

Assessment of Groundwater Quality of the Khan-Uul District of Ulaanbaatar, Mongolia

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Abstract Khan-Uul is one of the nine districts with the largest number of wells unconnected to the centralized drinking water supply line of Ulaanbaatar, the capital of Mongolia. In this study, a total of 134 groundwater samples were collected from 9 sub-districts of Khan-uul, and their physico-chemical parameters including pH, EC, TDS, Na⁺, Ca²⁺, Mg²⁺, Cl⁻, SO₄²⁻, HCO₃⁻, NO₃⁻, As, Cd, Zn, Cu, Pb, Cr, U contents were determined. For quality assessment, the measured values of the groundwater samples were compared against the standards set by the Mongolian standard for Drinking Water Quality (MNS 0900:2018) and the guidelines established by the World Health Organization (WHO) for Drinking Water Quality. Additionally, the water quality index, Gibbs diagram, and Piper diagram were employed to evaluate the suitability of the groundwater for drinking purposes. The electrical conductivity (4.48% of the samples) and the contents of total calcium (9%), magnesium (6%) and nitrate (20%) exceeded the permissible limit set by the guidelines of the MNS and WHO, both. According to the Gibbs diagram, all of the groundwater samples seemed to be ion-exchanged mainly from rock weathering dominance and the dominant hydro-chemical facies were the Ca-Mg-HCO₃ type. In order to calculate the water quality index (WQI), we selected sixteen parameters encompassing physical and chemical properties alongside the content of microelements. Although a majority of the groundwater samples, comprising 70.1% were classified as excellent for drinking purposes, 25.4% were deemed good and 4.5% were classified as poor, rendering them unsuitable for consumption.

Keywords: drinking water, groundwater quality, physico-chemical properties, Mongolia

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1. Introduction

The primary sources of drinking water are groundwater and surface water in nature. Groundwater, known for its relative purity compared to surface water, is critically important for drinking, irrigation, and industrial purposes. [1,2]. Therefore, determining the hydrochemical characteristics and the quality of groundwater is essential to assess whether it is suitable for use in various industries [3]. The abundance and the quality of the drinking water plays an important role in human health. [4,5]. Henceforth, the permissible limits of the ions contained in drinking water are specifically set by national standards the World Health Organisation and [6,7]. Nevertheless, the quality of groundwater is affected by number of factors such as the amount of domestic, agricultural and industrial waste water, geological formation, the state of land usage, rainfall and infiltration processes [1,3,8].

The assessment of the quality of the water from any

source can be accomplished through the evaluation of physicochemical, chemical, and biological properties. These properties are used to assess the quality of water and to determine its suitability for different applications including the protection of human health and the water ecosystem. Thus the acceptable limits for physical, chemical, and biological characteristics that can pose risks to human health have been established through various laws, regulations, and norms in both national and international scales. In addition, hydro-chemical parameters are widely used to indicate the source of the major ions, types of groundwater, water-rock interactions, and the environment of groundwater reservoir [9].

Ulaanbaatar, the capital of Mongolia, is comprised of nine districts, one of which is the Khan-Uul district. This district is renowned as a major industrial hub due to its diverse array of factories, including those producing food products, leather goods, woolens, textiles, as well as power plants, roads, and construction materials. The majority of the population uses water from the deep wells for drink, as the groundwater is the main source of water

in this area. Furthermore, households, businesses, organizations, herder families, and agricultural activities in Khan-Uul district heavily depend on groundwater for drinking and domestic purposes [10]. Therefore, assessing the groundwater quality in the area is crucial for protecting the health of residents and ensuring the uninterrupted operation of the factories and businesses located in the Khan-Uul district.

In this study, our focus was on the physicochemical properties of groundwater. We conducted analysis on the physical and chemical parameters of well water at 134 locations across the Khan-Uul district. The obtained values were compared with standard values set by the Mongolian National Standard for Drinking Water (MNS 0900:2018) and the World Health Organization (WHO) guidelines to ensure whether the quality of the water is in compliance with standard requirements to be used as drinking water and in other domestic applications.

2. Materials and Methods

2.1. Study Area

The present study was carried out in the Khan-Uul district, Ulaanbaatar city, Mongolia. This district is located in the southwestern part of Ulaanbaatar city, at the foot of Bogdkhan mountain and Tuul river valley, covering a total area of 485 km². The Khan-Uul district has 25 committees, which are the primary administrative units, 239035 populations and 23584 business entities. In addition, large-scale factories and power plants are located in this district. The common groundwater abstraction structures are hand wells, dug wells, borehole wells, and their yields mainly depend on the recharge conditions in this area.

2.2. Methods

The groundwater samples were collected from 134 hand/borehole wells, which are used for irrigation and

drinking purposes, from October to December in 2019. The field coordinates of sample locations were marked by using GPS and plotted on the Google map (Figure 1). Samples were collected after 10 minutes of pumping and transferred into pre-cleaned polyethylene bottles with 1 L capacity. The temperature (T°C), pH, electrical conductivity (EC) and total dissolved solids (TDS) of each water samples were measured in the field using digital meters namely, TOA-DKK HM-30P, CM-31P and EC/TDS tester, which was calibrated previously in the laboratory using standard solutions prior to the test. The major ions, Ca²⁺ and Mg²⁺, were analyzed by complex metric titration method, Na⁺ content was measured using flame photometer, Cl⁻ was estimated by AgNO₃ titration, HCO₃⁻ was estimated by a titration method, SO₄²⁻ content was determined by precipitation method using 10% barium chloride solution and the NO₃⁻ content was determined by UV-Spectrophotometer [11]. The contents of microelements were estimated by Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES).

2.3. Evaluation of Water Quality for Drinking Purpose

The Water Quality Index (WQI) is a widely used tool for assessing the water quality and is considered as a useful estimate to aggregate and comprehensively reflect water quality indicators. The values of WQI were computed as follows: each one of determined parameters (physical parameters: pH, EC and TDS, major cations and anions: Na⁺, Ca²⁺, Mg²⁺, Cl⁻, SO₄²⁻, NO₃⁻ and content of heavy metals: As, Cd, Zn, Cu, Pb, Cr, U) were assigned as weight based on perceived effects on the primary health and its influence on the drinking water quality [12]. The WQI was computed through three steps. In the first step, the weight (W_w) of each quality parameter was determined in groundwater samples. In this study, a maximum weight of 5 was assigned to NO₃⁻, As, Cd, Pb, Cr, U; 4 was assigned to pH, EC, TDS; 3 was assigned to Ca²⁺, Mg²⁺, Cl⁻, SO₄²⁻ while Na⁺, Cu, Zn assigned the weight of 2 (Table 1).

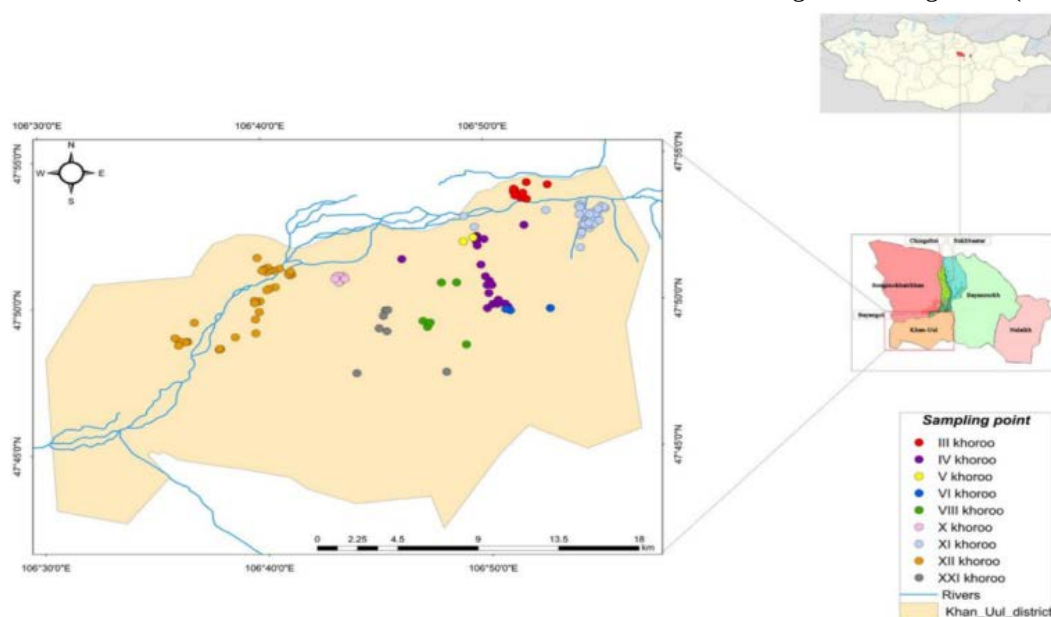


Figure 1. Location map of the groundwater samples taken across the Khan-Uul district of Ulaanbaatar city, Mongolia

Table 1. Values of W_w , W_i , and S_i of different parameters

Parameter	Unit	MNS 0900:2018	Weight (W_w)	Relative weight (W_i)
pH	-	6.5-8.5	4	0.07
EC	mS/m	100	4	0.07
TDS	mg/l	1000*	4	0.07
Ca^{2+}	mg/l	100	3	0.05
Mg^{2+}	mg/l	30	3	0.05
Na^+	mg/l	200	2	0.03
Cl	mg/l	350	3	0.05
SO_4^{2-}	mg/l	500	3	0.05
NO_3^-	mg/l	50	5	0.08
As	mg/l	0.01	5	0.08
Pb	mg/l	0.01	5	0.08
Cd	mg/l	0.003	5	0.08
Cr	mg/l	0.05	5	0.08
Zn	mg/l	5	2	0.03
Cu	mg/l	2	2	0.03
U	mg/l	0.03	5	0.08
SUM			60	1

*WHO

The second step was determination of relative weight and calculated by Eq 1 [12]:

$$W_i = \frac{W_w}{\sum_{i=1}^n W_w} \quad (1)$$

Where,

W_w - is the weight of each parameter

W_i - is relative weight

n - is the number of parameters.

The third step was a computation of the quality rating scale (q_i) for each quality parameters by following Eq 2.

$$q_i = \frac{C_i}{S_i} \quad (2)$$

Where,

q_i . is the concentration of each parameter in water sample

C_i . is concentration of each parameter in each water sample

S_i . is presents the permissible value of each parameter in the MNS 0900:2018.

The final step was the calculation of WQI by Eq 3.

$$WQI = \sum [W_i * q_i] * 100 \quad (3)$$

3. Results and Discussion

3.1. Physicochemical Properties

The main quality parameters of the samples are listed in Table 3. The pH values of the analyzed water samples ranged from 6.12 to 8.39, indicating slightly acidic to slightly alkaline nature of the water samples. According to the measurement, the pH values of all the 134 samples were found to be suitable for drinking as the values were within the permissible limits (6.5-8.5) set by MNS 0900:2018 and WHO guidelines for drinking water quality

[6,7]. In the natural water, bicarbonate ion is dominant anion with a pH value ranging between 4.5 and 9 [13]. Therefore, it can be assumed that the dominant anion of the samples was bicarbonate according to the pH range. The EC values of the samples were ranged from 11.0 to 201.0 mS/m with an average value of 44.98 mS/m. The maximum permissible limit of EC in drinking water is prescribed as 100 mS/m and 150 mS/m according to MNS 0900:2018 and WHO guidelines [6,7]. Based on the test results, the electrical conductivity of 128 water samples were within the permissible limit given by MNS 0900:2018 and WHO, and the EC of 6 samples were found to be exceeded the limit set by the drinking water standard. According to the L.A.Richards classification, all the studied groundwater samples were classified as excellent (<25 mS/m) and acceptable (75-200 mS/m) based on the results of EC measurement [14]. Moreover, it is indicating a low enrichment of salts in groundwater within this area. The elevated EC values in certain samples are likely attributable to intense anthropogenic activities in the area, as well as geological weathering conditions that lead to the accumulation of high concentrations of dissolved minerals [4].

The results of TDS measurement varied from 41 to 557 mg/l for the samples collected from Khan-Uul district and the values were all found to be below the acceptable level, which is 1000 mg/l, as set by the WHO guidelines [7]. According to the Davis and De Wiest classification, groundwater quality is categorized as follows: "desirable for drinking" when the Total Dissolved Solids (TDS) content is up to 500 mg/l, "permissible for drinking" when TDS ranges from 500 to 1000 mg/l, "useful for irrigation" when TDS is up to 3000 mg/l, and "unfit for drinking and irrigation" when TDS exceeds 3000 mg/l [15]. Based on this classification, 98% of the water samples can be classified as "desirable for drinking" and the remaining 2% of the samples can be categorized as "permissible for drinking" (Table 2).

Table 2. Classification of groundwater based on TDS [15]

TDS, mg/l	Water type	% of sample
<500	Desirable for drinking	98
500-1000	Permissible for drinking	2
<3000	Useful for irrigation	-
>3000	Unfit for drinking and irrigation	-

3.2. Main Anions and Cations

The test results of physical parameters and the dominant anions, cations and microelements of 134 underground water samples collected from the territory of Khan-Uul district are shown in Table 3. The calcium (Ca^{2+}) content ranged widely from 12.01 to 228.23 mg/l, with 12 samples surpassing the recommended drinking water limit. Magnesium ion (Mg^{2+}) concentrations varied between 2.43 and 97.28 mg/l, with 8 samples exceeding the recommended limit for drinking water. The permissible limit of Ca^{2+} and Mg^{2+} in drinking water are 100 mg/l and 30 mg/l according to the WHO and MNS 0900:2018 standards [6,7]. The concentration of Na^+ ions in the groundwater samples ranged from 1.45 to 133.2 mg/l, all falling within the acceptable limit of 200 mg/l for drinking water [6,7].

Table 3. Physicochemical parameters of groundwater samples which exceeded the permissible limits prescribed by MNS 0900:2018 and WHO

Parameters	Units	MNS 0900:2018	WHO	Concentration in the study area (min-max)	Average	Number of samples exceeding permissible limit
EC	mS/m	100	150	11.0-201.0	44.98	6
pH	-	6.5-8.5	6.5-8.5	6.12-8.39	7.27	3
TDS	mg/l	-	1000	41.0-557.0	156.14	0
Na ⁺	mg/l	200	200	1.45-133.2	20.86	0
Ca ²⁺	mg/l	100	100	12.01-228.23	55.24	12
Mg ²⁺	mg/l	30	30	2.43-97.28	12.14	8
HCO ₃ ⁻	mg/l	-	-	54.9-402.6	159.01	0
SO ₄ ²⁻	mg/l	500	500	1.65-269.12	31.38	0
Cl ⁻	mg/l	350	250	0.82-271.07	35.43	0
NO ₃ ⁻	mg/l	50	50	0-170.0	30.57	27
As	mg/l	0.01	0.01	1*10 ⁻⁴ -1.9*10 ⁻²	2*10 ⁻³	2
Cd	mg/l	0.003	0.003	1*10 ⁻⁵ -2*10 ⁻⁴	2*10 ⁻⁵	0
Zn	mg/l	5	3	0.005-0.1	0.007	0
Cu	mg/l	2	2	<0.005	0.005	0
Pb	mg/l	0.01	0.01	5*10 ⁻⁴ -1.8*10 ⁻³	5*10 ⁻⁴	0
Cr	mg/l	0.05	0.05	<0.01	0.01	0
U	mg/l	0.03	0.03	4*10 ⁻⁵ -2*10 ⁻²	2*10 ⁻³	0

The concentrations of bicarbonate ion (HCO₃⁻) determined in the samples ranged between 54.9-402.6 mg/l. In natural water bodies, the bicarbonate ion tends to be the dominant anion in the pH range of 4.5-9, meaning that the high concentration of HCO₃⁻ in the water indicates mineral dissolution [13]. The SO₄²⁻ concentration in the water of studied locations ranged from 1.65 to 269.12 mg/l, with an average of 31.38 mg/l. In all samples tested, the concentrations of SO₄²⁻ were found to be below the limits specified by both MNS 0900:2018 and WHO standards. The Cl⁻ content varied between 0.82 to 271.07 mg/l with an average of 35.43 mg/l. The chloride ion content of tested samples were within the permissible limit of 350 mg/l for drinking water according to the MNS 0900:2018 standard [6].

The NO₃⁻ content varied from 0 to 170 mg/l. with the content of nitrate ion in 27 groundwater samples exceeding the permissible limit of 50 mg/l in MNS 0900:2018 and WHO. It indicates that 20% of the groundwater samples from the study area were unsuitable for drinking taking into consideration that the nitrate pollution was the most serious form of pollution. Many environmental scientific researchers have classified nitrate sources as a nonpoint and point (chemical fertilizers, and septic tanks, sewage systems) source [3]. Therefore, the high levels of nitrate in the groundwater from the study area can be caused by human activities such as the discharge of agricultural, domestic and sewage water.

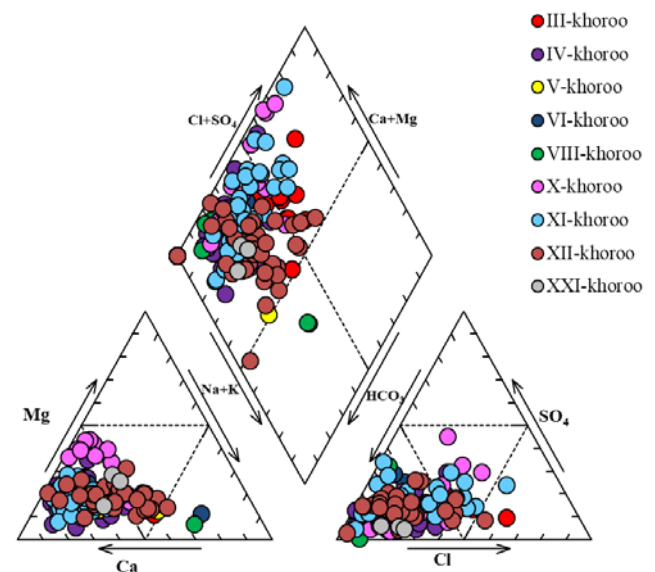
3.3. Heavy metals and Microelements

Table 3 also shows the analytical results of the contents of metals including As, Cd, Cr, Pb, Cu, Zn, and U in the groundwater samples. The contents of Cd, Cr, Pb, Cu, Zn and U were not exceeded the MNS 0900:2018 [6] and WHO [7] drinking water standards. However, As content of 2 groundwater samples has slightly exceeded the MNS 0900:2018 and WHO drinking water standards.

3.4. Hydro Geochemical Classification

3.4.1. Piper Diagram

Hydro chemical classifications of groundwater are made based on the contents of major ions, using the Piper diagram (Figure 2). The groundwater samples were mainly distributed in Field I, indicating that the hydro chemical types of these water is mainly Ca·Mg-HCO₃ type. Some samples were illustrating mixed Ca-Mg-Cl type and mixed Ca-Na-HCO₃ types. The cation triangle diagram shows that the majority of the samples belong to in the Ca²⁺ ion dominant type and the remaining samples were of mixed and Na⁺ ion types. Therefore, according to the anion triangle diagram the majority of the samples HCO₃⁻ type and the remaining samples were of mixed and Cl⁻ ion types (Figure 2).

**Figure 2.** Piper diagram of groundwater samples in the study area

3.4.2. Gibbs Diagram

Gibbs diagrams are often used to determine the relationship between water composition and aquifer lithological characteristics. Three different fields such as evaporation-crystallization dominance, rock weathering dominance and atmospheric precipitation dominance areas are shown in the Gibbs diagram. The rock-water interaction is the key procedure that controls the chemistry of groundwater in this studied region. According to the Gibbs diagram, all the sample of the studied area were rock weathering dominance (Figure 3, Figure 4). Furthermore, other researchers have similarly reported findings on weathering processes in the same region [10].

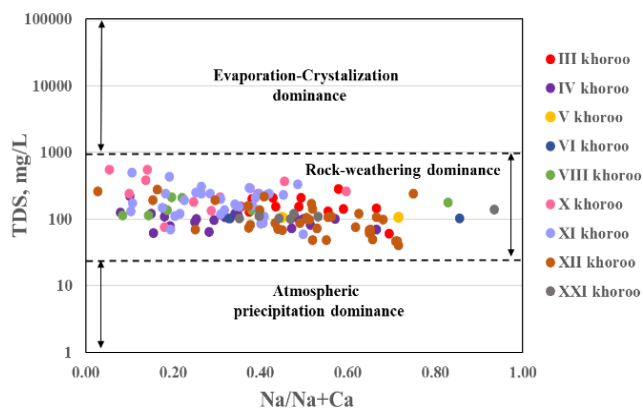


Figure 3. Gibbs diagram of groundwater samples in study area (cation)

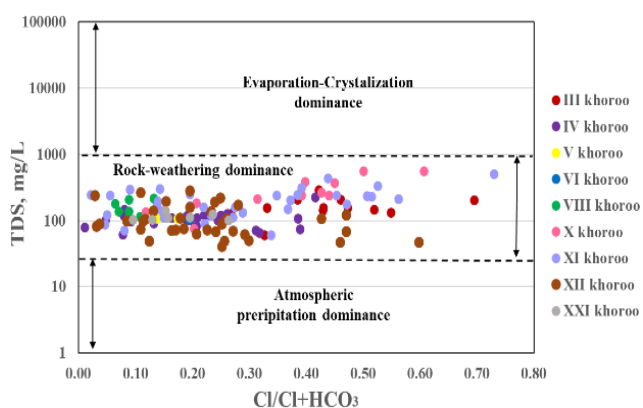


Figure 4. Gibbs diagram of groundwater samples in study area (anion)

3.5. Water Quality Index (WQI)

Table 4. Classification of underground water quality

WQI	Water class	Amount of wells	Percent %
WQI<25	Excellent	94	70.1
25<WQI<50	Good	34	25.4
50<WQI<100	Poor	6	4.5
100<WQI<150	Very poor	-	-
WQI>150	Unfit for drinking	-	-

The water quality index (WQI) is calculated to evaluate the suitability of water for drinking purpose [16]. Therefore, we calculated the index to ensure the suitability of water from deep wells within Khan-Uul district for drinking purposes. The WQI results are demonstrated in Table 4 and Figure 5. The Water Quality Index (WQI) assessments reveal that groundwater from 128 wells is

predominantly excellent or good, with WQI values ranging from 11.79 to 48.67, indicating suitability for drinking purposes. However, water from 6 other wells is categorized as poor quality, with WQI values ranging from 55.8 to 82.34.

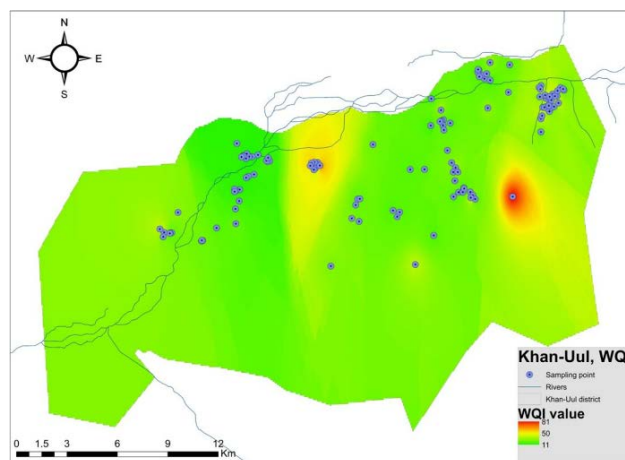


Figure 5. Spatial variation of water quality index (WQI) of groundwater samples in Khan-Uul district

4. Conclusion

In the present study, a total of 134 groundwater samples were collected from different locations across Khan-Uul district of Ulaanbaatar city, Mongolia and analyzed to evaluate their quality for drinking purposes. The following conclusions can be drawn based on the statistical analysis of monitoring data.

The physicochemical and chemical characteristics and water quality assessment of total 134 wells water in Khan-Uul district, Ulaanbaatar city, Mongolia were conducted between October 2019 and December 2019. According to the results of the physicochemical analysis, the pH values and TDS content of all the groundwater samples were within the permissible limit specified by the MNS 0900:2018 and WHO, except for one sample, where the pH of which was 6.12 and TDS of which was 1528 mg/l. Regarding the electrical conductivity measurements, 6 of the samples exceeded the permissible limit set by National and WHO standards.

In terms of sodium ion (Na^+) content, all samples met the permissible limits set by both the MNS 0900:2018 standard and WHO guidelines. Regarding the calcium ion (Ca^{2+}) content, 8.96% of the samples exceeded 100 mg/l. However, 91.04% of the samples met the drinking water standard for calcium ion content. Furthermore, regarding the Magnesium ion (Mg^{2+}) content, 94% of the sample fell within the permissible limit, while 6% exceeded the 30.00 mg/l threshold specified by the MNS 0900:2018 standard. The concentrations of bicarbonate ion (HCO_3^-) of the samples in the study area ranged from 54.9 to 402.6 mg/l. As for chloride and sulfate ions, all samples met the permissible limits set by both the MNS 0900:2018 standard and WHO guidelines. Regarding NO_3^- content, 80% of the samples (107 wells) complied with the permissible limits of both MNS 0900:2018 and WHO standards, while 20% (27 samples) contained nitrate ions above the permissible limit. The concentrations of heavy

metals and microelements such as copper (Cu), zinc (Zn), lead (Pb), iron (Fe), and chromium (Cr) were found to be below 0.005 mg/l, which is well within the maximum allowable limits set by MNS 0900:2018.

Based on the classification of samples collected from Khan-Uul district, the groundwater was identified as belonging to types such as Ca-Mg-Cl, Ca-Cl₂, mixed Ca-Na-HCO₃, and Na-HCO₃. Therefore, all of the samples were of rock weathering dominance. According to the Water Quality Index (WQI), 70.1% of the samples were categorized as excellent quality water, while 25.4% were classified as good and suitable for drinking. Only 4.5% of the samples exhibited poor water quality, rendering them unsuitable for drinking purposes.

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Statement of Competing Interests

The authors declare there is no conflicts.

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