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The main chemical properties of hot and cold mineral waters in Bayankhongor, Mongolia

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Abstract: In the current study, hot and cold mineral springs and sub mineral waters in the Bayankhongor province were examined for their chemical characteristics and identified cold mineral waters classification according to mineral water classification of Mongolia. The hot spring waters belong to Na^+-HCO_3- and Na^+-SO_4^{2-} types. The cold mineral spring of Lkham belongs to Ca^{2+}-HCO_3^- type. All sub mineral waters are generally located in the two areas (northern part or mountain forest area and the southern part or Gobi desert area). TDS concentrations of cold springs of the southern part in the study area were higher than northern part's cold springs. The total dissolved silica content of cold spring was ranged from 4.5mg/L to 26 mg/L which did not correspond to requirements of mineral water standard of Mongolia. Thus, these cold springs are belonging to sub mineral water classification. The sub mineral waters were characterized into four types such as a Ca^{2+}-SO_4^{2-}, Na^+-SO_4^{2-}, Na^+-HCO_3 and Ca^{2+} - HCO_3 by their chemical composition in the study area. The values for the quartz, chalcedony geothermometer and the Na/K geothermometer were quite different. The silica-enthalpy mixing model predicts a subsurface reservoir temperature between 124 and 197°C and most of the hot waters have been probably mixed with cold water. The result shows that an averaged value of calculated temperature ranges from 77°C to 119°C which indicates that studied area has low temperature geothermal resources.

Keywords: hot and cold mineral waters, chemical composition, Bayankhongor, Mongolia

INTRODUCTION

Mongolia consists of 21 provinces and Bayankhongor province is located in the southwestern part of the country and area covers 116,000 square kilometers. It is one of the largest provinces in Mongolia. The Bayankhongor province includes very diverse geographic areas. It is typically divided into three areas: the northern part belongs to mountain forest, the central part belongs to steppe and the southern part belongs to Gobi desert [3]. Hot and cold mineral waters are mainly distributed in the northern part of the Bayankhongor province (Khangai mountain area). Mongolians have used hot springs for many centuries, for bathing and small scale heating, as well as agricultural and medicinal purposes (e.g. treatment of high blood pressure, rheumatism, disease of the nervous system etc. using geothermal water). The first systematical study of hot mineral waters of Bayankhongor province was performed by Smirnov *et al.* during 1926-1927. Further more detailed investigation on the formation of mineral water, their distribution and chemical composition were studied by Marinov, Namnandorj [12, 13] etc. The monographs on mineral water resources of Mongolia were published in 1963 and 1966. Mongolia and Soviet Union's joint hydrochemical *Khubsgul* research group was performed research on complex study of hydromineral resources in Mongolia during 1976-1980.

Based on all previous research *The map of Mineral springs of Mongolia* were created in 1983. According to the results of many years of studies it has been established that Bayankhongor province has about 5 hot waters. The most investigated one is Shargaljuut hot spring and it's 54 km far from the Bayankhongor province center. The Shargaljuut hot spring consists of about 100 individual hot springs with temperature ranges from 45°C to 95°C.

Previous studies have determined chemical composition in hot springs of Bayankhongor province [2, 10]. They concluded that the hot springs are

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belong to Na^+-HCO_3^- and Na^+-HCO_3, SO_4 types. Isotopic study of hot springs in Bayankhongor province had done from 2012 to 2013 and concluded that the geothermal waters originate in the local meteoric waters [5].

of the hot and cold mineral waters in Bayankhongor province and to identify cold mineral waters classification using the mineral water classification of Mongolia.

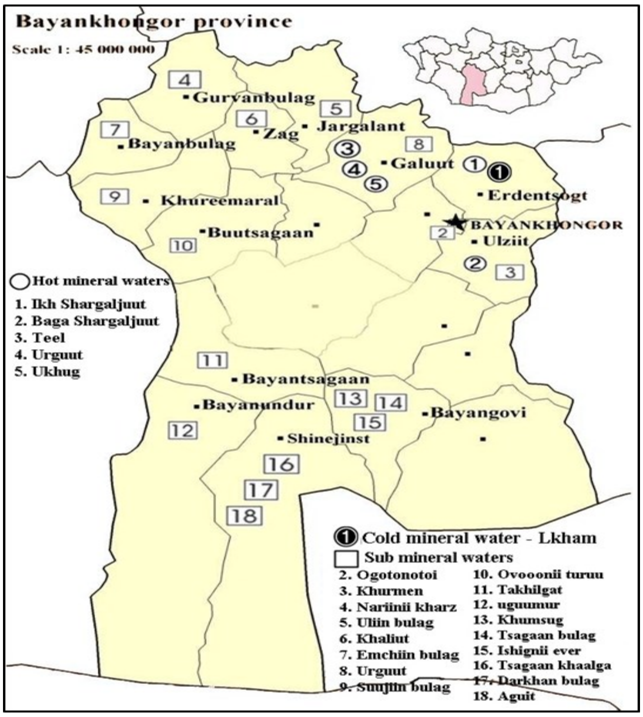

Fig. 1. Sample locality of hot and cold spring waters in the study area

Table 1. Sample locality in the study area

No	Sample type	Mineral waters	Latitude	Longitude	Altitude (m)	Temperature,˚C	pH	EC, mS/m	ORP, mV
1	Hot mineral waters	Ikh Shargaljuut	46°19' 57.7	101°13' 29.4	2150	95	9.6	37.1	315
2		Baga Shargaljuut	46°14' 02.4	101°09' 11.8	2057	57	9.5	37.1	394
3		Teel	46°51'43.4	100°06' 56.4	2112	32	9.7	28.3	177
4		Urguut	46°33' 54.3	100°24' 09.9	2330	42	8.4	44	80
5		Ukhug	46°47' 59.9	100°25' 53.8	2377	58	9.5	47.4	234
6	Cold mineral water	Lkham	46°20' 03.5	101°13' 38.3	2131	14	7.5	38.8	328
7	Sub mineral waters	Ogotonotoi	46°11' 25.1	100°43' 57.9	1870	< 10	7.4	34.3	382
8		Khurmen	45°41' 24.9	101°02' 30.5	1898	< 15	7.9	92.1	181
9		Nariinii kharz	47°24' 23.7	98°35' 12.1	2505	< 15	7.6	23	402
10		Uliin bulag	47°03' 37.3	99°42' 50.6	2264	< 15	7.8	25.5	408
11		Khaliut	46°46' 19.3	99°19' 03.3	1908	5	7.6	63.2	392
12		Emchiin bulag	46°53' 20.3	97°57' 40.2	2677	< 15	7.7	40.3	417
13		Urguut	46°48' 03.1	100°25' 58.5	2374	5	7.4	31.5	277
14		Suujiin bulag	47°06' 58.9	99°43' 37.8	2278	< 15	7.9	97.4	417
15		Ovoonii turuu	46°18' 10.6	98°51' 12.6	2102	< 15	7.9	44.7	414
16		Takhilgat	45°08' 26.5	98°47' 08.8	2000	<15	7.8	94.2	434
17		Uguumur	44°45' 02.8	98°23' 04.2	1982	< 15	7.9	105	420
18		Khumsug	44°46' 30	100°34' 43.3	1813	< 15	7.7	11.9	290
19		Tsagaan bulag	44°36' 10.6	100°20' 50.8	1506	< 15	7.5	113	287
20		Ishignii ever	44°21' 39.9	99°58' 039	2109	< 15	7.4	60.2	284
21		Tsagaan khaalga	44°25'22.3	99°18'59.2	1328	< 15	8.0	60.7	318
22		Darkhan bulag	44°30' 26.9	98°02' 01.6	2022	< 15	7.6	62.4	328
23		Aguit	44°17' 52.2	99°27' 17.8	2113	< 15	6.6	17.7	388

Detailed investigation of the cold mineral waters in Bayankhongor province has not been carried out. Aim of this study is to determine chemical characterization

EXPERIMENTAL

Twenty-three hot and cold spring samples (5 hot spring and 18 cold springs) were collected during July-

August, 2013 from Bayankhongor province in Mongolia Figure 1 and Table 1.

The analyses were carried out both in the field and in the laboratory. At the sampling site, spring samples were collected into 1000ml plastic bottles for subsequent chemical analysis that was made by flame photometer and standard methods in laboratory. Water temperature, pH, EC and ORP were measured by digital thermometer, a pH meter (TOA, HM-30P), EC meter (TOA, CM-31P) and ORP meter (TOA, RM-30P), respectively. Major cation concentrations (Ca^{2+}, Mg^{2+}) were determined by trilon-B titration whereas Na^+ and K^+ were determined by inductively coupled plasma optical emission spectrometry. The anions of HCO_3^-, Cl^- and SO_4^{2-} were determined by 0.1N HCl titration, 0.1N $AgNO_3$ titration and weight balance method, respectively. Dissolved silica was determined by molybdenum yellow method using a spectrophotometer (S2100 UV Spectrophotometer, Cole Parmer) and minor components (NH_4, Fe, NO_2 and NO_3) were determined by spectrophotometer. The total dissolved solid content was determined by evaporating 1 litre of filtered water sample at 100°C. Eventually, the residue was dried at 180°C for 2 hours. Analyses of major and minor compositions were carried out at the geochemical laboratory of the Institute of Chemistry and Chemical Technology of the Mongolian Academy of Science. The results of the chemical analysis of hot and cold springs from the Bayankhongor province in Mongolia are presented in Table 2.

RESULTS AND DISCUSSION

Chemical composition: The descriptions of sampling locations and geochemical results of hot and cold waters are listed in Tables 1 and 2. The discharge temperature of hot springs varied from 32 C to 95°C while their pH varied from 8.4 to 9.7 which indicates alkaline characteristics. The electric conductivity (EC) of hot springs varied from 28 mS/m to 47mS/m. The sodium cation is dominating in the hot springs (Table 2) ranging from 71 mg/L to 105 mg/L while the other cation concentrations such as those of K^+, Ca^{2+} and Mg^{2+} are very low. Total alkalinity values (HCO_3^-) is the dominant anion revealed up to 170 mg/L while chloride concentrations are below 26 mg/L and sulfate concentrations range from 25 mg/L to 49 mg/L. The sulfate concentration of Ukheg hot spring (sample №5) is higher than other hot springs. The total dissolved silica content of hot springs ranged from 45 mg/L to 104 mg/L. Total dissolved solids (TDS) concentration were ranged from 210 to 326 mg/L.

The bicarbonate (HCO_3) concentration of Lkham cold spring (Table 2; sample №6) is dominant cation ranges from 98 mg/L to 228 mg/L and dominant anions were Ca^{2+} (36 mg/L) and Na (36 mg/L).

Total dissolved solids (TDS) concentration (265 mg/L) was lower than that of the other cold springs. The total dissolved silica content of Lkham cold spring was 56 mg/L that correspond to requirements of mineral water standard of Mongolia. Therefore, cold spring of Lkam is belonging into cold mineral water classification.

Table 2. Chemical composition of water samples in the study area.

№	Sample type	Mineral waters	Na+K mg/l	Ca	Mg	NH_4	Fe_{total}	Cl	SO_4	HCO_3	NO_2	NO_3	SiO_2	TDS
1	Hot mineral waters	Ikh Shargaljuut	83	3.2	0.5	-	-	26	33	97	-	-	104	243
2		Baga Shargaljuut	84	2.4	0.5	-	-	13	49	97	-	-	84	246
3		Teel	71	3.2	0.5	-	-	13	25	97	0	0.4	45	210
4		Urguut	105	4.8	0.4	-	-	14	42	170			59	326
5		Ukhug	104	7.2	0.5	-	-	26	66	121	-	0.1	99	325
6	Cold mineral water	Lkham	36.1	36.1	4.9	-	-	40	49	98	-	1.7	56	265
7	Sub mineral waters	Ogotonotoi	44	28	4.9	0.1	-	40	8.2	146	0	1.2	11	272
8		Khurmen	89	44	39	0.5	-	66	115	293	0.23	15	25	661
9		Nariinii kharz	30	16	4.9	0.1	0.02	26	8.2	98	0.01	0.4	10	184
10		Uliin bulag	57	16	7.3	-	0.07	13	33	171	0.01	0.9	26	298
11		Khaliut	52	64	29	-	0.01	53	91	268	0.01	6.8	12	564
12		Emchiin bulag	55	52	4.4	0.8	0.11	40	33	220	0.01	0.1	19	405
13		Urguut	44	48	9.7	-	0.01	26	16	244	0	1.4	16	390
14		Suujiin bulag	143	56	29	0.2	-	66	189	342	0.01	0.5	18	825
15		Ovoonii turuu	66	40	9.7	0.1	-	26	41	244	-	4.1	22	431
16		Takhilgat	96	56	39	0.6	0.01	40	165	342	-	3.9	4.5	742
17		Uguumur	130	88	29	0.5	0.02	80	296	244	-	3.1	9.4	871
18		Khumsug	44	64	41	0.1	-	27	156	268	0.003	7.9	5.2	609
19		Tsagaan bulag	164	64	22	0.2	-	40	370	195	-	6.8	5.3	863
20		Ishignii ever	32	80	19	0.1	-	53	82	220	0.19	11	6.3	498
21		Tsagaan khaalga	60	48	15	0.3	-	40	66	220	0.02	7.5	11	456
22		Darkhan bulag	77	72	9.7	0.0	-	53	99	244	0.03	11	19	566
23		Aguit	30	12	7.3	0.2	-	26	8.2	97.6	0.06	1.1	10	183

The water temperatures of cold spring waters range from 5 to 15°C and the pH values range from 6.6 to 8.0. The electric conductivity (EC) of cold spring waters range from 17 mS/cm to 97 mS/cm Table 1. All cold springs are located in the two areas (northern part or mountain forest area and the southern part or Gobi desert area). The sodium concentration of cold springs (Table 2; sample № 7-15 and Figure 1; 2-10) in northern part of Bayankhongor province are dominant cation range from 30 mg/L to 143 mg/L except one cold spring (Table 2; sample №13 and dominant cation is Ca (48 mg/L)) and Ca concentrations values range from 16 to 64mg/l and Mg concentrations range from 4.4 mg/L to 39 mg/L, respectively. Total alkalinity values (HCO_3^-) is the dominant anion ranges from 32 mg/L to 342 mg/L, and chloride concentrations ranges from 13 mg/L to 66 mg/L. Sulfate concentrations range from 8.2 mg/L to 189 mg/L. Total dissolved solids (TDS) concentration was range from 184 to 564 mg/L except sample №14 (825 mg/L, Table 2).

The sodium is dominated cation in cold springs (Table 2; sample №16-23 and Figure 1; 11-18) of the southern part of Bayankhongor province and it ranges from 30 mg/L to 164 mg/L except two cold spring (Table 2; sample №18 and 20 and dominant cation is Ca (64 mg/L) and 80 mg/L) and Ca concentrations range from 12 to 88 mg/l and Mg concentrations range from 7.3 mg/L to 41 mg/L, respectively. Total alkalinity values (HCO_3^-) is the dominant anion and it ranges from 97 mg/L and 342 mg/L except for two cold spring (Table 2; sample № 18 and 19 and dominant anion is SO_4 (296 mg/L and 379 mg/L)). The chloride concentrations range from 26 mg/L to 53 mg/L. The sulfate concentrations range between 8.2 mg/L to 165 mg/L. Total dissolved solids (TDS) concentration are between 456 and 871 mg/L except for sample №23 (183 mg/L) in Table 2.

TDS concentrations of cold springs of the southern part in the study area were higher than cold springs of the northern part in the study area. The total dissolved silica content of cold spring is ranging from 4.5 mg/L to 26 mg/L which did not correspond to requirements of mineral water standard of Mongolia. Therefore, those cold springs are belonging into classification of sub mineral water.

The Piper diagram for the water samples in the study area are shown in Figure 2. All hot springs in the study area belong to Na^+-HCO_3^- type except one hot spring (Na^+-HCO_3, SO_4^{2-} type; sample №.5). The cold mineral spring of Lkham belong to Ca^{2+}-HCO_3^- type. The chemical composition of the sub mineral waters in the study area were characterized into four types. The sub mineral water of Uguumur (sample №17) belongs to Ca^{2+}-SO_4^{2-} type and sample №19 belongs to Na^+-SO_4^{2-} type. The sub mineral waters (sample № 7, 10, 14, 15 and 16) belongs to Na^+-HCO_3 type and other sub mineral waters are belong to Ca^{2+}-HCO_3 type, respectively.

The relationship between Ca^{2+} + Mg^{2+} and $HCO3^-$ concentrations is shown in Figure 3, where the broken line corresponds to the ion exchange of Ca^{2+} + Mg^{2+} with Na^+ + K^+ following the reaction with clay

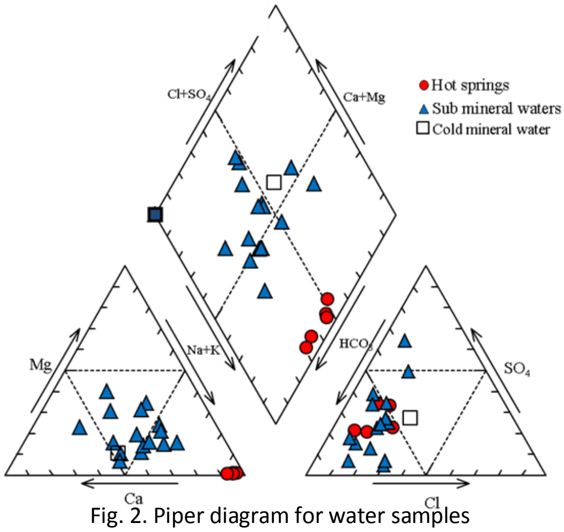

Fig. 2. Piper diagram for water samples

minerals after dolomite dissolution. This result implies that the cold springs are enriched with Ca^{2+}, Mg^{2+} and HCO_3^- due to dissolution of carbonate rocks (such as dolomite), whereas all hot springs plot below the broken line. A possible explanation for the observed result is that the hot springs are enriched with Na^+ and K^+ and depleted Ca^{2+} and Mg^{2+} because of ion exchange with clay minerals in the soil resulting a higher pH than that of the cold spring.

Geothermometers: The results of chemical geothermometers applied to the hot springs in the Bayankhongor province are given in Table 3. These estimates were obtained using methods suggested by Fournier (1977), Arnorsson (1983), Fournier and

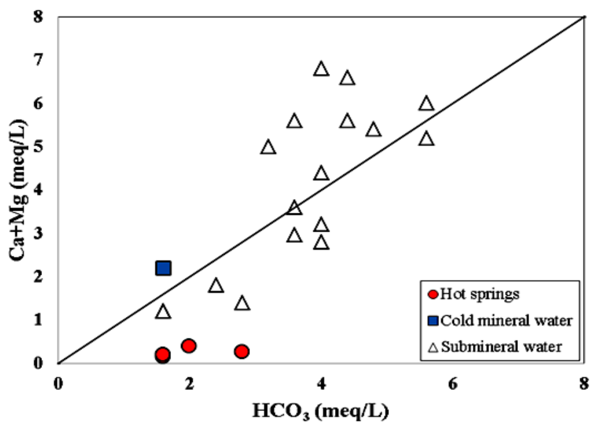

Fig. 3. The relation-ship between Ca^{2+} + Mg^{2+} and HCO_3^- concentrations

Truesdell (1973) and Giggenbach (1988) [1, 7, 9, 11]. The silica quartz geothermometer of Fournier (1977) [7] yielded the highest reservoir temperatures that ranges from 96°C to 139°C for all hot springs in the study area and higher than those calculated for equilibrium with chalcedony. For comparison, the silica–chalcedony temperature two equation proposed by Fournier (1977) and Arnorsson, (1983) [7, 1] gave reservoir temperature ranges from 66°C to 113°C. It's obvious that the chalcedony geothermometer by Fournier (1977) [7] yields relatively similar values for all samples compared to the calibration of Arnorsson *et al.* (1983) [1]. The solubility of silica in thermal waters increases with an increase in temperature (Fournier, 1977 and Arnorsson, 1983) [7, 1].

Temperatures are calculated for the hot springs based on the Na-K data and using two different calibrates Table 3. The Na-K geothermometers of Arnorsson et al. (1983) [1] and Giggenbach (1988) [11] give the reservoir temperature in the range 44-93°C and 103-148°C, respectively. It is obvious that the Na-K geothermometer by Giggenbach (1988) [11] yields relatively high values for all samples compared to the calibration of Arnorsson *et al.* (1983). The temperatures calculated (Table 3) using the Na-K-Ca geothermometer (β= 4/3) are similar, in the range between 87 to 121°C [9]. In this case, all hot springs, with an anomalous Na/K ratio and a higher calculated temperature, could be the result of additional chemical reactions after mixing, including possible cation exchange reactions [7, 4, 6]. The result shows that an averaged value of calculated temperature ranges from 77°C to 119°C among the studied hot springs. These calculated reservoir temperatures also correlate well with the surface discharge temperatures of each spring and indicate low temperature geothermal resources in the study area, suggesting that these resources can be used for room heating and production of electricity by a binary system.

Table 3. Geothermometer temperatures (°C) for hot springs in study area

No	Hot springs	T_{meas}	T_{means}	$T_{chal(1)}$	$T_{chal(2)}$	$T_{Qtz\,(3)}$	$T_{Na\text{-}K\,(4)}$	$T_{Na\text{-}K\,(5)}$	$T_{Na\text{-}K\text{-}Ca\,(6)}$
1	Ikh Shargaljuut	95	116	113	111	139	81	137	115
2	Baga Shargaljuut	57	99	100	99	128	56	114	99
3	Ukhug	58	77	66	68	96	44	103	87
4	Teel	32	90	81	81	110	56	113	98
5	Urguut	42	119	110	108	136	93	148	121

T_{means} - averaged values of calculated temperatures;
(1),(3): Fournier (1977), (2), (4): Arnórsson et al. (1983), (5): Giggenbach (1988), (6): Fournier and Truesdell (1973)

The silica-enthalpy mixing model: Truesdell and Fournier (1977) [14] proposed a plot of dissolved silica versus the enthalpy of water to estimate the temperature of the deep hot water component. Figure 4 depicts the silica-enthalpy mixing model based on chalcedony solubility and quartz solubility. The cold groundwater sample was assumed to be represented by the available data for the chemical composition of cold springs in the study area. The black line between the cold water and the mixed thermal water intersects the chalcedony solubility curve where enthalpy is equal, from 520 to 840 kJ/kg and corresponds to the estimated reservoir temperature from 124 to 197°C.

Subsurface temperature estimates using this method are higher than those obtained using the chalcedony geothermometer, indicating that most of the hot

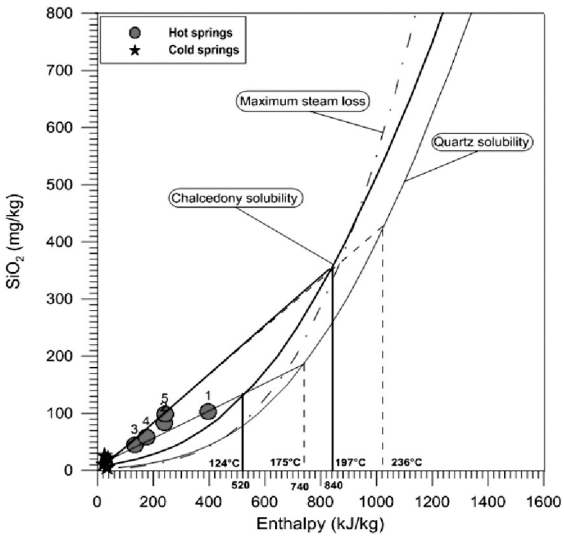

Fig. 4. The silica-enthalpy mixing model for samples from Bayankhongor province.

waters have probably mixed with cooler water in the reservoir or that conductive cooling probably took place during the up flow of the hot water. The broken line between the cold water and the mixed thermal water intersects the quartz solubility curve where the enthalpy is equal, from 740 to 1020 kJ/kg, and corresponds to the estimated reservoir temperature from 175 to 236°C, here using the quartz geothermometer (quartz-no steam loss Fournier, 1977). The hot waters in the study area have a difference of less than 50°C between the measured and calculated quartz geothermometer temperatures therefore, this model is not applicable [8].

CONCLUSIONS

Hot springs, cold mineral waters and sub mineral waters in the Bayankhongor province were examined for their chemical characteristics.

The hot spring waters are belong to Na^{+}-HCO_3- and Na^{+}-SO_4^{2-} types. All cold springs are located in two areas (northern part or mountain forest area and the southern part or Gobi desert area). TDS concentrations of cold springs of the southern part in the study area were higher than northern part's cold springs. The total dissolved silica content of cold spring were ranged from 4.5 mg/L to 26 mg/L which did not correspond to the requirements of mineral water standard of Mongolia. Therefore, these cold springs belong to the classification of sub mineral water. The cold mineral spring of Lkham belong to Ca^{2+}-HCO_3^{-} type. The chemical composition of the sub mineral waters in the study area were characterized into four types. The sub mineral water of Uguumur (sample №17) belongs to Ca^{2+}-SO_4^{2-} type and sample №19 belongs to Na^{+}-SO_4^{2-} type. The sub mineral waters (sample № 7, 10, 14, 15 and 16) belong to Na^{+}-HCO_3 type and other sub mineral waters belong to Ca^{2+} - HCO_3 type, respectively. The cold springs are enriched with Ca^{2+}, Mg^{2+} and HCO_3^{-} due to the dissolution of carbonate rocks such as dolomite. The hot springs are enriched with Na^{+} and K^{+} due to depletion of Ca^{2+} by ion exchange of underlying clay minerals and become more alkaline (higher pH) than that of the cold springs. The calculated equilibrium temperature ranges from 77°C to 119°C among the studied hot springs and it indicates that studied area has low temperature geothermal resources.

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