3.0	0.12	0.35	2.5	0.10	8.3	1.1	2.1	0.7	0.39	0.44	0.03	40.0
Max	20.2	8.31	68.6	33.1	20.2	2.6	3.1	0.23	0.59	3.5	0.23	11.2	1.7	2.9	0.8	0.77	1.00	0.05	48.1
Min	14.3	7.72	42.5	2.6	2.8	2.5	3.0	0.03	0.02	1.9	0.03	6.8	0.8	1.7	0.6	0.05	0.09	0.03	34.3

Table 2 continued

Type of sample locations	*T*	pH	EC	HCO_3^-	SO_4^{2-}	Cl^-	NO_3^-	CO_3^{2-}	CO_2	SiO_2	HBO_2	Ca	Mg	Na	K	Al	Fe	Sr	TDS
Non-endemic villages of Gongbujiangda County																			
Average	16.6	8.32	62.9	26.0	7.5	1.8	3.0	0.53	0.32	2.8	0.07	9.3	1.3	2.3	0.8	0.11	0.18	0.04	43.0
Max	18.2	8.78	76.6	36.2	8.1	2.7	3.1	1.26	0.73	4.9	0.13	10.7	1.7	3.4	1.1	0.16	0.26	0.04	54.3
Min	14.4	7.78	54.6	17.9	7.1	0.0	3.0	0.07	0.10	1.7	0.03	8.4	1.0	1.7	0.5	0.03	0.06	0.03	37.2

Table 3 Average, maximum, and minimum values of trace element concentrations of water samples (in μg/L)

Type of sample locations	Se	Mn	Cd	Co	Cu	Ba	Mo	Pb	Cr	Ni	V	Zn	As	Li
Endemic villages of Sangri County														
Average	0.70	22.1	0.04	0.43	2.0	11.6	2.0	9.6	1.3	8.2	19.6	16.8	5.0	2.2
Max	0.88	31.4	0.10	1.00	9.4	14.6	2.7	23.2	4.2	46.5	42.1	69.7	9.7	5.9
Min	0.51	10.5	0.00	0.00	0.0	5.1	1.1	0.5	0.0	0.0	0.5	0.2	1.0	0.6
Non-endemic villages of Sangri County														
Average	0.84	9.7	0.01	0.23	1.0	7.1	2.3	6.1	1.6	2.4	25.4	12.7	7.8	2.2
Max	1.12	12.7	0.02	0.41	1.8	9.5	4.1	16.5	3.0	5.7	70.6	17.8	10.7	3.1
Min	0.56	6.3	0.00	0.00	0.0	4.8	1.3	0.6	0.0	0.0	0.4	3.8	3.0	1.3
Endemic villages of Nimu County														
Average	0.22	45.7	0.01	0.86	2.8	7.3	1.9	1.6	3.1	2.9	1.3	20.6	1.7	2.4
Max	0.33	55.7	0.01	1.12	2.9	8.1	2.0	1.8	3.2	3.1	1.6	27.5	1.9	3.0
Min	0.07	33.2	0.01	0.66	2.7	6.5	1.8	1.4	2.9	2.7	1.0	17.0	1.6	1.9
Non-endemic villages of Nimu County														
Average	0.23	12.7	0.01	0.40	2.2	6.1	2.4	1.1	2.2	2.0	3.6	75.4	3.5	13.1
Max	0.48	32.5	0.01	0.57	3.9	8.5	6.1	2.7	3.0	3.9	12.1	365.2	8.6	29.3
Min	0.07	1.1	0.00	0.31	0.7	4.0	0.9	0.4	1.8	1.0	0.6	14.0	0.6	1.4
Endemic villages of Xietongmen County														
Average	1.03	879.6	0.08	12.2	24.7	127.3	1.6	25.3	8.2	11.5	24.4	98.0	7.6	28.4
Max	1.05	918.8	0.11	16.1	37.3	160.3	1.9	31.0	8.8	13.7	28.9	107.3	10.3	31.0
Min	1.00	840.3	0.05	8.26	12.2	94.2	1.3	19.6	7.6	9.3	19.9	88.7	5.0	25.7
Non-endemic villages of Xietongmen County														
Average	0.74	23.6	0.01	0.59	3.7	11.9	2.0	1.4	2.4	2.6	2.0	50.6	2.8	5.4
Max	1.05	41.5	0.02	0.84	6.6	16.2	3.0	2.3	2.5	3.7	2.6	93.4	6.0	11.2
Min	0.19	1.8	0.01	0.30	1.4	7.0	1.4	0.5	2.3	1.2	1.5	20.9	1.1	2.5
Endemic villages of Gongbujiangda County														
Average	0.27	26.1	0.06	0.83	31.6	6.9	0.6	1.1	3.1	4.7	0.6	29.0	0.6	1.2
Max	0.35	59.2	0.22	1.88	120.6	11.5	0.8	2.0	3.8	9.1	1.4	59.9	0.9	1.8
Min	0.13	5.0	0.01	0.38	1.4	4.5	0.5	0.6	2.1	1.7	0.2	14.9	0.3	0.6
Non-endemic villages of Gongbujiangda County														
Average	0.31	6.2	0.02	0.42	3.6	5.3	2.2	2.5	3.5	14.3	0.3	36.8	1.0	1.6
Max	0.48	10.0	0.03	0.48	6.4	6.6	3.4	5.9	3.6	28.9	0.4	63.0	1.4	2.3
Min	0.22	2.2	0.01	0.38	1.3	4.4	0.7	0.6	3.3	1.9	0.2	19.8	0.7	0.8

words, there is basically no difference in hydrochemical type between water samples from KBD-affected areas and those from KBD-unaffected areas. In fact, the concentrations of most major constituents and the TDS values of the endemic samples do not show anomalies as compared to the non-endemic samples (see Table 2). For instance, the average TDS values of water samples from the KBD-affected villages of Sangri and Nimu County are 54.6 and 41.4 mg/L, respectively, lower than those from the KBD-unaffected villages (91.5 and 75.8 mg/L, respectively). However, in the KBD-affected and KBD-unaffected villages of Xietongmen County, the average TDS values of the drinking water samples were 129.2 and 71.3 mg/L, respectively, the former being evidently higher than the latter. In Gongbujiangda County, the average TDS values in drinking water are almost the same between the KBD-affected and KBD-unaffected villages (40.0 and 43.0 mg/L, respectively). It is worth noting that a Russian geochemist Vinogradov (1949) proposed that KBD is caused by deficiency of calcium and excess of strontium in drinking water and other ingested media in the environment. However, this proposed idea is not supported by this study. In Sangri, Nimu and Gongbujiangda counties, the average concentrations of both Ca and Sr in the endemic samples were lower than those in the non-endemic samples, whereas in Xietongmen County, the situation was the reverse.

Although there are no significant differences in the concentrations of most major constituents between the endemic samples and the non-endemic samples, Na, Al, and Fe are exceptions. It can be seen from Fig. 2a that the average Na concentrations in the water samples from the KBD-affected villages of Sangri, Nimu, Xietongmen, and Gongbujiangda counties are all less than those from the KBD-unaffected villages of the corresponding county. Similarly, in every county, the average Al and Fe concentrations in the endemic samples are higher compared to the non-endemic samples (Fig. 2b, c). The average Al and Fe concentrations of the endemic samples collected from Xietongmen County are especially high and 33.3 and 32.3 times those of the non-endemic samples, respectively. It is possible that these elements may have relations to the KBD occurrence in the study areas. Interestingly, M. Aiiso and K. Hiyeda have also indicated that chronic intake of Fe from drinking water or food may result in KBD, but the mechanism by which excessive Fe intake induces KBD has not been determined (Guo 2008).

Selenium

Whether Se deficiency in the environment can cause KBD is still under debate. In 1972, Professor D. Mo of Xi'an Medical University of China reported for the first time that the selenium concentrations in drinking waters and food crops in some KBD areas were lower than those in KBD-unaffected areas (Mo et al. 1975). Since then, the relationship between KBD prevalence and selenium deficiency in environmental media or human organs has been intensively investigated in China. The most significant result of these studies is that KBD-affected areas of China

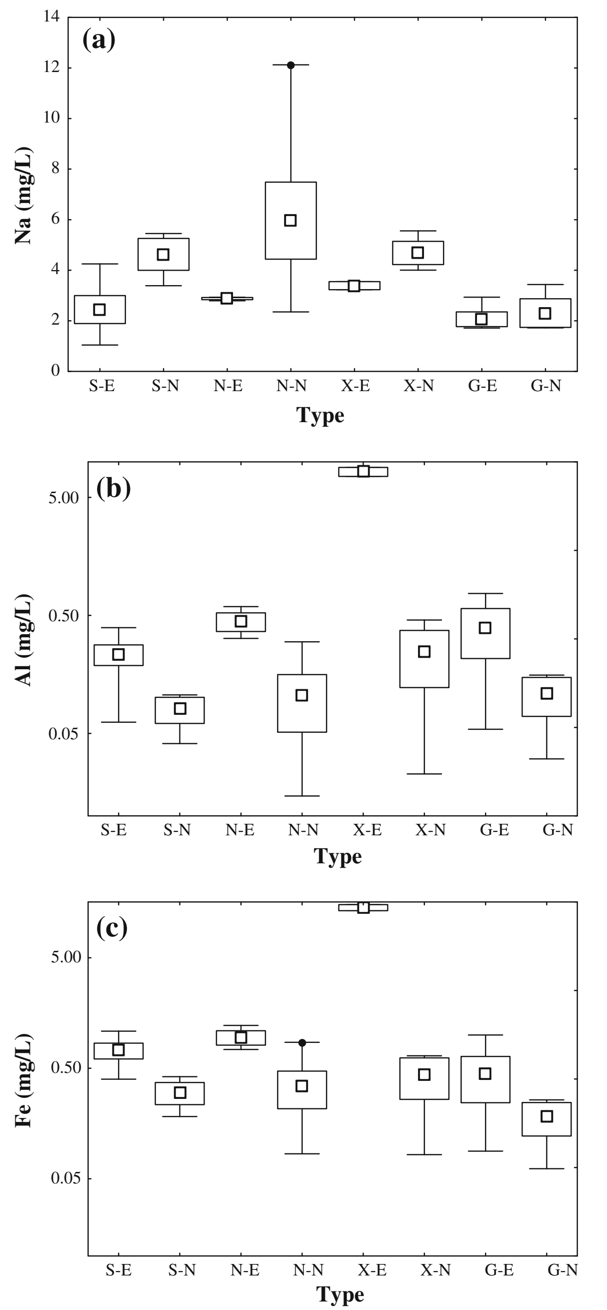

Fig. 2 *Box* and *whisker plots* of the Na (**a**), Al (**b**), and Fe (**c**) concentrations for water samples of different type. The meanings of type S-E, S-N, N-E, N-N, X-E, X-N, G-E and G-N are as follows. *S-E* samples collected from the endemic villages of Sangri County, *S-N* samples collected from the non-endemic villages of Sangri County, *N-E* samples collected from the endemic villages of Nimu County, *N-N* samples collected from the non-endemic villages of Nimu County, *X-E* samples collected from the endemic villages of Xietongmen County, *X-N* samples collected from the non-endemic villages of Xietongmen County, *G-E* samples collected from the endemic villages of Gongbujiangda County, *G-N* samples collected from the non-endemic villages of Gongbujiangda County. The *boxes* show the mean value minus standard error, the mean value, and the mean value plus standard error. The smallest and largest values are indicated by the small *horizontal bars* at the end of the whiskers. *Bullet* represents outlier values

are generally located along a northeast–southwest belt where the selenium concentrations of surface soils are usually lower than 0.125 mg/kg (Tan et al. 2002). However, there are many exceptions. For example, selenium levels are very low in Yulin and Luonan of Shaanxi Province, China, but there is no KBD occurrence in these two areas. Conversely, in many endemic KBD areas, such as Yidu of Shandong Province and Banma of Qinghai Province, soil selenium levels are relatively high.

To evaluate the relationship between selenium concentration of drinking water and KBD occurrence in Tibet, we compared the average selenium concentrations of the endemic water samples and those of the non-endemic water samples. The results indicate that although the average selenium concentrations in the water samples from the endemic villages of Sangri and Gongbujiangda counties (0.70 and 0.27 μg/L, respectively) are slightly lower than those from the non-endemic villages (0.84 and 0.31 μg/L, respectively), the endemic samples from Xietongmen County (1.03 μg/L) have higher average selenium concentrations as compared to the non-endemic samples (0.74 μg/L). In Nimu County, there is little difference in average selenium concentration between the endemic samples (0.22 μg/L) and the non-endemic samples (0.23 μg/L). In fact, no significant statistical difference in selenium concentration was found between the endemic water samples and the non-endemic water samples in each of the four counties (the *P* levels are much higher than 0.05). So the selenium concentration of drinking water does not correlate with the prevalence of KBD in the study areas. Further study should focus on inspecting whether or not the prevalence of KBD in Tibet results from selenium deficiencies in other environmental media (such as soil and food crop).

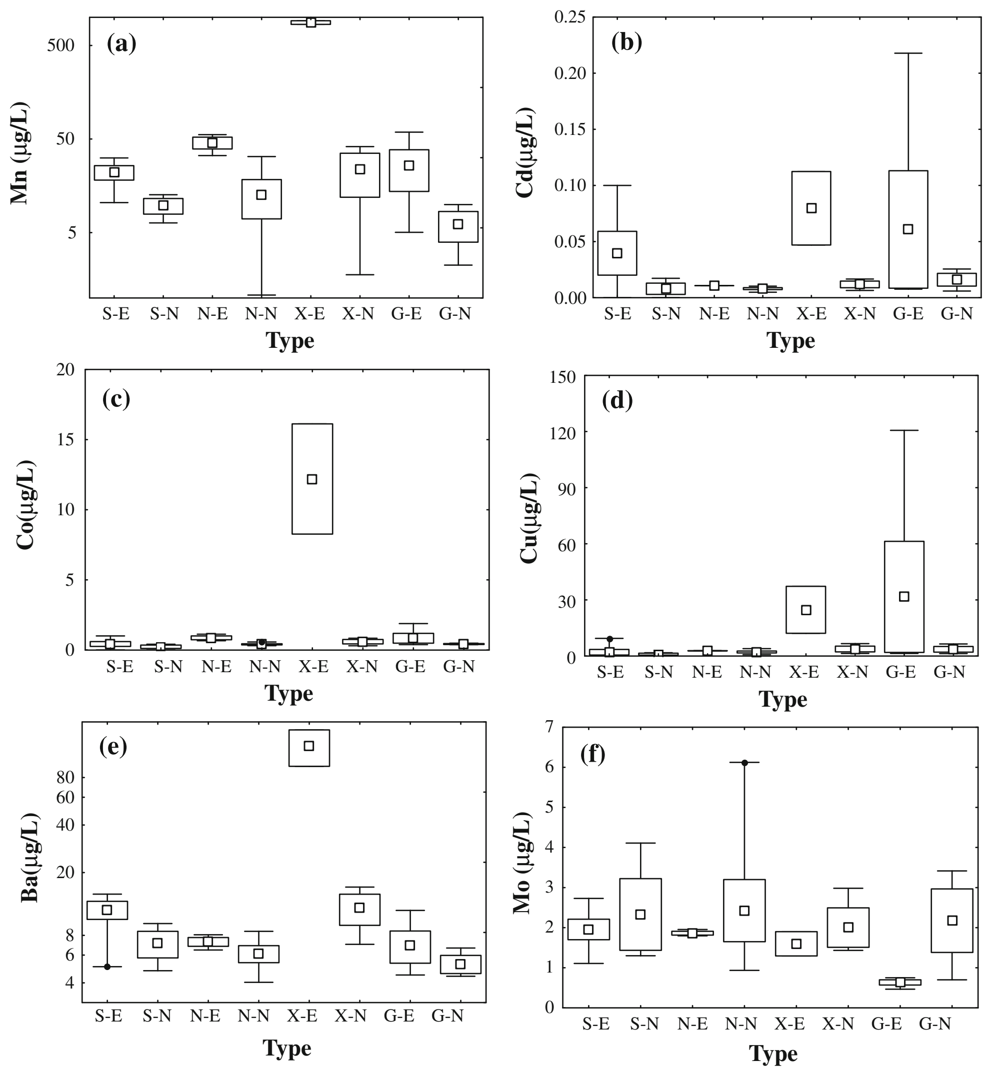

Fig. 3 *Box* and *whisker plots* of the Mn (**a**), Cd (**b**), Co (**c**), Cu (**d**), Ba (**e**) and Mo (**f**) concentrations for water samples of different type. The meanings of the types and the legend of the figure are the same as in Fig. 2

Other trace elements

Similar to Se, some other trace elements in drinking water, including Pb, Cr, Ni, V, Zn, As, and Li, do not correlate with KBD occurrence in the study areas. However, Mn in the drinking water samples is different. The average Mn concentration of the endemic samples is higher than that of the non-endemic samples (Fig. 3a). Specifically, the drinking water samples collected from the endemic areas of Sangri, Nimu, Xietongmen, and Gongbujiangda counties have average Mn concentrations of 2.3, 3.6, 37.3 and 4.2 times higher than those from the corresponding KBD-unaffected areas, which is in accordance with the research results of Voshchenko and Ivanov (1990). They concluded that manganese may play an important role in the etiology of KBD occurring in Russia, and proposed that excessive intake of manganese from drinking water can induce osteoclast activation, which in turn inhibits bone growth and causes KBD.

Besides manganese, the average concentrations of Cd, Co, Cu and Ba in the drinking water samples from the KBD-affected and KBD-unaffected villages were also compared, and the results are the same as for Mn. As Fig. 3b, c, d, and e shows, the water samples from the KBD-affected villages have higher average Cd, Co, Cu and Ba concentrations than those from the KBD-unaffected villages. Furthermore, contrary to Mn, Cd, Co, Cu and Ba, the average Mo concentration in the water samples from the KBD-affected areas of each county was lower than those from the corresponding KBD-unaffected areas (Fig. 3f). It is interesting that Cu and Ba were more enriched in drinking waters and soils in the KBD areas of Russia as compared to the background values as well (Muchkin 1967). However, whether or not the Cd, Co, Cu, Ba and Mo concentration anomalies in drinking water are related to the occurrence of KBD has not been ascertained through pathological studies. Thus, more investigations in other KBD areas are needed to further reveal the relationship between the prevalence of KBD and the Cd, Co, Cu, Ba and Mo concentrations in drinking water.

Conclusions

In Sangri, Nimu, Xietongmen and Gongbujiangda counties, there are no distinct differences in hydrochemical type between the drinking water samples from the KBD-affected villages and those from the KBD-unaffected villages. Almost all the water samples are of HCO_3–Ca, HCO_3–Ca·Na, and $HCO_3 \cdot SO_4$–Ca types. Also most of the major constituents in drinking water, including HCO_3^-, SO_4^{2-}, Cl^-, NO_3^-, CO_3^{2-}, CO_2, Ca, Mg, K, Sr, SiO_2, and HBO_2, are not correlated with KBD occurrence in the study areas. However, the Na, Al and Fe concentrations of drinking water in the KBD-affected villages of Sangri, Nimu, Xietongmen and Gongbujiangda were significantly different from that in the KBD-unaffected villages of the corresponding county, indicating that the anomalous concentrations of these constituents may be related to the prevalence of KBD.

The Se concentrations in drinking water are not correlated to the occurrence of KBD. In Xietongmen County, the average Se concentration of the endemic water samples is even higher than that of the KBD-unaffected samples. Among other trace elements, Mn, Cd, Co, Cu and Ba are of higher average concentration in the endemic samples than in the non-endemic samples, whereas the results for Mo are lower. In other words, the enrichment of Mn, Cd, Co, Cu and Ba and the deficiency of Mo in drinking water may be related to the prevalence of KBD in the study areas. However, the anomalous differences in these elements must be further substantiated in other areas, and pathological studies are required to substantiate any link between KBD disease and these elemental anomalies.

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