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Article

Tap water quality analysis in Ulaanbaatar City

Iveel Munkhbat[1]*, Binderya Badamdorj[1]*, Enkhzaya Otgontogoo[1]*, Tuvshinjargal Munkhbat[1]*, Lkhamsuren Tsogtbaatar[1]

[1]New Era International School, Ulaanbaatar, Mongolia

*authors contributed equally

SUMMARY

There have been several issues concerning the water quality in Ulaanbaatar, Mongolia in the past few years. In 2019, some apartment residents filed complaints regarding tap water quality, and others suffered from health issues. In this study, we collected 28 samples from 6 districts of Ulaanbaatar to check if the water supply quality met the standards of the World Health Organization, the Environmental Protection Agency, and a Mongolian National Standard, MNS 0900:2018. We hypothesized that the water in Zaisan, an area where the underground well is used as a water resource rather than the central water system, will have poorer quality, show higher hardness levels, and lower pH and total alkalinity than the other regions in Ulaanbaatar. We carried out a comprehensive analysis of metal concentrations (lead, iron, copper, mercury, aluminum, manganese, and zinc), mineral concentrations (nitrite, nitrate, sulfate, free chlorine, and total chlorine), pH, alkalinity, and hardness using a water test kit and pH meter. Only three of the samples fully met all the requirements of the global standards. However, 21 samples had a lower pH level than the recommended range of 6.5–8.5. Supporting our hypothesis, the samples in Zaisan showed higher hardness (>120 ppm) and alkalinity levels (20–200 ppm) over the other districts in the city. Overall, the results show that it is important to ensure a safe and accessible water supply in Ulaanbaatar to prevent future water quality issues.

INTRODUCTION

Improved water supply and better water management can help countries thrive economically and reduce poverty (1). Serious issues in tap water quality are hardness (mineral content), iron, sulfides, chlorides, pH, and pathogens (2). If the amounts of some minerals such as sulfates, nitrates, nitrites, and other elements in water are over the limit of standard ranges, it can cause health problems. The process of purifying and transporting water is related to its quality, as the process determines the levels of water contaminants.

As of 2019, there are approximately 83,650 inhabited apartments in the Mongolian capital city Ulaanbaatar, and most residents use their tap water daily (3). There are seven primary water resources in Ulaanbaatar City. The water is purified and stored in protected areas under the Mongolian Water Supply and Sewerage Authority monitor. Three types of pipes are used to distribute the supply throughout the region: plastic, cast iron, steel (**Figure 1**) (4). While most apartments in the city are connected to the central water system, Zaisan neighborhood apartments are not, meaning the water is not taken from the previously stated resources.

There have been complaints from residents in Zaisan about the inadequate quality of their tap water in 2019 and cases of illnesses caused by pathogens (5). The news reports and complaints included that underground water does not pass-through adequate stages of treatment and is inconvenient for use because of its taste (5). This incident shows that water quality must be studied thoroughly and needs to meet the World Health Organization (WHO), Mongolian National Standard (MNS) 0900:2018, and Environmental Protection Agency (EPA) standards to verify water supply safety. Standard metrics for pH is 6.5–8.5, hardness is 0–200 ppm, and total alkalinity 20–200 ppm. If some of the metrics do not fall within the appropriate range, it may cause health effects. For example, low pH may lead to increased levels of heavy metals and potential poisoning. (6)

We hypothesized the water in Zaisan would show higher levels of hardness and lower pH levels and total alkalinity than the other regions in Ulaanbaatar. As rocky hills and mountains surround Zaisan, its underground water supply has direct contact with limestone and other minerals, which might contribute to high hardness levels. Furthermore, there are prior reports about soil pollution in Zaisan, which is potentially caused by wooden toilets dug directly into the soil leading to lower pH, total alkalinity, and unsafe coliform levels (5).

We tested our hypothesis using a pH meter and Varify water test kits to measure the metals (lead, iron, copper, mercury, aluminum, manganese, and zinc), mineral ions (nitrite, nitrate, sulfate, free chlorine, total chlorine, and fluoride), pH, total alkalinity, and hardness in 9 samples from Zaisan and 19 samples from other areas of Ulaanbaatar (**Figure 2**). We selected locations with high population densities and that were located close to the city center. In comparison to tap water in other regions, Zaisan's tap water supply had a higher average water hardness and lower pH and total alkalinity. The results of our research may be used as supporting evidence to urge water quality in Ulaanbaatar city.

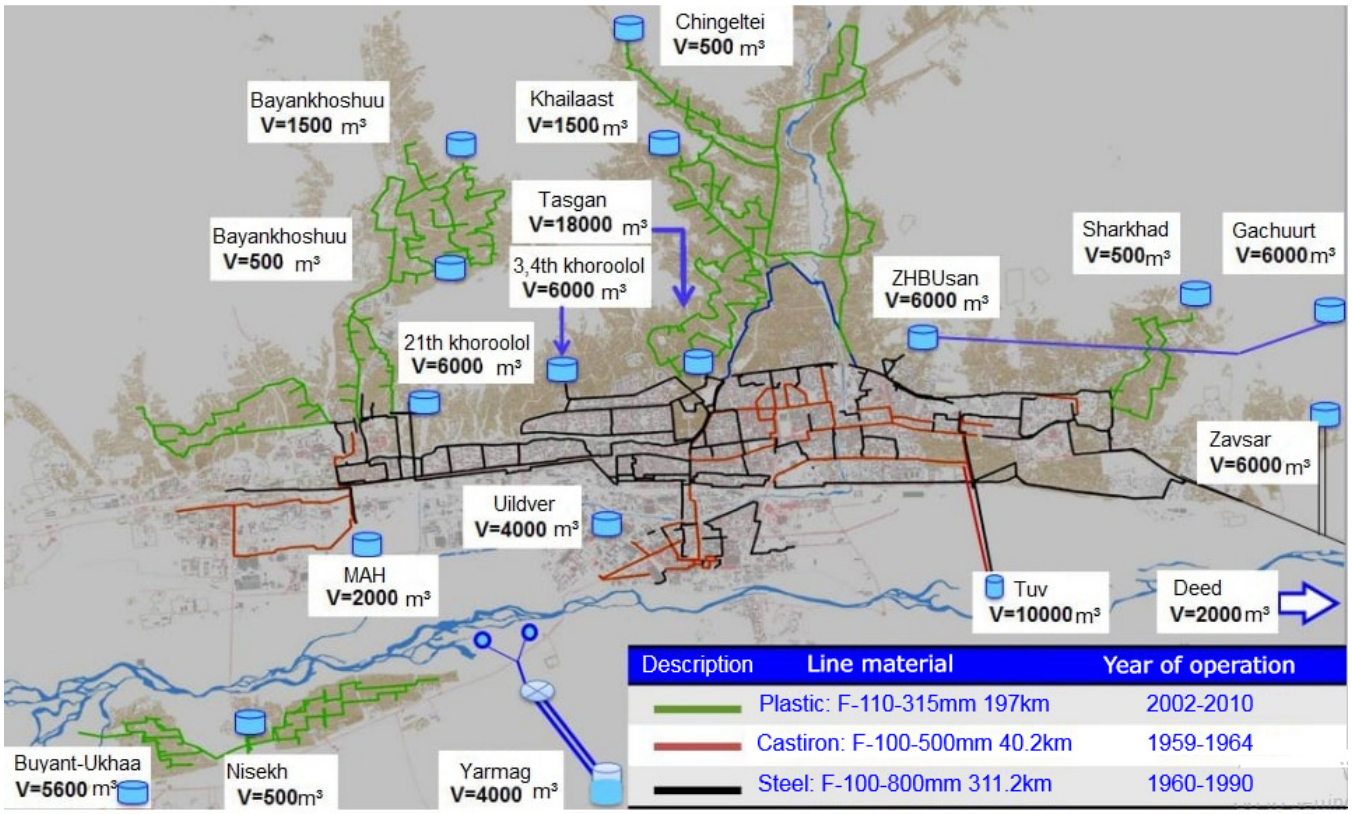

Figure 1. Types of pipes in Ulaanbaatar City. Blue cylinder symbols indicate the temporary storage of water supplies before being transported into the pipes. All water storages are labeled with their names. V = volume of the storage.

RESULTS

To determine whether the tap water quality in Zaisan is lower than the water quality in other locations in Ulaanbaatar, we collected samples from various sites in Zaisan and Ulaanbaatar and used the Varify water test kit and a pH meter to measure 16 parameters of water quality (**Figure 2**) (7). We numbered the collected samples and coded them by their locations (**Table 1**). We obtained all the results by comparing test strips to the color chart provided by the Varify test kit and measuring parameters in parts per million (ppm) or parts per billion (ppb) (**Table 2**). Our test showed that lead, manganese, aluminum, copper, mercury, nitrite, nitrate, fluoride, total chlorine, and free chlorine were not detected in any of the water samples. In addition, we tested for significant differences in pH, total alkalinity, and hardness using an unpaired t-test.

pH

The pH values of collected samples ranged between 5.8 to 6.7, with 21 samples not meeting the three global standards for water quality and showing values lower than the standard of 6.5 to 8.5 (**Figure 3**). Zaisan samples did not have a statistically significantly lower pH average than other districts (p = 0.425); however, they did show a greater range of pH values than the other districts, with the highest being 6.7 and the lowest being 5.8 (**Table 2**). Overall, the pH values of all samples were slightly acidic, which may lead to increased levels of heavy metals and certain health effects such as poisoning (6).

Metal analysis

When we analyzed the concentrations of seven metals (copper, zinc, manganese, lead, mercury, aluminum, and

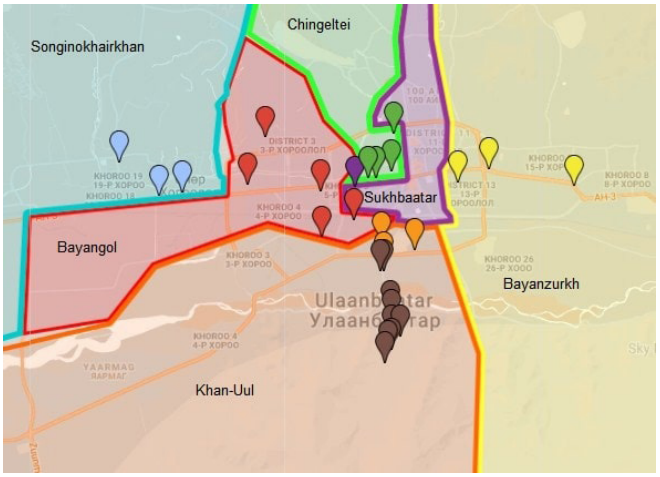

Figure 2. Locations of collected samples. Each district is shaded using distinct colors. Points show the exact locations where we gathered the samples (15).

Table 1. Location of tested samples.

Districts	Sample code	Location	Districts	Sample code	Location
Songino khairkhan	SK 1	15 khoroo 20th apartment	Zaisan	Z 1	Royal Green Villa
	SK 2	Sodon horoolol		Z 2	Zaisan Star
	SK 3	17 khoroo 33rd apartment		Z 3	Golden Buddha
Khan-Uul	Kh U1	1 khoroo 49th apartment		Z 4	Royal Crown Village
	Kh U2	Rapid Harsh Town		Z 5	Seoul Royal County
	Kh U3	Gegeenten khotkhon		Z 6	Nomuun Khotkhon
Sukhbaatar	Su 1	4 khoroo 24-A apartment		Z 7	Luxury Zaisan Village
Chingeltei	CH 1	Circle K, Ard kino theater		Z 8	19 khoroo 55 apartment
	CH 2	3 khoroo 22nd apartment		Z 9	Circle K, Buddha Vista
	CH 3	6 khoroo 58th apartment	Bayangol	BG 1	3 khoroo 71st apartment
	CH 4	State Department Store		BG 2	5 khoroo 7th apartment
Bayanzurkh	Bz 1	X apartment		BG 3	10 khoroo 33rd apartment
	Bz 2	Nomin supermarket, zuun 4 zam		BG 4	Yusun-Erdene town
	Bz 3	6 khoroo K-7 apartment		BG 5	Altai Khotkhon

iron), three samples had iron and zinc levels higher than the recommended ranges. The concentrations of lead, copper, mercury, aluminum, and manganese were within the safe limits of WHO and EPA standards. Zaisan samples did not show harmful levels of heavy metals. However, the zinc concentration in a Bayangol sample (BG 3; 5 ppm) was over the WHO standard limit of 3 ppm. In two samples of Khan-Uul, the amount of iron also exceeded the WHO standard limit of 2 ppm (KH U1 and KH U2; 5 ppm). Even a low concentration of these metals can be detrimental to health (8).

Total alkalinity

The total alkalinity of the collected water samples was between 0 and 180 ppm, with eight samples being outside the safe range of 20–200 ppm (**Figure 4**) (9). Three samples from Zaisan and five samples from other districts had a total alkalinity value of 0 ppm (**Table 2**). The Zaisan supply had lower total alkalinity with an average of 35.6 ppm compared to water from other districts with an average of 70.5 ppm.

Mineral ions

This study measured sulfate, nitrite, nitrate, fluoride, total chlorine, and free chlorine. Sulfate levels of all the tap water samples were around 200 ppm, while nitrite, nitrate, fluoride, total chlorine, and free chlorine of all samples were 0 ppm. Therefore, all the resulting values recorded in **Table 2** were within the acceptable range.

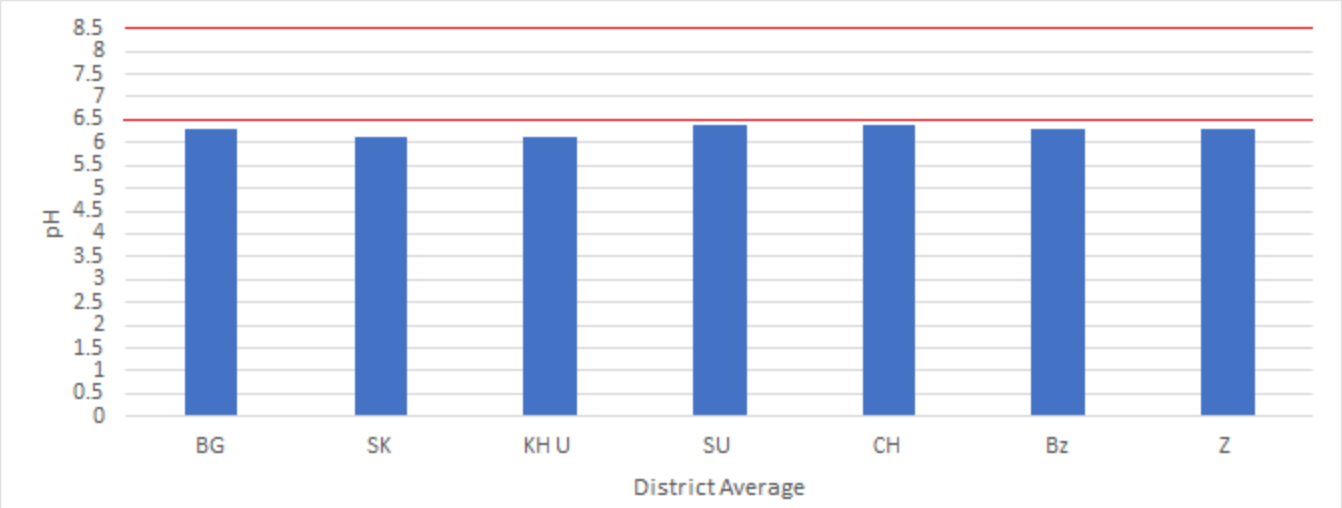

Figure 3. pH comparison. Average pH levels of six districts and nine samples from Zaisan are displayed. The boundary of two red lines shows acceptable pH levels (6.5 – 8.5). The letters on the x-axis are the short codes given to each district.

Hardness

The hardness values in this study were between 25 and 425 ppm (**Figure 5**). A value of 50 ppm or below is soft, 50 to 250 ppm is moderately hard, 250 to 425 ppm is hard, and 425 ppm or higher is very hard (10). When we did an unpaired t-test for comparison, the Zaisan values were significantly higher than the other samples, which varied between 100 and 425 ppm, showing the area has hard water (p = 0.000009) (**Table 2**). According to the EPA standards, the hardness value is recommended to be between 0 and 120 ppm (16). Although high hardness levels do not have a severe negative effect on human health, this may cause some inconvenience in household use, such as causing mineral deposition inside the pipes, reducing the efficiency of detergents, and leaving mineral deposits on clothes (10).

Bacteria

Certain types of coliform bacteria, such as *E. coli*, can cause diarrhea, nausea, and jaundice (11). The Varify test kit has two packages that indicate the presence of coliform bacteria which is commonly found in water. It shows a yellow solution for safe levels and a blue solution for harmful levels when dissolved in water samples. Due to limited tools, we tested only two samples. Considering the previous pathogen poisoning incident and the possibility of still showing positive results, we chose the two samples from Zaisan (Z1, Z3). Our results indicated that the presence of harmful bacteria was unlikely, showing completely yellow solutions for both samples.

DISCUSSION

We hypothesized that tap water from Zaisan would have poorer quality than central tap water as measured by higher hardness levels and lower total alkalinity and pH levels. Our results showed that of all the 28 samples we took from Ulaanbaatar residential and commercial areas, only three samples (BG1, CH 2 and Z 7) fully met the WHO, MNS 0900:2018, and EPA standards (**Table 2**). The rest of the samples did not meet the standard limits by one or more

Table 2. Summary of data results.

	Sample code	Iron/ ppm	Zinc/ ppm	Total Alkalinity/ ppm	Hardness/ ppm	Sulfate/ ppm	pH
Location of samples	BG 1	0	2	40	25	200	6.5
	BG 2	0	2	0	25	200	6.5
	BG 3	0	5	180	50	200	6.3
	BG 4	0	2	40	50	200	6.1
	BG 5	0	2	0	50	200	6
	AVG	**0**	**2.6**	**52**	**40**	**200**	**6.3**
	SK 1	0	2	180	25	200	6.1
	SK 2	0	2	180	50	200	6.1
	SK 3	0	2	40	25	200	6.2
	AVG	**0**	**2**	**133**	**33**	**200**	**6.1**
	KH U1	5	2	0	100	200	6
	KH U2	5	2	40	50	200	6.3
	KH U3	0	2	180	25	200	6
	AVG	**3.3**	**2**	**73**	**58**	**200**	**6.1**
	Su 1	0	2	40	50	200	6.4
	CH 1	0	2	0	25	200	6.3
	CH 2	0	2	80	25	200	6.5
	CH 3	0	2	40	25	200	6.4
	CH 4	0	2	0	50	200	6.4
	AVG	**0**	**2**	**30**	**31**	**200**	**6.4**
	Bz 1	0	2	180	25	200	6.3
	Bz 2	0	2	40	25	200	6.2
	Bz 3	0	2	80	25	200	6.4
	AVG	**0**	**2**	**100**	**25**	**200**	**6.3**
	AVG All Districts	**0.5**	**2.2**	**70.5**	**38.2**	**200**	**6.3**
	Z 1	0	2	80	425	200	6.6
	Z 2	0	2	0	100	200	6.1
	Z 3	0	2	0	100	200	6.1
	Z 4	0	2	40	250	200	6.4
	Z 5	0	2	80	425	200	6.5
	Z 6	0	2	40	250	200	6.6
	Z 7	0	2	40	50	200	6.7
	Z 8	0	2	40	425	200	5.9
	Z 9	0	2	0	100	200	5.8
	AVG	**0**	**2**	**35.6**	**236.1**	**200**	**6.3**
Standards	WHO	<2	<3	-	-	<400	6.5- 8.5
	MNS:0900:2018	<0.3	<5	-	7 mg- eq/l	<500	6.5- 8.5
	EPA	<0.3	<5	20- 200	0- 120	<250	6.5- 8.5

NOTE: *"AVG" indicates the average of each district. Lead, manganese, aluminum, copper, mercury, nitrite, nitrate, fluoride, total chlorine, and free chlorine were not detected in any of the water samples. "AVG All Districts" row includes the average value of the six districts except Zaisan. The light orange shade indicates samples that did not meet 1 out of 3 standards. The orange shade indicates samples that did not meet 2 out of 3 standards. The dark orange shade indicates samples that did not meet any standards.*

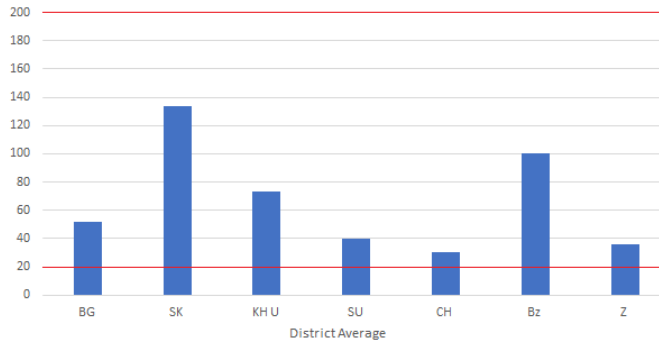

Figure 4. Total alkalinity comparison. Average values of total alkalinities in six districts and nine samples from Zaisan are displayed. The boundary of the red line shows an acceptable value of total alkalinity (20 – 200 ppm). The letters on the x-axis are the short codes given to each district.

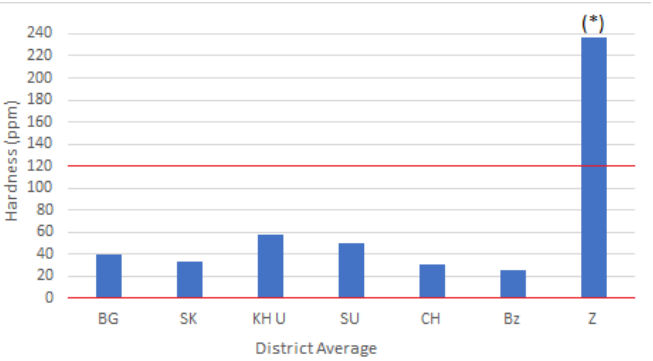

Figure 5. Hardness comparison. The diagram compares the average hardness value of samples from six districts with nine samples from Zaisan. The letters on the x-axis are the short codes given to each district. The boundary of red lines indicates the acceptable range of hardness (0 – 120 ppm). ****p<0.0001.

parameters.

For hardness, 5 out of 28 samples were higher than the EPA standard, all of which were from the Zaisan area. This statistically significant result supported part of our hypothesis as well as the previous complaints regarding inconvenience from the Zaisan residents. Therefore, we speculate that the groundwater in the Zaisan region is close to limestone and other calcium-containing rocks and minerals, resulting in high hardness levels. We speculate these differences are caused because the well water is poorly treated and filtered compared to the central water.

While the values of the other five mineral ion parameters (sulfate, nitrite, nitrate, total chlorine, and free chlorine) were within appropriate ranges, the pH levels of 21 samples did not meet the three standards, showing acidic values below 6.7. We believe that the acidity of the water may be related to the air and soil pollution in the city and poor water monitoring. In the case of mineral ions, the test kit we used had limitations in obtaining more precise values, as the kit had wide intervals between readings. We expect advanced investigations such as titration and spectrometry would improve results.

When we analyzed the concentrations of seven metals (copper, zinc, manganese, lead, mercury, aluminum, and iron), three samples from other districts had iron and zinc levels higher than the recommended ranges. We suspect that metal pipes used for transporting the water might have affected its levels of iron and zinc, as it is possible for acidic water to corrode pipes and elevate the number of metal contaminants (12).

To summarize the results, Ulaanbaatar's water quality is poor when compared to local and global standards since only 11% of the samples met the water quality requirements. As predicted, the water in the Zaisan area showed more measurements outside the standard range than in the other parts of the city, which is probably because of the type of water supply used in the neighborhood. Our research provides evidence that Ulaanbaatar water should be treated to meet the required standards and prevent negative health effects.

For more reliable results, we can repeat the analysis in all four seasons as Mongolia has extreme weather, which can affect the water quality. Especially for underground wells, the water levels change from season to season and thus might affect the number of contaminants such as hardness. The location of the sampling points should be the same for all analyses so that there can be a fair comparison. Also, we suggest retesting the samples with advanced analytical techniques and tools for better accuracy and precision. For example, we can better quantify microbial contamination in the tap water by measuring the total *E. coli*, fecal coliform, and total coliform concentrations in the tap water. Tests for other heavy metals such as arsenic, cadmium, and chromium may also be useful for further detecting harmful substances in the water supply.

As we showed that the hardness level in the Zaisan area was significantly higher than the other regions, a cation filter for softening and alkalinizing water may be beneficial. Since acidic water can increase metal levels and induce negative health effects, we should reanalyze the water supply in this area and treat it to reach the appropriate pH range (13).

MATERIALS AND METHODS

All tap water samples were collected between 1 pm and 9 pm on the same day during the summer. The sample collection adhered to the WHO guidelines (14). PET (polyethylene terephthalate) 500 mL bottled waters were purchased from local supermarkets to collect the samples. The collected samples were kept in the dark for approximately 12 hours at a constant room temperature to avoid any effect of light and temperature. Fifteen water quality parameters and the pH were measured in a school laboratory at room temperature. The analysis of 15 parameters was carried out using the Varify water test kit, which is CE and ISO certified, and EPA compliant. The test kit indicates conformity with health, safety, and environmental protection standards (6). The Varify kit consists of 100 strips that show 16 parameters and two bottles of powder for the bacteria test. This test was chosen because it has enough strips to repeat the experiment twice for each sample.

In addition, two samples from Zaisan were tested using the packages for bacterial testing, which contains powder that indicates the presence of coliform bacteria. We poured 200 mL of the samples into the powder, shook the containers to make a homogenous solution, and then left them in the dark for 48 hours at room temperature, away from sunlight.

The 16 parameters included metals such as lead, iron, copper, mercury, aluminum, zinc, and manganese, hardness, total alkalinity, free chlorine, total chlorine, and some anions such as nitrite, nitrate, and sulfate. The experiment was done using the instructions of the water kit. The test strip was dipped into a 50 mL water sample for 2 seconds and set for 60 seconds until the color changed. Then the strip was compared to the color chart given with the Varify test kit within 30 seconds to obtain values for each parameter (**Figure 6**). The test was repeated twice for each sample. Each parameter has varying value ranges, and all are expressed in ppm or ppb.

The pH of each sample was measured with a digital pH meter (PH-009(I)) and calibrated using 6.86 and 4.003 pH buffer solutions. Each sample was poured in the beaker to above the immersion line of the pH meter. After each measurement, the beaker was rinsed with distilled water. To ensure that values were as accurate as possible, we took measurements while the water was stirred until the value stabilized.

We used the Microsoft Excel t-test formula to compare the average of Zaisan with the average of all regions except Zaisan to compare total alkalinity, pH, and hardness. Then we tested all the values with a student's unpaired t-test with an α level of 0.05 to assess the significance of the results.

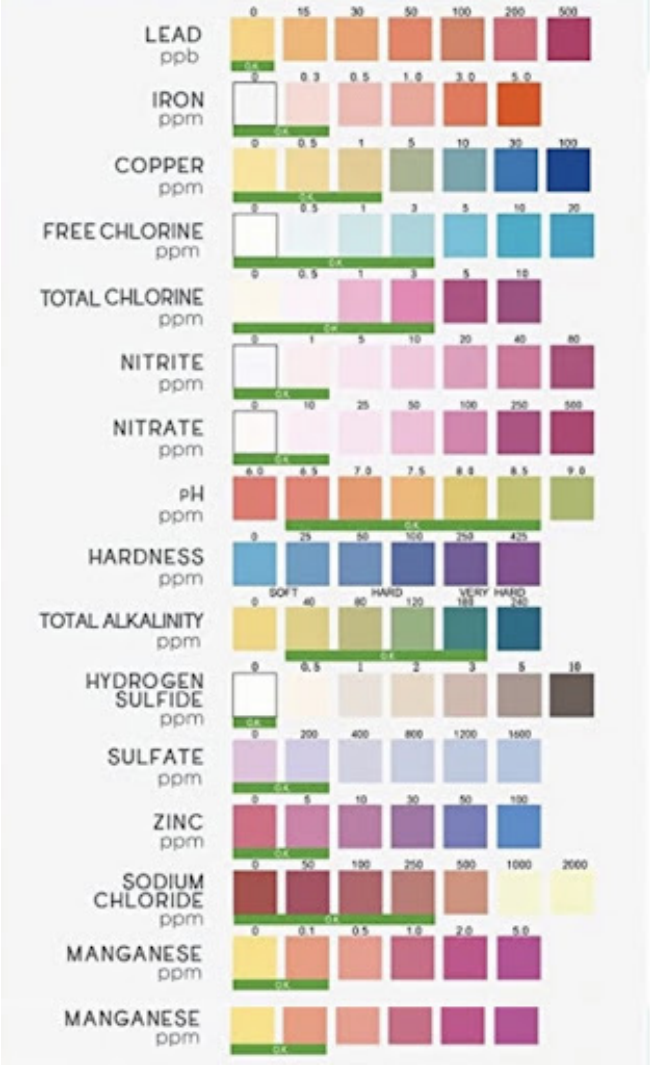

Figure 6. Color chart for parameter testing. The resolution guide is provided by the Varify water test kit website (16). Results were taken by comparing color change on the strips with the colors shown in this figure.

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