

Hydrochemical characteristics and element contents of natural waters in Tibet, China

TIAN Yuan^{1,2}, *YU Chengqun¹, *LUO Kunli¹, ZHA Xinjie³, WU Jianshuang¹, ZHANG Xianzhou¹, NI Runxiang^{1,2}

1. Institute of Geographic Sciences and Natural Resources Research, CAS, Beijing 100101, China;

2. University of Chinese Academy of Sciences, Beijing 100049, China;

3. Xi'an University of Science and Technology, Xi'an 710054, China

Abstract: Sixty water samples (35 groundwater samples, 22 surface water samples and three hot-spring water samples) were collected at 36 points from villages and towns in Lhasa city, Nagchu (Nagqu) prefecture, Ali (Ngari) prefecture and Shigatse (Xigaze) prefecture (Tibet) in 2013 to study the hydrochemical characteristics and element contents of natural waters. The concentrations of elements were determined in the water samples and compared with the concentrations in water samples from other regions, such as southeast Qinghai, south Xinjiang, east Sichuan and west Tibet. The hydrochemical species in different areas were also studied. Water in most parts of Tibet reaches the requirements of the Chinese national standard and the World Health Organization international standard. The pH values of the water samples ranged from 6.75 to 8.21 and the value for the mean total dissolved solids was 225.54 mg/L. The concentration of arsenic in water from Ali prefecture exceeded the limit of both the Chinese national standard and the international standard and the concentration of fluoride in water from Shuanghu exceeded the limit of both the Chinese national standard and the international standard. The main hydrochemical species in water of Tibet is $\text{Ca}(\text{HCO}_3)_2$. From south to north, the main cation in water changes from Ca^{2+} to Na^+ , whereas the main anions in water change from HCO_3^- to Cl^- and SO_4^{2-} . The chemistry of river water and melt water from ice and snow is dominated by the rocks present at their source, whereas the chemistry of groundwater is affected by many factors. Tectonic divisions determine the concentrations of the main elements in water and also affect the hydrochemical species present.

Keywords: element concentrations; hydrochemical species; water chemistry; water quality; Tibet

1 Introduction

The Tibet Autonomous Region (26°44'–36°32'N, 78°25'–99°06'E) is located on the Qing-

Received: 2014-10-20 **Accepted:** 2014-11-16

Foundation: National Key Technologies R&D Program in the 12th Five-Year Plan of China, No.2011BAD17B05-4, No. 2011BAC09B03; National Key Basic Research Program of China (973 Program), No.2014CB238906; National Natural Science Foundation of China, No.40872210, No.41172310, No.40171006

Author: Tian Yuan (1991–), Graduate student in Institute of Geographic Sciences and Natural Resources Research, CAS, specialized in geology and health, environmental science. E-mail: tiany.13s@igsnr.ac.cn

***Corresponding author:** Yu Chengqun, Professor, E-mail: yucq@igsnr.ac.cn
Luo Kunli, Professor, E-mail: luokl@igsnr.ac.cn

hai-Tibet Plateau on the southwestern border of China. It has a land area of $1.22 \times 10^6 \text{ km}^2$ with an average elevation being $>4 \text{ km}$ above sea level. The geology of Tibet is complicated and diverse and there are unique geological hazards in this region (Shen *et al.*, 2011).

According to *China's Water Resource Report in 2007* (MWR, 2009), the inflowing rivers and lake water in Tibet have enormous capacity, low elements concentrations and are of good quality; the waters are mainly composed of rain, ice/snow melt water and groundwater. The average volume of surface water resources in Tibet is $4.394 \times 10^{11} \text{ m}^3$ per year, which accounts for 17% of the total surface water resources of China's mainland. The total volume of groundwater resources in Tibet is about $9.661 \times 10^{10} \text{ m}^3$. The cover area and volume of the glaciers in Tibet account for 48.2% of the surface cover and 53.6% of the total volume of the glaciers in China (MWR, 2009; Bian *et al.*, 2010). The volume of ice/snow melt water in Tibet is about $3 \times 10^{11} \text{ m}^3$.

Zhang *et al.* (2013) analyzed the quality of drinking water in Nyingchi, Tibet in 2011, which showed that the water quality in Nyingchi did not often reach the required standard for drinking water. Liu and Ge (2012) determined trace elements in lake water from a mining area using the inductively coupled plasma mass spectrometry (ICP-MS) and compared the results with those obtained by four other methods to determine the optimum sample recovery rate. Bu *et al.* (2011) determined the concentration of arsenic in three fish ponds in Lhasa. The arsenic concentration in Quxu Niedang fish pond was the highest at $>60 \text{ }\mu\text{g/L}$. Nie *et al.* (2011) analyzed the microbiological indicators in drinking water from counties in Lhasa and found that the water quality did not often reach the required microbiological standards for drinking water. Wang *et al.* (2013) studied the hydrochemical characteristics of Lake Manasarovar and Lake Rakshastal and showed that the pH was inversely proportional to the amount of dissolved oxygen. Zheng *et al.* (2007a, 2007b, 2008) monitored and tested the water quality in some areas of Naqu and Biru where troops were stationed; the water samples did not often reach the required standard for drinking water and the arsenic concentration commonly exceeded the Chinese national standard. Zhang *et al.* (2009) and Li *et al.* (2010) analyzed the hydrochemical characteristics of water samples collected from the Niyang and Yarlung Zangbo rivers in Tibet and reported some basic data for the water samples. Liu *et al.* (2013) analyzed the results of a drinking water safety project in rural areas of Shannan in 2012; the results showed that some water samples were polluted. Luo *et al.* (2010) surveyed the water quality of about 140 urban drinking water sources in Tibet and found that 96.9% of the drinking water samples in urban areas met the required standard for drinking water. Zhao *et al.* (2002) investigated the water quality of self-supplied water sources in some remote areas where troops were stationed and water sanitation was poor.

There have been few systematic studies of the geochemical features and element concentrations of waters in Tibet. We investigated the elemental composition and distribution of water in Tibet in August 2013 (Figure 1) and collected water samples for analysis. From September to October, we determined the elemental composition and hydrochemical characteristics of water samples at the Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences (IGSNRR, CAS). We also studied the hydrochemical and element characteristics of these water samples. This paper is a comprehensive report of the concentration and distribution of elements in waters from different geological areas of Tibet.

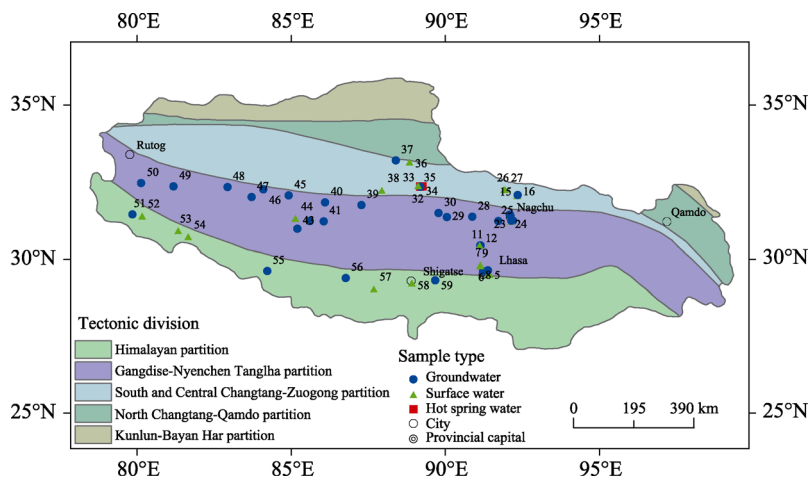


Figure 1 Geographical location, tectonic divisions (based on Ma *et al.*, 2002) and distribution of water sampling points in Tibet

2 Study areas and methods

2.1 Sampling sites and types of samples

Sixty water samples (35 groundwater samples, 22 surface water samples and three hot-spring samples) were collected (Tables 1 and 2) from the majority of counties in Lhasa

Table 1 Distribution of surface water sampling locations in Tibet

Sample No.	Date	Latitude (°)	Longitude (°)	Elevation (m)	Sample site	Sample type
1	2013.04.27	29.566389	91.401144	4196	No.7 team, Xincang village, Dazi county	River water
2	2013.04.27	29.570000	91.393056	4287	No.7 team, Xincang village, Dazi county	Ice/snow melt
5	2013.07.13	29.604167	91.380833	3970	No.6 team, Xincang village, Dazi county	River water
6	2013.07.20	29.873056	91.093333	3972	Bailang village, Linzhou county	River water
7	2013.07.20	29.873056	91.093333	3972	Bailang village, Linzhou county	River water
8	2013.07.20	29.871667	91.092500	3954	Bailang village, Linzhou county	River water
9	2013.07.20	29.850000	91.092222	4041	Bailang village, Linzhou county	River water
12	2013.07.24	30.495000	91.069167	4317	Dangxiong field station	Ice/snow melt
14	2013.08.04	32.105833	92.285278	4645	Nyainrong, Nyainrong county	River water
15	2013.08.04	32.109722	92.302500	4634	Nyainrong, Nyainrong county	Ice/snow melt
21	2013.08.05	31.273333	92.102778	4450	Kema village, Luoma town, Nagchu	River water
26	2013.08.08	32.301111	91.868056	4683	Amdo county	River water
27	2013.08.08	32.303333	91.906944	4732	Shenkagang village, Amdo county	River water
35	2013.08.11	32.433056	89.081111	4791	Duoma township, Shuanghu county	River water
36	2013.08.11	33.206944	88.798611	4981	Shuanghu county	Ice/snow melt
38	2013.08.12	32.286944	87.901944	4754	Cuozechuoma town, Shuanghu county	River water
44	2013.08.17	31.370000	85.091667	4728	Gerze county	River water
52	2013.08.21	31.451111	80.120556	4675	Alzadar county	River water
53	2013.08.21	30.970278	81.285000	4679	Baga town, Burang county	Ice/snow melt
54	2013.08.22	30.776389	81.613611	4625	Huoer town, Burang county	Ice/snow melt
57	2013.08.22	29.088611	87.637778	4048	Lhatse county	River water
58	2013.18.23	29.278889	88.879167	3777	Shigatse	River water

Table 2 Distribution of groundwater sampling locations in Tibet

Sample number	Date	Latitude (°)	Longitude (°)	Elevation (m)	Sample site	Depth (m)
3	2013.04.28	29.642406	91.180731	3666	Tibet University, Lhasa	–
4	2013.04.28	29.642950	91.180108	3666	Tibet University, Lhasa	6
10	2013.07.23	30.476389	91.099722	4297	Damxung county	5
11	2013.07.23	30.477500	91.103056	4281	Damxung county	30
13	2013.08.03	31.475908	92.062089	4521	Nagchu town, Nagqu county	–
16	2013.08.04	32.110000	92.303611	4612	Nyainrong	10
17	2013.08.04	31.465556	92.062778	4508	Nagchu town, Nagchu	10
18	2013.08.05	31.468611	92.059167	4534	Nagchu town, Nagchu	–
19	2013.08.05	31.271944	92.158611	4471	Kema village, Luoma town, Nagqu county	10
20	2013.08.05	31.271944	92.160000	4439	Kema village, Luoma town, Nagqu county	5
22	2013.08.05	31.469167	92.047500	4523	Nagchu town, Nagqu county	27
23	2013.08.05	31.275833	92.105278	4459	Nagqu field station, Nagqu county	10
24	2013.08.06	31.471944	92.047500	4506	Nagqu Agriculture Bureau, Nagqu county	–
25	2013.08.07	32.264050	91.681160	4685	Amdo county	–
28	2013.08.09	31.405278	90.835278	4606	Baila town, Baingoin county	6
29	2013.08.09	31.395000	90.007778	4703	Baingoin county	15
30	2013.08.10	31.523333	89.741111	4576	Mendang town, Baingoin county	4
31	2013.08.10	32.390000	89.218889	4703	Duoma town, Shuanghu county (40°C)	–
32	2013.08.10	32.386667	89.149167	4701	Duoma township, Shuanghu county (50°C)	–
33	2013.08.10	32.388056	89.149722	4708	Duoma township, Shuanghu county (60°C)	–
34	2013.08.10	32.384444	89.145278	4705	Duoma town, Shuanghu county	15
37	2013.08.12	33.233056	88.352222	4811	Jiacuo, Shuanghu county	4
39	2013.08.13	31.786111	87.234722	4553	Nyima county	–
40	2013.08.15	31.876944	86.061667	4797	Asuo town, Nyima county	6
41	2013.08.15	31.253056	86.014722	4726	Juncang town, Nyima county	8
42	2013.08.16	31.263333	85.563056	4690	Cishi town, Cuoqin county	10
43	2013.08.16	31.018056	85.153889	4649	Cuoqin county	10
45	2013.08.17	32.098611	84.878889	4433	Dongco, Gerze county	–
46	2013.08.17	32.300000	84.055278	4447	Gerze county	11
47	2013.08.18	32.040697	83.669022	4398	Marm, Gerze county	5
48	2013.08.19	32.371667	82.891111	4474	Wenbudangsang town, Geji county	–
49	2013.08.19	32.388333	81.143333	4542	Geji county	5
50	2013.08.20	32.503333	80.090000	4308	Seng-ge Kambab	–
51	2013.08.21	31.481389	79.801111	3755	Tholing, Zanda county	35
55	2013.08.22	29.652169	84.181464	4602	Laozhongba town, Zhongba county	6
56	2013.08.22	29.419006	86.724014	4632	Sangsang town, Ngamring county	10
59	2013.18.23	29.346667	89.635833	3752	Dazhu village, Shigatse	15
60	2013.08.24	29.676389	91.344722	3699	Dazi county Lhasa field station	30

city, Nagchu prefecture, Ali prefecture and Shigatse prefecture in Tibet. The tap water for everyday use in Tibet comes from untreated shallow wells, river water and ice/snow melt water. These samples (nine samples from the Himalayan partition, 38 samples from Gangdise–Nyenchen Tanglha partition and 13 samples from the South and Central Changtang–Zuogong partition) therefore reflected the range of hydrochemical characteristics and types of natural water in Tibet.

2.2 Sampling and analysis

2.2.1 Sampling and preservation

The authors strictly complied with the methods in *Monitoring and Analysis Methods for Water and Waste Water* (MEP, 2002) to collect water samples from different geological areas in Tibet in August 2013. The sample containers used were colorless 0.5 L polythene plastic barrels and were dipped into nitric acid for 24 h before use. The containers were then washed sequentially with 10% hydrochloric acid solution and tap water. The containers were then washed with distilled water and finally flushed three times with sampling water.

2.2.2 Methods of analysis

The water samples were analyzed at the IGSNRR, CAS. The pH, E_c , RES, salinity (SAL), total dissolved solids (TDS) and temperature were determined using a Switzerland Mettler Toledo pH tester (SevenGo SG2) and Switzerland Mettler Toledo E_c tester (SevenGo SG3). The E_h was determined in situ using a Shanghai Sanxin ORP tester (SX712). The total hardness (TH) was calculated from the concentrations of Ca^{2+} and Mg^{2+} . The alkalinity (as HCO_3^-) was determined by acid–base titration (MH, 1985; MEP, 2002). The chloride (Cl^-) concentration of the water samples was determined using a chloride ion-selective electrode (Hirokazu *et al.*, 1985; Yu *et al.*, 2010) and the fluoride (F^-) concentration was determined using a fluoride ion-selective electrode (MH, 1985; MEP, 2002). All water samples were stored in pre-cleaned plastic bottles at 4°C before analysis. Selenium and arsenic were determined by hydride generation atomic fluorescence spectrometry (MH, 1985; MEP, 2002). The concentrations of the major cations (Ca^{2+} , Mg^{2+} , Na^+ , K^+ , P, Sr, B and SiO_2) and the SO_4^{2-} anion were determined by inductively coupled plasma atomic emission spectrometry (Optima 5300 DV, Waltham, Massachusetts in the United States, PerkinElmer). The concentrations of trace elements (Li, Zn, U, Rb, Ba, Bi, Co, Cs, Ga, In, Ti, V, Ag, Al, Be, Cd, Cr, Cu, Fe, Hg, Mn, Mo, Ni, Pb and Tl) were determined by ICP-MS (PerkinElmer, DRC-e). In each test method, a parallel sample was determined to ensure the stability of the data after every 20 samples. The percentage error in all the samples ranged from $\pm 0.19\%$ to $\pm 4.96\%$, i.e. less than $\pm 5\%$ (Figure 2). Therefore these data are accurate and dependable (Shen *et al.*, 1993; Ji *et al.*, 2007).

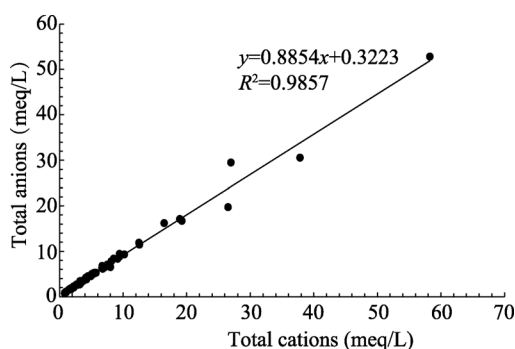


Figure 2 Total cations versus total anions in water samples from Tibet

3 Results

3.1 Hydrochemical characteristics and element concentrations

The water samples collected from Tibet have good hydrochemical and sensory characteristics (Tables 3 and 4). The pH in these samples ranged from 6.75 to 8.21, with a mean value of 7.54. The average TDS was about 225.54 mg/L, except for the hot-spring water. Because the majority of the water samples were collected from surface runoff, which is mainly re-charged by ice/snow melt, the hardness of these samples ranged from soft to moderately hard.

3.2 Trace element concentrations

The background concentrations of elements from different geological settings not only affect the hydrochemical characteristics of the major elements in water, but also affect the hydrochemical characteristics of the trace elements (Warren, 1989; Webster, 1994). The

Table 3 Hydrochemical characteristics and element concentrations in surface water samples from Tibet

Sample number	pH	E_h (mV)	E_c (μ S/cm)	TDS (mg/L)	TH (mg/L)	Ca^{2+} (mg/L)	Mg^{2+} (mg/L)	Na^+ (mg/L)	K^+ (mg/L)	HCO_3^- (mg/L)	SO_4^{2-} (mg/L)	Cl^- (mg/L)	SiO_2 (mg/L)
1	7.62	336	179	90	84	28.9	2.8	2.2	0.7	39.7	32.6	11.0	6.8
2	7.30	293	197	99	105	40.2	1.2	1.9	0.3	91.5	10.6	6.1	10.2
5	7.36	220	151	76	77	26.6	2.6	2.4	0.4	54.9	3.2	12.8	12.6
6	7.45	224	96	48	44	13.6	2.4	2.7	0.7	15.3	12.0	8.7	6.5
7	7.38	217	80	40	37	11.3	2.0	1.4	0.5	9.2	11.5	9.0	5.7
8	7.29	235	95	47	44	13.6	2.4	2.8	0.7	21.4	12.2	10.1	6.6
9	7.31	227	76	38	36	11.2	1.9	1.4	0.5	10.7	11.9	6.6	5.8
12	7.15	226	133	66	68	21.5	3.5	1.3	0.8	39.7	21.5	8.8	4.5
14	7.77	202	263	131	133	38.3	9.0	9.7	1.5	122.0	7.8	7.2	9.1
15	7.55	209	348	174	186	53.0	12.8	9.7	1.2	155.6	12.6	34.3	10.4
21	7.37	213	187	93	78	20.8	6.3	13.9	1.6	73.2	12.3	10.0	8.8
26	7.65	185	529	265	268	67.1	24.1	27.1	3.0	268.5	59.8	14.4	7.6
27	7.81	175	401	200	217	69.8	10.1	14.6	2.0	253.2	8.6	9.6	11.0
35	7.80	185	1530	765	443	73.0	62.5	218.7	3.9	192.2	521.0	98.9	8.7
36	8.02	172	344	172	180	26.3	27.5	11.9	3.7	125.1	32.8	27.5	9.1
38	8.21	168	278	139	158	45.4	10.6	4.7	1.3	94.6	44.3	12.4	8.5
44	7.90	188	368	184	196	58.6	11.8	11.8	1.8	155.6	56.3	13.6	11.8
52	7.72	209	595	298	352	75.8	38.9	9.0	4.3	167.8	158.5	17.5	9.7
53	7.90	200	172	86	89	23.8	7.0	4.4	0.7	18.3	39.3	21.9	4.7
54	7.96	207	90	45	43	12.8	2.6	3.1	0.9	3.1	12.3	20.3	6.2
57	7.64	219	226	113	121	40.3	4.9	4.6	0.8	79.3	30.7	15.4	9.4
58	7.73	225	355	178	194	50.9	15.9	8.9	0.5	128.1	43.6	18.3	18.3

Table 4 Hydrochemical characteristics and element contents in groundwater samples from Tibet

Sample number	pH	E_h (mV)	E_c (μ S/cm)	TDS (mg/L)	TH (mg/L)	Ca ²⁺ (mg/L)	Mg ²⁺ (mg/L)	Na ⁺ (mg/L)	K ⁺ (mg/L)	HCO ₃ ⁻ (mg/L)	SO ₄ ²⁻ (mg/L)	Cl ⁻ (mg/L)	SiO ₂ (mg/L)
3	7.28	262	250	125	119	38.1	5.6	7.0	1.3	91.5	21.3	8.5	12.7
4	7.31	244	261	131	124	38.6	6.5	7.4	1.5	85.4	27.2	9.5	9.6
10	6.95	245	279	139	134	39.9	8.1	10.5	1.5	103.7	10.4	15.8	16.9
11	7.11	233	161	81	83	24.3	5.3	3.2	1.0	64.1	6.4	10.0	11.1
13	7.10	252	1587	793	605	131.4	66.5	152.2	7.8	485.1	156.0	182.1	10.0
16	7.37	213	600	300	320	112.3	9.4	13.7	1.8	280.7	29.6	26.6	10.6
17	7.28	230	1399	699	563	102.4	73.8	112.0	4.0	515.6	143.7	152.8	9.0
18	7.81	205	404	202	165	31.7	20.6	33.7	3.7	155.6	44.1	16.3	6.8
19	7.37	220	467	233	237	69.1	15.4	19.7	3.2	192.2	35.3	18.1	25.5
20	6.93	235	458	229	227	61.9	17.4	18.6	4.1	167.8	46.0	16.2	33.1
22	7.07	243	2480	124	667	151.4	69.2	292.0	13.6	167.1	95.5	860.6	12.6
23	7.34	222	732	366	216	52.2	20.5	103.2	5.0	378.3	44.3	32.0	9.4
24	7.20	220	1055	528	445	134.0	26.4	77.6	5.4	387.5	94.5	89.7	15.4
25	7.37	207	554	277	282	69.2	26.1	23.3	2.9	259.3	49.5	17.2	9.6
28	7.86	191	337	168	169	33.2	20.6	15.8	1.5	198.3	12.0	10.5	10.6
29	7.56	210	804	402	389	126.2	17.5	34.5	3.6	405.8	52.7	15.6	15.4
30	7.79	195	307	154	148	32.6	15.9	16.7	2.5	61.0	19.3	65.0	10.1
31	6.75	245	1999	1000	472	144.4	26.7	363.3	20.8	970.2	86.4	35.3	25.9
32	7.46	226	4360	2180	182	48.7	14.5	1171.0	53.4	2785.6	196.3	57.5	31.5
33	7.19	220	2970	1487	183	57.3	9.5	732.3	33.8	1424.8	137.8	40.1	89.9
34	7.55	180	972	486	315	81.6	26.5	131.5	8.5	585.8	43.0	18.1	22.9
37	7.77	189	693	346	336	79.6	32.8	35.3	7.4	231.9	146.6	40.9	9.3
39	7.89	187	669	334	169	26.1	25.0	98.1	5.6	195.3	64.6	50.7	13.7
40	7.84	193	540	270	224	56.8	19.8	45.2	6.5	286.8	49.5	21.6	11.6
41	7.89	185	340	170	171	59.5	5.3	16.4	1.8	146.4	9.5	39.9	15.2
42	7.64	201	814	407	368	102.5	26.7	43.7	4.8	106.8	154.5	119.7	17.4
43	7.93	193	266	133	134	36.5	10.2	10.0	3.0	109.8	24.8	19.4	16.7
45	7.55	208	793	397	428	100.3	42.6	33.3	4.2	347.8	93.0	37.8	16.6
46	7.73	199	628	314	210	38.1	27.5	71.0	4.0	207.5	76.0	51.4	17.4
47	7.64	223	72	36	315	51.4	44.9	59.8	16.2	205.9	122.1	79.0	36.8
48	7.73	202	433	217	206	44.3	23.0	24.4	3.5	183.1	49.8	25.1	12.0
49	7.81	199	270	135	107	35.7	4.3	21.0	2.7	85.4	29.9	21.6	17.3
50	7.62	208	578	289	243	66.2	18.6	42.6	3.9	231.9	48.8	44.0	17.2
51	7.81	202	311	155	163	40.2	15.0	10.2	2.5	97.6	53.0	13.6	13.5
55	7.46	230	770	385	362	124.1	12.4	18.2	2.3	238.0	39.9	86.7	13.7
56	7.55	222	457	229	233	69.8	14.1	12.0	1.2	112.9	36.2	61.9	15.6
59	7.81	223	300	150	178	29.9	24.7	3.3	0.7	137.3	5.5	17.7	21.1
60	7.72	233	211	106	107	35.7	4.4	5.7	1.5	42.7	26.9	27.7	11.9

average selenium concentration of the water samples was 0.154 $\mu\text{g/L}$ (maximum 0.898 $\mu\text{g/L}$). The average fluoride concentration was 0.44 mg/L (maximum 7.24 mg/L). However, the average fluoride concentration of the hot-spring water samples was 4.62 mg/L , higher than that of the other samples. The fluoride concentration in Shuanghu county was also high, with an average concentration of about 2.31 mg/L (Tables 5 and 6).

3.3 Test results of toxic elements

The average arsenic concentration in water samples (except the hot-spring water samples) in Tibet was 8.66 $\mu\text{g/L}$. The arsenic concentration in northern Tibet (Damxung, Shuanghu, Gerze, Geji and Seng-ge Kambab) was higher than that in other areas of Tibet, with an average value of about 113.23 $\mu\text{g/L}$, 11 times higher than the *Standards for Drinking Water Quality* (MH, 2006; 10 $\mu\text{g/L}$) (Tables 7 and 8). The water in these areas is therefore not suitable for drinking.

Table 5 Concentrations of trace elements in surface water samples from Tibet

Sample number	Li ($\mu\text{g/L}$)	Sr (mg/L)	B (mg/L)	Zn ($\mu\text{g/L}$)	Se ($\mu\text{g/L}$)	F (mg/L)	U ($\mu\text{g/L}$)	Rb ($\mu\text{g/L}$)	Ba ($\mu\text{g/L}$)	Co ($\mu\text{g/L}$)	Cs ($\mu\text{g/L}$)	Ga ($\mu\text{g/L}$)	V ($\mu\text{g/L}$)
1	0.25	0.10	0.01	1.48	0.00	0.02	0.20	0.36	4.43	0.04	0.00	0.20	0.08
2	0.87	0.09	0.01	0.36	0.20	0.04	0.15	0.05	0.42	0.06	0.01	0.01	-0.11
5	0.16	0.07	0.01	7.77	0.00	0.04	0.24	0.28	1.56	0.03	0.46	0.08	0.77
6	2.29	0.05	0.09	3.48	0.00	0.04	0.03	0.62	3.16	0.06	0.10	0.17	0.11
7	0.33	0.04	0.01	2.16	0.00	0.04	0.02	0.31	1.86	0.04	0.03	0.10	-0.12
8	2.20	0.05	0.10	1.97	0.03	0.04	0.04	0.51	2.65	0.07	0.06	0.13	0.04
9	0.38	0.04	0.01	1.12	0.00	0.04	0.02	0.37	1.92	0.05	0.04	0.11	-0.06
12	0.92	0.06	0.01	1.86	0.00	0.06	0.71	0.77	3.26	0.03	0.03	0.17	-0.06
14	12.6	0.14	0.12	0.57	0.01	0.25	5.57	0.65	11.97	0.07	0.04	0.54	-0.07
15	10.2	0.49	0.09	1.17	0.08	0.36	3.28	1.99	7.77	0.07	0.83	0.38	-0.07
21	8.23	0.09	0.11	3.06	0.02	0.17	0.18	1.42	5.74	0.10	0.17	0.36	0.31
26	42.5	0.37	0.25	0.92	0.07	0.16	1.13	5.10	50.22	0.08	2.22	2.24	-0.30
27	14.4	0.26	0.22	0.55	0.01	0.16	3.37	0.57	25.26	0.10	0.03	1.10	-0.16
35	140	3.05	1.50	2.91	0.52	0.58	10.85	0.42	13.08	0.10	0.18	0.56	0.27
36	18.3	0.30	0.18	57.33	0.25	0.15	0.93	1.84	29.23	0.03	0.69	1.28	0.28
38	8.87	0.25	0.24	1.97	0.11	0.13	1.58	0.50	7.19	0.05	0.10	0.32	-0.23
44	162	0.24	0.52	1.72	0.18	0.18	1.20	6.96	16.13	0.05	18.83	0.69	-0.36
52	22.3	0.69	0.34	4.18	0.85	0.04	1.35	7.76	12.15	0.06	12.05	0.50	-0.43
53	2.48	0.18	0.07	5.80	0.13	0.15	0.31	0.66	13.27	0.09	0.28	0.60	-0.43
54	2.59	0.08	0.14	3.70	0.19	0.07	0.08	0.78	5.95	0.03	0.07	0.24	-0.36
57	2.67	0.12	0.10	2.46	0.22	0.24	0.52	0.17	1.29	0.04	0.03	0.05	-0.41
58	7.3	0.29	0.21	1.45	0.45	0.14	0.95	0.27	5.07	0.05	0.09	0.21	-0.09

Table 6 Concentrations of trace elements in groundwater samples from Tibet

Sample number	Li (μg/L)	Sr (mg/L)	B (mg/L)	Zn (μg/L)	Se (μg/L)	F (mg/L)	U (μg/L)	Rb (μg/L)	Ba (μg/L)	Co (μg/L)	Cs (μg/L)	Ga (μg/L)	V (μg/L)
3	48.9	0.15	0.18	55.80	0.00	0.09	2.39	6.08	6.49	0.05	5.45	0.30	0.15
4	50.3	0.15	0.20	7.68	0.00	0.12	2.41	6.49	11.98	0.06	9.06	0.58	0.09
10	2.97	0.15	0.13	1.16	0.00	0.04	0.30	0.09	33.48	0.07	0.02	1.66	-0.08
11	1.15	0.09	0.02	21.54	0.00	0.06	0.21	0.07	25.74	0.04	0.16	1.33	-0.16
13	105	1.03	0.37	7.14	0.04	0.38	5.54	4.49	87.75	0.58	0.99	4.22	0.38
16	12.7	0.27	0.15	3.40	0.00	0.08	1.95	0.57	64.37	0.31	0.03	3.10	0.21
17	95.3	1.40	0.49	1.47	0.05	0.48	5.83	0.88	24.06	0.41	0.02	1.07	0.32
18	54.4	0.31	0.31	0.99	0.03	0.26	2.15	5.88	21.20	0.07	2.06	0.98	0.32
19	60.6	0.29	0.18	2.06	0.01	0.43	1.49	4.53	18.29	0.10	0.03	0.85	-0.27
20	85.0	0.27	0.18	10.43	0.00	0.27	0.24	5.68	53.84	0.65	0.02	2.54	-0.26
22	79.8	0.80	0.36	4.40	0.05	0.22	4.09	9.31	71.36	0.36	0.64	3.12	2.19
23	121.77	0.28	0.41	3.24	0.00	0.33	0.93	2.87	8.80	0.06	0.03	0.38	-0.04
24	24.6	0.45	0.32	2.00	0.03	0.10	2.93	1.01	60.78	0.34	0.01	2.70	0.20
25	39.9	0.88	0.22	4.79	0.08	0.19	1.65	2.14	73.71	0.09	0.04	3.24	-0.12
28	10.4	0.25	0.21	24.22	0.07	0.20	1.48	0.38	42.85	0.06	0.01	1.92	0.34
29	37.4	0.63	0.22	22.15	0.05	0.19	22.77	0.46	41.98	0.23	0.01	1.81	-0.06
30	35.7	0.26	0.31	2.90	0.05	0.33	1.44	1.19	26.70	0.05	0.04	1.18	0.13
31	745	1.64	2.92	18.34	0.04	3.05	0.42	82.40	94.15	0.28	85.13	4.50	-0.58
32	2658	1.96	8.61	1.94	0.13	7.24	0.06	190.64	75.57	0.10	428.09	3.33	0.10
33	1495	1.77	5.35	1.80	0.06	3.56	0.31	125.09	102.19	0.05	144.69	4.69	-0.22
34	295	0.86	1.18	2.47	0.15	1.34	1.45	33.29	104.00	0.11	48.34	4.75	0.81
37	29.9	0.47	0.60	6.76	0.75	0.27	13.46	2.93	33.63	0.10	15.38	1.44	-0.09
39	96.5	0.51	1.62	6.16	0.22	0.32	4.74	1.46	43.89	0.13	0.07	1.96	2.06
40	142	0.67	1.05	1.76	0.16	0.33	3.75	18.55	104.26	0.09	7.65	4.64	3.42
41	18.98	0.23	0.43	2.12	0.08	0.14	1.93	0.35	43.80	0.08	0.07	1.97	0.13
42	64.7	0.71	1.06	3.44	0.10	0.26	11.61	0.57	28.43	0.20	0.08	1.23	0.13
43	27.7	0.19	0.77	2.91	0.09	0.24	1.30	1.19	11.28	0.05	0.11	0.49	-0.23
45	55.0	0.79	0.60	2.59	0.24	0.39	2.71	3.17	25.84	0.09	1.66	1.11	-0.13
46	49.5	0.55	1.11	0.99	0.49	0.33	2.29	1.09	24.86	0.05	0.07	1.09	0.55
47	458	0.45	2.11	428.69	0.53	1.20	9.08	51.88	23.02	0.08	119.46	0.98	1.84
48	116	0.79	0.96	68.11	0.57	0.19	1.86	14.48	36.96	0.05	70.10	1.64	0.28
49	33.0	0.16	1.39	15.97	0.14	0.14	1.26	5.20	12.03	0.05	0.99	0.52	0.43
50	159	0.41	2.32	6.95	0.09	0.14	3.41	6.22	30.70	0.17	6.99	1.33	0.34
51	30.3	0.41	0.58	5.94	0.24	0.11	1.72	2.06	39.20	0.04	0.77	1.72	-0.01
55	14.2	0.46	0.07	3.80	0.11	0.04	2.27	0.25	9.52	0.15	0.04	0.39	-0.23
56	7.49	0.33	0.10	3.35	0.90	0.06	0.86	0.68	17.18	0.10	0.78	0.76	-0.25
59	3.12	0.12	0.09	1.19	0.18	0.07	0.43	0.43	6.84	0.04	0.45	0.28	-0.29
60	31.9	0.13	0.15	24.38	0.18	0.11	1.14	3.75	6.17	0.04	5.46	0.26	-0.47

Table 7 Concentrations of toxic elements in surface water samples from Tibet

Sample number	Al (μg/L)	As (μg/L)	Be (μg/L)	Cr (μg/L)	Cu (μg/L)	Fe (μg/L)	Mn (μg/L)	Mo (μg/L)	Ni (μg/L)	Pb (μg/L)	Se (μg/L)
1	3.26	1.10	0.05	6.77	0.31	76.00	0.09	1.56	0.71	0.00	0.00
2	0.37	2.05	0.04	10.71	0.21	106.38	0.06	0.72	0.93	0.01	0.20
5	0.59	89.38	0.06	9.79	−0.05	66.10	0.04	0.21	0.57	0.00	0.00
6	87.74	0.90	0.03	4.90	0.64	68.68	0.65	0.23	0.55	0.06	0.00
7	16.93	0.30	0.03	2.96	0.54	36.31	0.13	0.23	0.53	0.02	0.00
8	60.61	0.76	0.09	3.10	0.57	60.99	2.44	0.24	0.54	0.05	0.03
9	26.73	0.31	0.04	2.58	0.51	43.60	0.41	0.25	0.44	0.04	0.00
12	3.57	10.59	0.01	4.97	0.09	51.28	0.11	0.61	0.50	0.00	0.00
14	1.34	0.68	0.05	5.65	0.94	97.90	1.45	0.71	2.08	0.02	0.01
15	0.80	1.74	0.03	4.83	0.16	121.11	0.36	1.58	1.19	0.04	0.08
21	385.72	0.86	−0.02	6.87	0.78	251.87	2.75	0.27	1.23	0.25	0.02
26	4.52	1.51	−0.06	2.42	0.26	134.14	0.04	0.33	1.54	0.01	0.07
27	2.00	1.36	−0.04	2.01	0.38	167.27	0.34	1.06	2.02	0.02	0.01
35	0.98	1.63	−0.04	2.39	1.52	140.65	0.09	2.80	1.95	0.01	0.52
36	0.30	2.22	−0.04	6.03	0.86	50.03	0.11	0.80	0.51	0.05	0.25
38	2.20	2.96	−0.01	1.18	0.18	87.86	0.05	0.58	0.91	0.00	0.11
44	0.99	3.44	−0.07	1.09	−0.02	109.53	0.16	0.64	1.02	0.01	0.18
52	1.45	1.81	0.00	1.91	−0.03	146.57	0.13	0.34	1.86	0.01	0.85
53	84.26	0.73	−0.02	0.67	0.37	75.09	6.62	0.52	1.06	0.05	0.13
54	42.07	6.97	0.02	0.62	0.13	44.11	0.55	1.51	0.54	0.07	0.19
57	1.08	1.20	−0.05	1.08	−0.07	75.46	0.27	0.88	0.73	0.01	0.22
58	0.70	2.00	−0.08	8.40	0.08	91.71	0.11	0.44	0.87	0.01	0.45

4 Discussion

4.1 Hydrochemical characteristics

The water samples collected (except for sample numbers 20 and 30) were weakly alkaline (Tables 3 and 4) and the pH of these water samples met both the Chinese national standard and the international standard (WHO, 2004; MH, 2006) (Table 9). The TDS and TH in the natural waters of Tibet also met both the Chinese national standard and the international standard (WHO, 2004; MH, 2006). Some of the water samples also met the national *Drink Natural Mineral Water Standard* (GAQS, 2008) (samples collected from Kema village, Luoma town, Nagchu county; Marm town, Gerze county; and Baga town, Burang county; Table 9).

4.2 Toxic elements

Arsenic poisoning is a common endemic disease. The main symptom of arsenic poisoning is

Table 8 Concentrations of toxic elements in groundwater samples from Tibet

Sample number	Al (μg/L)	As (μg/L)	Be (μg/L)	Cr (μg/L)	Cu (μg/L)	Fe (μg/L)	Mn (μg/L)	Mo (μg/L)	Ni (μg/L)	Pb (μg/L)	Se (μg/L)
3	0.19	1.96	-0.02	10.35	-0.04	98.39	0.07	0.96	0.77	0.01	0.00
4	0.46	3.10	-0.04	10.63	0.02	100.00	0.02	0.80	0.82	0.00	0.00
10	99.64	0.48	0.06	9.66	0.23	96.70	0.39	0.10	0.86	0.01	0.00
11	0.55	1.06	-0.04	8.46	-0.01	59.88	0.83	0.08	0.53	0.03	0.00
13	0.95	0.38	0.00	13.97	1.55	344.86	242.76	0.59	5.75	0.09	0.04
16	1.10	0.54	0.04	18.13	1.07	257.68	0.11	0.16	2.71	0.01	0.00
17	7.28	0.58	-0.01	12.06	0.88	238.17	0.09	0.39	2.61	0.01	0.05
18	33.97	5.09	0.05	3.48	0.62	78.13	0.30	0.67	1.60	0.02	0.03
19	0.75	0.64	-0.01	7.97	0.19	148.33	0.23	0.24	1.46	0.01	0.01
20	0.49	0.61	-0.07	16.32	0.04	143.27	514.97	0.21	1.84	0.01	0.00
22	1.15	1.05	-0.03	6.78	3.35	320.31	19.15	0.41	5.85	0.02	0.05
23	0.49	0.63	-0.03	4.62	0.50	112.17	0.55	0.15	1.13	0.01	0.00
24	0.30	0.47	0.02	4.87	0.84	269.51	0.11	0.10	3.46	0.01	0.03
25	0.26	1.20	-0.08	2.86	0.31	140.86	0.03	0.51	1.40	0.00	0.08
28	1.19	0.87	0.00	2.98	0.15	65.05	0.08	0.20	0.75	0.01	0.07
29	4.38	3.21	-0.08	3.77	0.59	246.08	0.55	0.91	2.45	0.02	0.05
30	0.44	1.54	-0.02	2.00	0.12	62.22	0.06	0.99	0.66	0.02	0.05
31	0.67	46.19	0.14	60.90	2.51	333.99	2.82	2.25	4.22	0.02	0.04
32	2.13	333.92	0.07	19.04	7.56	125.91	5.81	0.11	1.64	0.07	0.13
33	0.63	219.94	0.23	33.60	4.51	110.92	6.62	0.30	1.03	0.02	0.06
34	0.47	2.46	-0.03	9.48	0.82	155.70	0.20	0.58	1.60	0.02	0.15
37	0.45	1.29	0.00	3.63	0.94	156.06	0.06	2.19	1.79	0.01	0.75
39	0.62	6.81	-0.04	6.45	1.16	45.64	0.07	2.19	0.74	0.01	0.22
40	1.35	4.42	-0.05	1.84	0.53	107.69	0.04	0.59	1.25	0.01	0.16
41	1.27	3.77	-0.03	1.49	0.17	107.52	0.00	0.47	1.10	0.01	0.08
42	0.67	2.22	0.05	1.64	0.84	190.51	0.01	2.36	2.07	0.05	0.10
43	0.49	4.46	-0.04	1.20	0.13	65.08	0.01	0.54	0.65	0.01	0.09
45	0.47	1.28	0.04	3.68	0.04	188.20	0.04	1.06	1.89	0.01	0.24
46	0.43	3.03	-0.02	7.20	0.29	64.15	0.42	1.02	0.70	0.01	0.49
47	0.31	163.55	-0.06	1.50	0.74	89.59	0.94	6.02	0.98	0.02	0.53
48	0.68	57.96	-0.10	2.07	0.20	80.98	0.02	1.28	0.81	0.01	0.57
49	7.98	56.21	-0.03	0.81	0.06	64.30	0.00	0.98	0.65	0.01	0.14
50	0.91	17.48	0.02	1.61	0.30	122.64	0.13	0.59	1.82	0.01	0.09
51	0.63	1.09	-0.03	1.62	0.00	74.42	0.02	0.72	0.73	0.01	0.24
55	0.86	1.51	-0.04	5.66	0.12	238.44	0.11	0.36	2.18	0.01	0.11
56	21.45	3.56	-0.03	2.78	0.25	133.97	2.34	0.64	1.44	0.02	0.90
59	0.97	2.50	0.01	4.65	0.09	53.98	0.00	0.18	0.92	0.02	0.18
60	1.55	1.87	-0.03	1.02	0.00	65.49	0.62	1.34	0.75	0.01	0.18

Table 9 Major and trace element test standards for water quality

Parameter	<i>Standards for Drinking Water Quality</i> (MOHC, 2006)	<i>Guidelines for Drinking Water Quality</i> (WHO, 2004)	<i>Drink Natural Mineral Water</i> (AQSIQ, 2008)
pH	6.5–8.5	6.5–9.5	—
TDS (mg/L)	1000	1000	≥1000
TH (mg/L)	450	500	—
Na ⁺ (mg/L)	200	200	—
SO ₄ ²⁻ (mg/L)	250	500	—
Cl ⁻ (mg/L)	250	250	—
H ₂ SiO ₃ (mg/L)	—	—	≥25.0
Li (μg/L)	—	—	≥200
Sr (mg/L)	—	—	≥0.2
B (mg/L)	0.5	0.5	<5
Zn (μg/L)	1000	3000	≥200
Se (μg/L)	10	10	≥10
F (mg/L)	1	1.5	<1.5
U (μg/L)	—	15	—
Ba (μg/L)	700	700	<700

skin alteration, including dermal hyperkeratosis, verrucous keratosis and skin cancer (Smith, 1992). Some patients also experience gastrointestinal or hepatic dysfunction (Zhao *et al.*, 2002). Studies have shown that the arsenic concentration in water is mainly affected by the underlying lithology (Qing *et al.*, 2007). In Damxung, Shuanghu, Gerze, Geji and Seng-ge Kambab of northern Tibet, the arsenic concentration is high (Tables 7, 8 and 10). As a result, people who live in these regions may be affected by arsenic poisoning through drinking water. Therefore it is essential to carry out further research on endemic arsenic poisoning in these prefectures as well as on the distribution and genesis of water with a high arsenic concentration. The fluoride concentration in Shuanghu county exceeded both the Chinese national standard and the international standard (WHO, 2004; MH, 2006). The toxic elements in water from other regions meet both these standards, which means that water in these regions is suitable for drinking.

4.3 Hydrochemical characteristics

The ratio of major ions in water can be clearly shown with a Piper plot (Piper, 1944); the percentage of major ions determines the hydrochemical type of water (Chen *et al.*, 2014; Piper, 1944; Shen *et al.*, 2007; Zhu *et al.*, 2011). The main hydrochemical types of water samples in Tibet are as follows: Ca-Mg-HCO₃ (eight samples); Ca-Mg-HCO₃-SO₄ (eight samples); Ca-HCO₃ (five samples); Ca-HCO₃-Cl (three samples); Ca-Na-Mg-HCO₃ (three samples); Na-Ca-HCO₃ (three samples); Ca-Mg-HCO₃-Cl (two samples); Mg-Ca-HCO₃ (two samples); Na-HCO₃ (two samples) (Figure 3; Tables 3 and 4).

Table 10 Harmful element test standards for water quality

Element (μg/L)	<i>Standards for Drinking Water Quality</i> (MOHC, 2006)	<i>Guidelines for Drinking-Water Quality</i> (WHO, 2004)	<i>Drink Natural Mineral Water</i> (AQSIQ, 2008)
Ag	50	100	<50
Al	200	200	—
As	10	10	<10
Be	2	—	—
Cd	5	3	<3
Cr	50	50	<50
Cu	1000	2000	<1000
Fe	300	300	—
Hg	1	1	<1
Mn	100	400	<400
Mo	70	70	—
Ni	20	20	<20
Pb	10	10	<10
Se	10	10	<50
Tl	0.1	—	—

The predominant cation and anion in the water samples from Tibet were Ca^{2+} and HCO_3^- , respectively. The major cations in water were $\text{Ca}^{2+} > \text{Na}^+ > \text{Mg}^{2+} > \text{K}^+$ and the major anions were $\text{HCO}_3^- > \text{SO}_4^{2-} > \text{Cl}^-$ (Figure 4). From south to north, the main cation in water changed from Ca^{2+} to Na^+ , whereas the main anions in water changed from HCO_3^- to Cl^- and SO_4^{2-} . The surface runoff and groundwater in Tibet are recharged mainly by ice/snow melt water and rain.

The main water type in northern Tibet, in the Yarlung Zangbo river catchment, the Lhasa river catchment, the Nianchu river catchment, the Nyang river catchment and the internal flow lake basin area is pore water from loose rocks. Bedrock fissure water is mainly distributed from north of the Himalayas to south of the Changtse Mountains. Karst water is mainly distributed in the central and western Changtang Plateau.

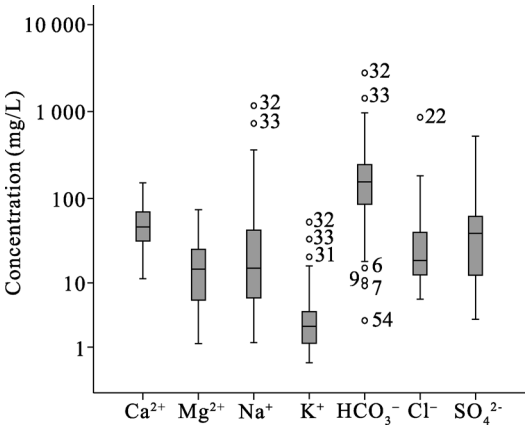


Figure 3 Box and whisker plots showing the variation of major ion concentrations in water samples from Tibet

4.4 Preliminary discussion on the causes of variation in Tibetan water samples

The boomerang envelope model developed by Gibbs (1970) describes three types of water: (1) water from evaporation/crystallization; (2) water dominated by rock type; and (3) water

from atmospheric precipitation. The chemical composition of surface water in Tibet is mainly controlled by rock weathering (Figure 5).

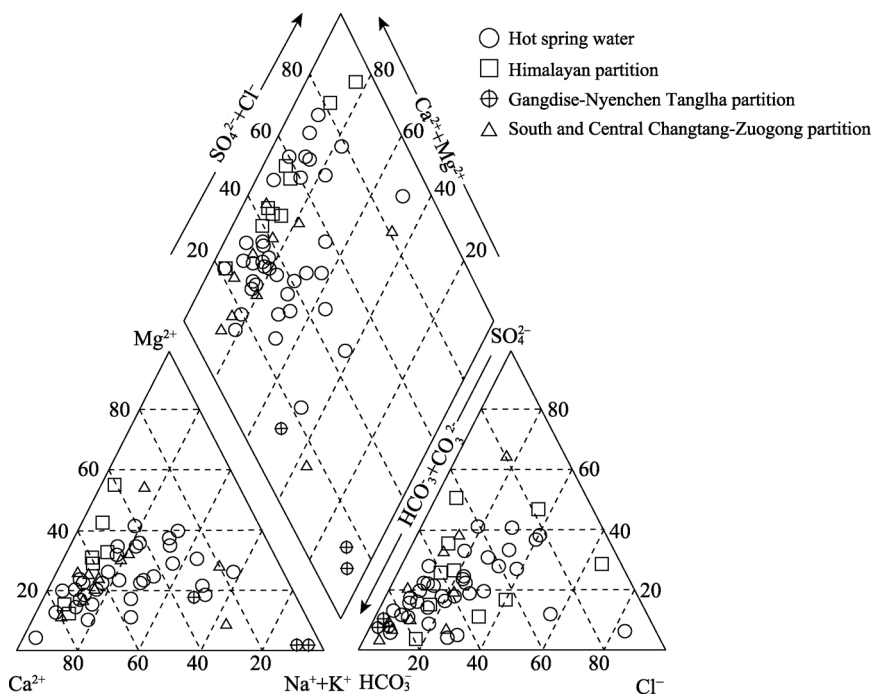


Figure 4 Piper diagram showing the major concentrations of cations and anions in waters of Tibet by geological setting

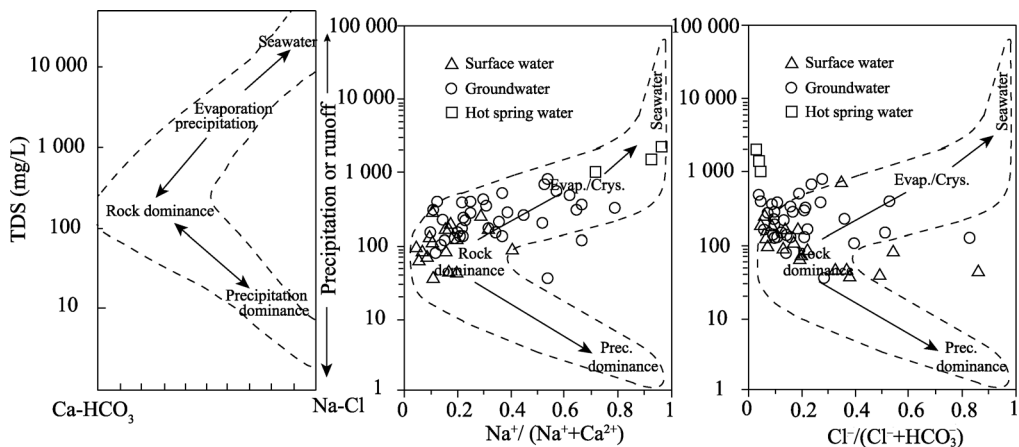


Figure 5 Plots of the major ions within the Gibbs boomerang envelope for waters in Tibet

The control of the chemical composition of surface water in Tibet by rock weathering is consistent with results from elsewhere in the world, including the Yangtze River, the Amazon River and the Ganges (Gibbs, 1970). The results for groundwater in the Gibbs boomerang envelope plot are relatively fragmented, which suggests that the chemical composition of groundwater is diverse and complicated. As a result of the high temperatures, the concentrations of elements in the hot-spring waters are high and water samples are close to the

seawater type in the Gibbs boomerang envelope.

4.5 Regional comparison

In order to explore the differences in the hydrochemical characteristics of different regions, we compared the average values for water samples collected from the Tibetan region with the average values for water samples collected from Southern Xinjiang, the Tongtian River in Qinghai, the Qinghai Lake Basin, Huanglong (Yellow Dragon), Maoxian county and Zamtang county of Sichuan, Yarlung Zangbo River between Lhasa–Nyingchi and Shegyla Mountain (Table 11).

Table 11 Hydrochemical characteristics in different regions of western China

	Tibet	Southern Xinjiang	Tongtian River	Qinghai Lake Basin	Huanglong	Maoxian county	Zamtang county	Yarlung Zangbo River between Lhasa–Nyingchi	Shegyla Mountain
Number of samples	57	154	9	75	9	63	423	62	9
pH	7.55	7.64	8.09	8.09	6.59	7.7	7.43	7.74	7.46
K ⁺	3.09	17.87	6.77	1.87	0.4	2.36	14.25	3.16	0.14
Na ⁺	34.93	336.97	118.02	36.42	3.14	19.12		4.89	0.03
Ca ²⁺	55.25	90.1	51.77	37.38	253.78	70.36	33.77	29.74	1.6
Mg ²⁺	18.69	73.78	18.82	16.04	20.94	28.38	10.4	5.56	3.82
Cl [−]	47.67	509.41	179.88	47	0.73	7.37	3.9	3.87	7.41
SO ₄ ^{2−}	54.68	429.08	83.34	39.35	23.2	119.6	8.05	25.83	62.52
HCO ₃ [−]	169.67	260.28	170.63	183.37	777.44	226.27	171.21	90.28	33.9
Reference	This study	Liu <i>et al.</i> (2014), Pang <i>et al.</i> (2010), Zhang <i>et al.</i> (1995)	Su <i>et al.</i> (1987)	Xu <i>et al.</i> (2010)	Wang <i>et al.</i> (2009)	Du (2011)	Cao (2011)	Liu (2011)	Ren <i>et al.</i> (2002)

The hydrochemical types of the Southern Xinjiang, Qinghai Tongtian River, Lake Qinghai catchment, Sichuan Yellow Dragon, Sichuan Maoxian county, Sichuan Zamtang county, Yarlung Zangbo River between Lhasa and Nyingchi and Shegyla Mountain are: Na-Mg-Cl-SO₄, Na-Ca-Cl-HCO₃, Ca-Na-Mg-HCO₃-Cl, Ca-HCO₃, Ca-Mg-HCO₃-SO₄, Ca-Mg-HCO₃, Ca-Mg-HCO₃-SO₄ and Mg-SO₄-HCO₃, respectively. It can be inferred that different locations lead to different hydrochemical types (Table 11 and Figure 6).

5 Conclusions

The data obtained in this study are representative of the natural hydrochemical characteristics in Tibet as a result of the limited human activities in this region. The water quality in most regions of Tibet is good and meets both the Chinese national standard and the international standard (WHO, 2004; MH, 2006). Some of the water samples also met the national *Drink Natural Mineral Water Standard* (GAQS, Inspection and Quarantine of the People's Republic of China, 2008). The arsenic and fluoride concentrations in Damxung, Shuanghu,

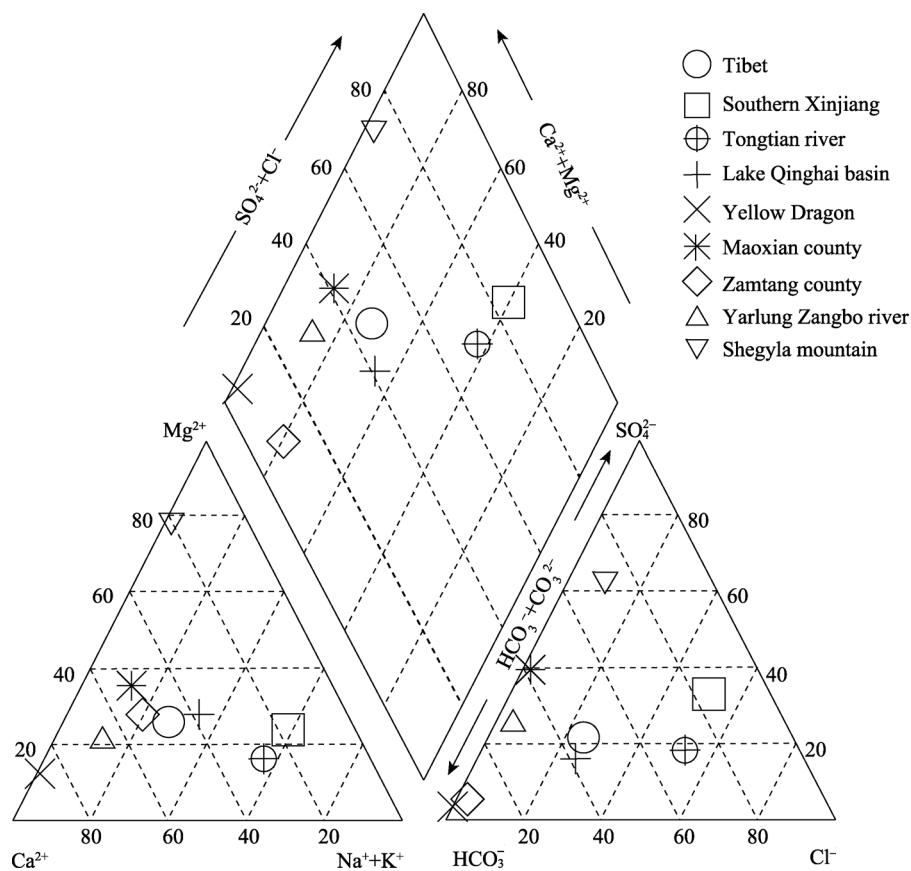


Figure 6 Piper diagram showing major ion compositions of natural water in different regions of western China

Gerze, Geji and Seng-ge Kambab of northern Tibet are higher than those specified in the Chinese national standard and the international standard (MH, 2006; WHO, 2004).

The results of this study can be summarized as follows.

(1) The pH value of water samples ranges from 6.75 to 8.21 and most of the water samples are weakly alkaline.

(2) The mean value of TDS in water samples is 225.54 mg/L, except for the hot-spring water samples. Therefore the majority of water in Tibet is suitable for drinking.

(3) The arsenic concentration in water samples from Ali prefecture and the fluoride concentration in water samples from Shuanghu exceed both the Chinese national standard and the international standard (WHO, 2004; MH, 2006). Further studies are needed on fluorosis and endemic arsenic poisoning resulting from drinking water.

(4) The dominant ions in water from Tibet are Ca^{2+} and HCO_3^- . The main hydrochemical types of Tibetan water are Ca-HCO_3 , Ca-Mg-HCO_3 and $\text{Ca-Mg-HCO}_3\text{-SO}_4$. From south to north, the main cation in water changes from Ca^{2+} to Na^+ , whereas the main anions in water change from HCO_3^- to Cl^- and SO_4^{2-} .

(5) River water and ice/snow melt water are dominated by the rock type and the formation of groundwater is affected by many factors. The element concentrations in hot-spring water are high and are similar to seawater.

References

- Bianduo, Bianbaciren, Laba *et al.*, 2010. The response of water level of Selin Co to climate change during 1975–2008. *Acta Geographica Sinica*, 65(3): 313–319. (in Chinese)
- Buduo, Jiang D S, Ren J Y *et al.*, 2011. Preliminary study on the arsenic water of fisheries in Lhasa Region. *Journal of Tibet University*, 26(1): 15–24. (in Chinese)
- Cao N, 2011. An analysis of the characteristics of geological environment in the Kashin-Beck disease (KBD) area in the Rangtang county [D]. Chengdu: Chengdu University of Technology. (in Chinese)
- Chen L, Wang G C, Hu F S *et al.*, 2014. Groundwater hydrochemistry and isotope geochemistry in the Turpan Basin, northwestern China. *Journal of Arid Land*, 6(4): 378–388.
- Du J T, 2011. Hydrogeochemical research of Kashin-Beck disease [D]. Chengdu: Chengdu University of Technology. (in Chinese)
- General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China (GAQS), 2008. GB 8537–2008. Drinking Natural Mineral Water. (in Chinese)
- Gibbs R J, 1970. Mechanisms controlling world water chemistry. *Science*, 170: 1088–1090.
- Hirokazu H, Yoshiki W, Satoshi O, 1985. Silver chloride pre-treatment for the direct potentiometric determination of chloride in stream waters using a solid-state chloride ion-selective electrode. *Analyst*, 110(9): 1087–1090.
- Ji Q G, Wang B Q, 2007. The data processing and application of groundwater chemical composition. *Land and Resources of Southern China*, 2007(1): 31–33. (in Chinese)
- Li H J, Zhang N, Lin X T, 2010. Spatio-temporal characteristics of Yarlung Zangbo River in Tibet. *Journal of Henan Normal University*, 38(2): 126–130. (in Chinese)
- Liu C, Gesanguomu, 2012. Direct determination 22 kinds of trace elements of lake water in Tibet by ICP-MS. *Tibet's Science & Technology*, (2): 27–31. (in Chinese)
- Liu X Y, Shi Y, 2013. Tibet Shannan rural drinking water safety project in 2012 water quality monitoring results. *Journal of Tibet Medicine*, 35(3): 54–55. (in Chinese)
- Liu Y L, Luo K L, Lin X X *et al.*, 2014. Regional distribution of longevity population and chemical characteristics of natural water in Xinjiang, China. *Science of the Total Environment*, 473/474: 54–62.
- Liu Zhao, 2011. The characterization of hydrochemical and isotopic in the natural water of the Yarlung Tsangpo Lhasa-Nyingchi [D]. Chengdu: Chengdu University of Technology. (in Chinese)
- Luo D, Huang C Y, Yin T, 2010. Assessment of water quality and water security on centralized drinking water sources in towns of Tibet. *Water Conservancy Science and Technology and Economy*, 16(4): 420–422. (in Chinese)
- Ma L F, Deng X Z, 2002. China Geological Map Explanation. Beijing: Geological Press. (in Chinese)
- Ministry of Environment Protection of the People's Republic of China, 2002. Methods for Chemical Analysis of Water and Waste Water. 4th ed. Beijing: China Environmental Science Press. (in Chinese)
- Ministry of Health (MH) of the People's Republic of China, 1985. GB5750 85. Standards for Drinking Water Test. (in Chinese)
- Ministry of Health (MH) of the People's Republic of China, 2006. GB 5749–2006. Standards for Drinking Water Quality. (in Chinese)
- Ministry of Water Resources (MWR) of the People's Republic of China, 2009. China's Water Resource Report in 2007. (in Chinese)
- Nie L X, 2011. Drinking water microorganism index analysis of 6 counties in Tibet rural area. *Journal of Tibet Medicine*, 32(1): 56–57. (in Chinese)
- Pang Z H, Huang T M, Chen Y N, 2010. Diminished groundwater recharge and circulation relative to degrading riparian vegetation in the middle Tatim River, Xinjiang Uygur, Western China. *Hydrol. Process*, 24: 147–59.
- Piper M A, 1944. A graphic procedure in the geochemical interpretation of water-analyses. *Transactions, American Geophysical Union*, 25: 914–928.
- Qing Z Y, Jing Z, Ying W *et al.*, 2007. Hydrochemical processes controlling arsenic and selenium in the Changjiang River (Yangtze River) system. *Science of the Total Environment*, 377(1): 93–104.

- Ren Q S, Wang J S, Zhang B *et al.*, 2002. Different forms of water quality analysis in southeastern Tibetan fir forest. *Journal of Northeast Forestry University*, 30(2): 52–54. (in Chinese)
- Shen Y L, Zhou M W, 2011. The environmental geological assessment in Tibet. Sichuan *Acta Geologica Sinica*, 31: 89–92. (in Chinese)
- Shen Z L, Zhu W H, 1993. Hydrogeochemical Basis. Beijing: Geological Publishing House, 83–91. (in Chinese)
- Smith A H, Hopenhayn-Rich C, Bates M N *et al.*, 1992. Cancer risks from arsenic in drinking water. *Environ. Health Perspectives*, 97: 259–267.
- Su C J, Tang B X, 1987. The hydrochemical characteristics of Tongtian River. *Mountain Research*, 5(3): 143–146. (in Chinese)
- Wang H J, Liu Z H, Zheng C, 2009. Hydrochemical variations of Huanglong spring and the stream in Huanglong ravine, Sichuan province. *Geochimica*, 38(3): 307–314. (in Chinese)
- Wang J B, Peng P, Ma Q F *et al.*, 2013. Investigation of water depth, water quality and modern sedimentation rate in Mapam Yumco and La'ang Co, Tibet. *Journal of Lake Sciences*, 25(4): 609–616. (in Chinese)
- Warren V H, 1989. Geology, trace elements and health. *Social Science & Medicine*, 29(8): 923–926.
- Webster J G, Brown K L, Vincent W F, 1994. Geochemical processes affecting ice-snow melting water chemistry and the formation of saline ponds in the Victoria Valley and Bull Pass region, Antarctica. *Hydrobiologia*, 281(3): 171–186.
- World Health Organization (WHO), 2004. Guidelines for Drinking Water Quality. Recommendation 1, 3rd ed. World Health Organization, Geneva, 306–308.
- Xu H, Hou Z H, An Z S *et al.*, 2010. Major ion chemistry of waters in lake Qinghai catchments, NE Qinghai-Tibet Plateau, China. *Quaternary International*, 2010, 212: 35–43.
- Yu C Z, Fu E H, 2010. Determination of chloride in water by ion-selective electrode method. *Chemical Analysis and Meterage*, 19(1): 40–42. (in Chinese)
- Zhang N, Li H J, Wen Z Z *et al.*, 2009. Spatio-temporal characteristics of Niyang River in Tibet. *Journal of Henan Normal University*, 37(6): 79–82. (in Chinese)
- Zhang J, Takahashi K, Wushiki H *et al.*, 1995. Water geochemistry of the rivers around the Taklimakan desert (NW China): Crustal weathering and evaporation processes in arid land. *Chemical Geology*, 119: 225–37.
- Zhang X Y, Li X J, Dawa *et al.*, 2013. Drinking water hygiene monitoring and analysis in 2011, Tibet Nyingchi. *Journal of Tibet Medicine*, 34(1): 62–64. (in Chinese)
- Zhao S L, Wang L F, Liang J H, 2002. The damage and remove measure of arsenic in drinking water. *Modern Preventive Medicine*, 2002(5): 651–652. (in Chinese)
- Zhao W, Liu D H, Zhang H P *et al.*, 2002. Investigation of water quality on individual supply well in Tibet servicemen outstation. *Journal of PLA Preventive Medicine*, 20(6): 427–428. (in Chinese)
- Zheng B M, Li S Z, Li S S *et al.*, 2007. The analysis and significance of water quality in certain department troops adopt the provide for oneself centered type water supply dwell in Tibet Naqu district. *Journal of Henan Preventive Medicine*, 18(5): 332–334. (in Chinese)
- Zheng B M, Li S Z, Ma K J *et al.*, 2007. The investigation and analysis of the spring and well water of certain part halt in Tibet Biru country. *Journal of Henan Preventive Medicine*, 18(4): 245–246. (in Chinese)
- Zheng B M, Li S Z, Zhou X B, 2008. The detection of 11 bathhouses's bathwater quality at certain part and habitat in Tibet Naqu. *Journal of Henan Preventive Medicine*, 19(3): 168–171. (in Chinese)
- Zhu B Q, Yang X P, Rioual P *et al.*, 2011. Hydrogeochemistry of three watersheds (the Erlqis, Zhungarar and Yili) in northern Xinjiang, NW China. *Applied Geochemistry*, 26(8): 1535–1548.