Assessment of groundwater quality in Songinokhairkhan District, Ulaanbaatar, Mongolia

Enkhjargal Togtokh[1*], Odsuren Batdelger[1], Bambasuren Zorigt[1], Uuriintuya Gantsetseg[1], Gerelt-Od Dashdondog[1], Dalaijargal Sandag[1], Erdenesetseg Tsogtbayar[1] and Renchinbud Badrakh[1]

[1]Institute of Geography and Geoecology, Mongolian Academy of Sciences, Ulaanbaatar, Mongolia

[*]Corresponding author: enkhjargalt@mas.ac.mn

Abstract. This study presented the hydrochemical characteristics of groundwater in the "Songinohairkhan district. We collected 111 samples from deep and dug wells in 2020 and major ions and pollution indicators were analyzed in the laboratory, and calculated the Water Quality Indices (WQI). The most dominant water type was first Ca-HCO_3 (70.3%), the second was Mg-HCO3, Mg-[Ca]-HCO_3 (15.3%), the third was Ca-mixed and Ca-[Na]-mixed (2.7%), the fourth was Ca-CI (0.9%). In the case of mineralization, about 0.9% of the groundwater showed very fresh, 75.7% was fresh, 20.7% was freshly or relatively high mineralization, and 2.7% was salty. However, in the case of hardness, 15.3% was soft, 53.2% was softish, 23.4% was slightly hard, 3.6% was hard, and 4.5% was very hard. About 12.6% of the samples were dominated by magnesium and manganese concentrations exceeded the standard of drinking water in the 21 samples (18.9%) which was 1.1-3.16 times higher than the permissible level of the standard. Additionally, As, Sr, and U were found to be higher than the MNS0900:2018 standard in some groundwater. The WQI indicated that the groundwater samples were excellent (65.8 %), good (27%), poor (4.5%), very poor (1.8%), and 0.9% of the samples showed unsuitable water for drinking purposes. Generally, in the study region, fresh and softish water was distributed and most of the samples were suitable for drinking water standards. The Emelt, Tolgoit, and Bayankhoshuu areas have groundwater with relatively high mineralization and hardness. In other words, about 18% of groundwater does not meet the above standard in one or several parameters.

Keywords: First Keyword, Second Keyword, Third Keyword.

O. Batdelger et al. (eds.), *Proceedings of the Fourth International Conference on Environmental Science and Technology (EST 2023)*, Advances in Engineering Research 224,
https://doi.org/10.2991/978-94-6463-278-1_13

1 Introduction

Groundwater is one of the main components of the water cycle in nature and its aquifers are important units of river basin hydrology. Furthermore, it is a critical component of geochemical processes and has many important ecological functions, including supporting spring water, forming the base flow of rivers, and sustaining lakes and wetlands [1]. More than 50% of the world's population is estimated to rely on groundwater resources to meet their daily water needs, and groundwater is the only water source for people living in arid and semi-arid regions [2]. Groundwater quality depends on several things, such as the quality of recharged water, atmospheric precipitation, inland surface water, and on subsurface geochemical processes. Temporal differences in groundwater geochemistry can be caused by recharged water, hydrological and human factors [3]. Today, more than 65 percent of the total population of Mongolia lives and works in Ulaanbaatar. Mongolia's main water resource is groundwater, and activities of all socioeconomic sectors directly depend on groundwater resources and their potential. Rapid population growth, fast industrial development, and unplanned urbanization have resulted in severe groundwater degradation [4]. In particular, the natural properties of groundwater, especially its recharge, location, movement, regime, and composition, are beginning to change as an impact of human activities such as the construction process. On the other hand, natural water that has changed as a result of these impacts, in turn, harms our lives and economies. Many studies show that water quality changes and cannot meet hygiene requirements due to waste ponds (toilets, restrooms, etc.) depending on the peculiarity of Ger districts of Ulaanbaatar city that have existed for many years [4, 5]. Songinokhairkhan district is the largest by area and the most densely populated district among the 9 districts in Ulaanbaatar. In this district, there are many sources of water pollution compared to other districts. For example, wool and cashmere processing industries, garbage discharge points, and livestock slaughterhouses. Therefore, a survey on the quality of groundwater is necessary, which is a major resource of the drinking water supply. To assess water quality, we used Water Quality Indices (WQI), which is widely used for the assessment of groundwater quality around the world due to its ability to fully express water quality information and is one of the most effective tools and important parameters for the evaluation and management of groundwater quality [6].

2 Materials and Methods

2.1 Study area.

The Songinokhairkhan district is located in the southwestern part of Ulaanbaatar city. About 48% of the Mongolian total population lives in the capital city (Ulaanbaatar) as of April 2022. The Songinokhairkhan district has 1200.63 hectares of land and about 21% of the total population of Ulaanbaatar [7].

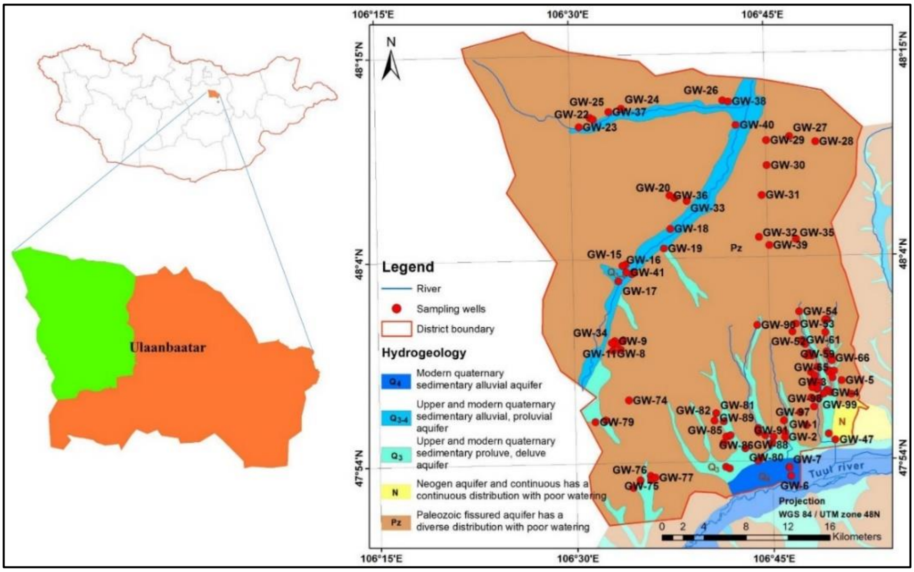

Fig 1. Location of groundwater sampling in the study area

2.2 Sampling and analysis.

The Songinokhairkhan district has a total of 43 subdistricts. Water samples were taken for chemical and microelement analysis from 17 of the subdistricts in this study. A total of 111 groundwater samples were collected in 2020 and the depths of the wells varied from 12 to 156 m. Each groundwater sample was collected after 15 min of pumping until the values of the physicochemical parametres stabilized.

Temperature (T), electrical conductivity (EC), total dissolved solids (TDS), oxidation reduction potential (ORP), and pH were measured in the field using portable equipment (HANNA HI98195). Turbidity was measured using a turbidity metre (HANNA HI 93703) turbidity meter.

Briefly, chemical analyses were performed in the Water analysis laboratory of the Institute of Geography and Geoecology. The titration method determined the major ions (Ca^{2+}, Mg^{2+}, Cl^-, HCO_3^-, and CO_3^{2-}). Additionally, NO_2^-, NO_3^-, NH_4^+, Fe^{3+}, SO_4^{2-} were analyzed using a spectrophotometer (HI833329).

Heavy metal concentrations of the Heavy Metals (i.e., Al, As, Cd, Cu, Co, Fe, Pb, Sr, Mo, Ni, Zn, Hg, and U) in groundwater samples were measured by inductively coupled plasma-optical emission spectrometry in the SGS laboratory.

2.3 Water Quality Index Determination

The WQI is generally used to assess groundwater quality by converting multiple groundwater quality parameters into a single value [6]. Therefore, in this study, 13 selected physicochemical parameters (pH, EC, TDS, Ca^{2+}, Mg^{2+}, Na^+, Cl^-, HCO_3^-, SO_4^{2-} -, F, As, U, Sr) were used to estimate the WQI of groundwater (see Table 1). To determine the WQI (Eq. (1)), each parameter was assigned a specific weight value (Wi) based on its potential to affect groundwater quality for drinking purposes [8]. The maximum weight of 5 has been assigned to parameters such as Sr, U, and As due to their major importance in the assessment of water quality. Bicarbonate was given a minimum weight of 1 because it plays an insignificant role in water quality assessment. Other parameters such as total dissolved solids, chloride, sulphate, calcium, magnesium, and sodium were assigned a weight between 2 and 4 depending on their importance in the overall quality of water for drinking purposes [9].

Table 1. The relative weight of chemical parameters [10].

Parameters	WHO standard	Weight (w_i)	Relative weight (W_i)
pH	6.5-8.5	3	0.067
EC (μS/cm)	1500	4	0.089
TDS (mg/L)	500	4	0.089
Ca^{2+} (mg/L)	75	3	0.067
Mg^{2+} (mg/L)	30	3	0.067
Na^{+} (mg/L)	200	3	0.067
HCO_3^- (mg/L)	120	1	0.022
Cl^- (mg/L)	250	3	0.067
SO_4^{2-} (mg/L)	250	4	0.089
F- (mg/L)	1.5	2	0.044
Sr (mg/L)	2	5	0.111
As (mg/L)	0.01	5	0.111
U (mg/L)	0.03	5	0.111
Total	-	45	1.000

The WQI Calculation Method developed by Samuel et al. (2019) was used for groundwater quality assessment. The relative weight of the parameters was computed using the relationship in Equation (1) below:

$$Wi = \frac{wi}{\sum_{i=1}^{n} wi} \quad (1)$$

Wi represents the relative weight of the parameter, wi is the weight of each parameter, and n is the total number of parameters. The calculated relative weight values (Wi) for each parameter are given in Table 1. For each of the parameters, a quality rating scale (qi) was determined using the relationship in Equation (2) below:

$$qi = \frac{Ci}{Si} * 100 \quad (2)$$

where qi is the quality rating and Ci is the concentration (mg/L) of each chemical parameter in each water sample. Si is the WHO drinking water standard for each of the parameters. The sub-index and WQI were computed using the relationship in Equations (3) and (4), respectively.

$$SIi = Wi \times qi \quad (3)$$

$$WQI = \sum Sii \quad (4)$$

where SIi is the subindex of the i-th parameter and qi is the rating based on the concentration of the i-th parameter. Table 2 shows the range of the specified WQI for drinking water (see Table 2).

2.4 Statistical and Evaluation Methods

In this study, distribution maps of TH, TDS and WQI were generated using the ArcGIS software version, while water quality graphical analysis was determined using Grapher software, and SPPS21 software was used for the classification of TDS and TH and the statistical analysis.

3 Result and discussion

3.1 Statistical analysis

A statistical summary of the physicochemical parameters (e.g., Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^{-}, SO_4^{2-}, Cl^{-}, TDS, EC, and pH) was determined and given in Table 2.

Table 2. The relative weight of chemical parameters [11].

Parameters	Min	Max	Mean	Std. Deviation	WHO 2011*	MNS 0900:2018	% of unsuitable groundwater
pH	6.7	7.68	7.3	0.3	6.5-8.5	6.5-8.5	-
EC (µS/cm)	198	2336	541.5	290.8	1500	1000.0	1.8%*, 5.4%
TDS (mg/L)	99	1168	306.3	156.5	500	-	7.2%
Ca^{2+}(mg/L)	23	232.5	60.1	28.0	75	100	13.5%*, 4.5%
Mg^{2+}(mg/L)	5.5	94.8	20.8	14.9	30	30.0	18.9%
Na^{+}(mg/L)	6.9	139.7	25.0	21.7	200	200.0	-
HCO_3^{-}(mg/L)	85.4	475.8	226.3	60.8			-
Cl^{-} (mg/L)	0.2	610.6	34.7	67.0	250	350.0	0.9%
SO_4^{2-} (mg/L)	0.4	300	49.4	53.2	250	500.0	-
F (mg/L)	0.36	8.0	0.9	0.8	0.7-1.5	0.7-1.5	42.3%
As (µg/L)	0.03	454	10.5	48.7	10	10	7.2%
Sr (µg/L)	211	6593	1019.7	899.9	2000	20	10.8%
U (µg/L)	0.03	62.5	8.0	8.8	30	30	3.7%

Most of the samples were predominantly slightly alkaline, the value of which ranged from 6.70 to 7.68, with a mean value of 7.30. This indicates that all water samples do not exceed the limit of 6.5-8.5 according to the National and WHO standards for drinking purposes. The EC of the water samples ranged from 198 to 2336 µS/cm with a mean of 541.5 µS/cm. Most samples did not exceed the standard except for 6 samples. The TDS ranged from 99 to 1168 mg/L, averaging 306.3 mg/L, and eight samples exceeded the WHO standard limit (500 mg/L) (see Table 2).

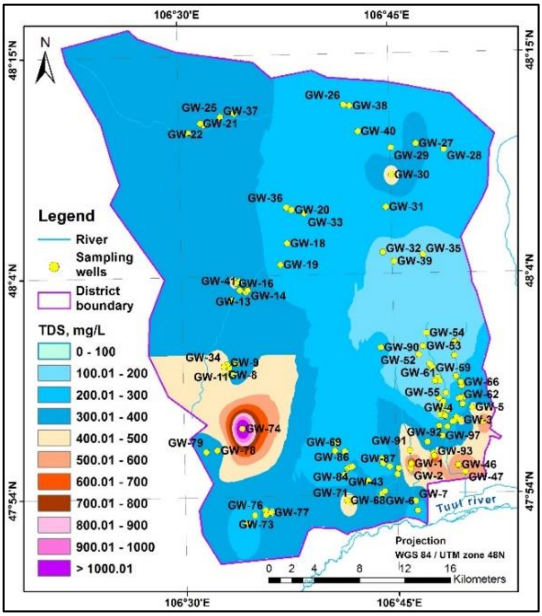

Fig 2. Spatial distribution of dissolved solids (TDS) in the study area

As shown in Figure 2, high concentrations of TDS (>500 mg/L) were observed near the Emelt, Tolgoit and Bayankhoshuu areas. The dominant major cation was calcium and concentrations ranging from 23 mg/L to 232.5 mg/L with an average of 60.1 mg/L. Six samples (GW3, GW5, GW67, GW74, GW93) exceeded the standard permissible limit by calcium. The cation concentrations are in the order of Ca^{2+}>Mg^{2+}>Na^{+}+ K^{+} (see Fig. 4). Bicarbonate (HCO_3^-) was dominant in the anions. HCO_3^- ranges between 85.4 mg/L and 475.8 mg/L, averaging 66.3 mg/L (see Table 3). Generally, the concentrations of the major anions are in the order of HCO_3^->Cl^->SO_4^{2-} (see Fig. 4).

The total hardness varies between 1.6 and 19.4 meq/L with an average of 4.7 meq/L considering that five samples were in the very hard category and most of the samples belong to the moderately hard category in the study area (see Table 2 and Fig. 3). As shown in Figure 3, high concentrations of total hardness (>7 meq/L) were observed near the Emelt, Tolgoit, and Bayankhoshuu areas.

3.2 Water Quality and Chemical Composition

Durow diagrams are important to understand the hydrochemical types, evolution, and properties of groundwater [9]. The diagram revealed that most of the samples in this study belong to Ca-HCO_3 (70.3%) type followed by Mg-HCO_3 and Mg-[Ca]-HCO_3 (15.3%), Ca-Mixed, Ca-[Na]-Mixed (5.4 %), Na-HCO_3 (2.7%) and Ca-CI (0.9%) respectively (see Fig. 4).

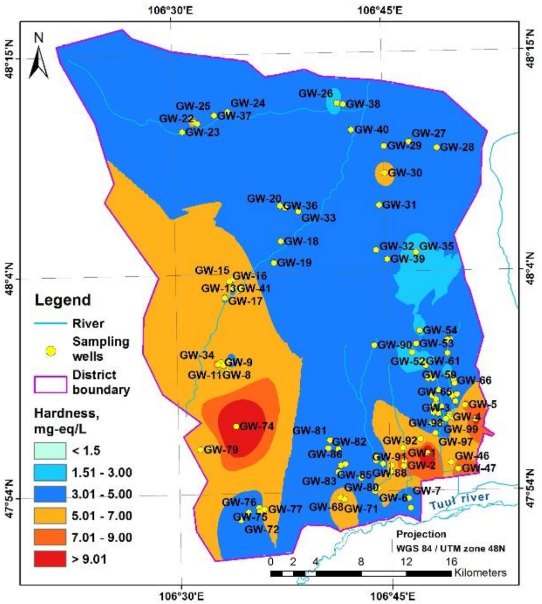

Fig.3. Spatial distribution of total hardness (TH) in the study area

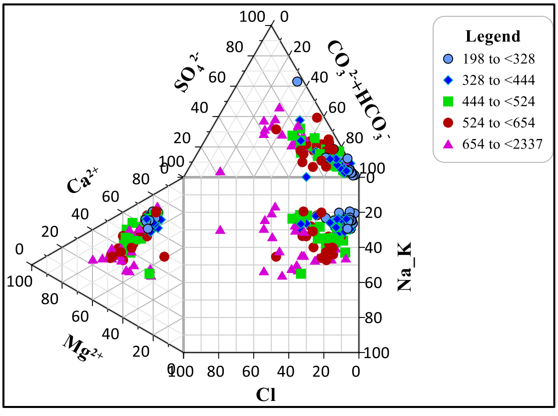

Fig 4. Durow diagram showing the chemical composition of groundwater in the study area

Total hardness (TH) in mg/L was determined by (2.497 Ca^{2+}+4.115 Mg^{2+}), according to Todd (WQI) [6]. A detailed classification of groundwater quality based on TDS and TH (see Fig. 5) shows that the majority of groundwater samples were classified into the soft-fresh category.

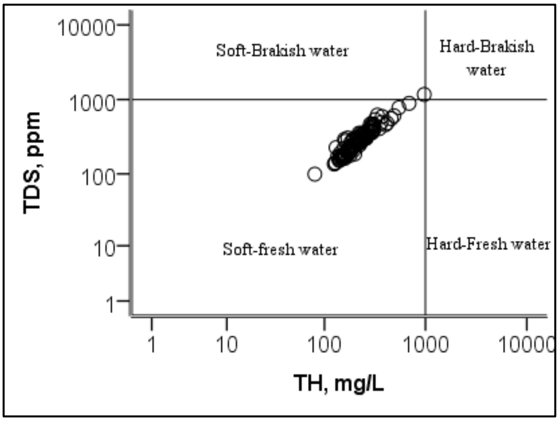

Fig 5. Groundwater quality in the Songinokhairkhan district based on dissolved solids and total hardness

WHO and Mongolian drinking water standards specified between 0.7 and 1.5 mg/L. The clear effect of inadequate fluoride intake in humans is an increased risk of dental caries in all ages. Fluoride concentrations greater than 1.5 mg/L in drinking water have adverse health effects on humans if ingested for a prolonged period [12].

The results show that 40.5% of all water samples have a low fluoride content (F 0.49-0.68 mg/L), while 1.84% have a high fluoride content (>F1.5 mg/L), which does not meet the drinking water standards (see Table 2).

3.3 Water Quality Index Determination

The WQI for all sampling points was calculated to determine their suitability for drinking purposes according to the methodology.

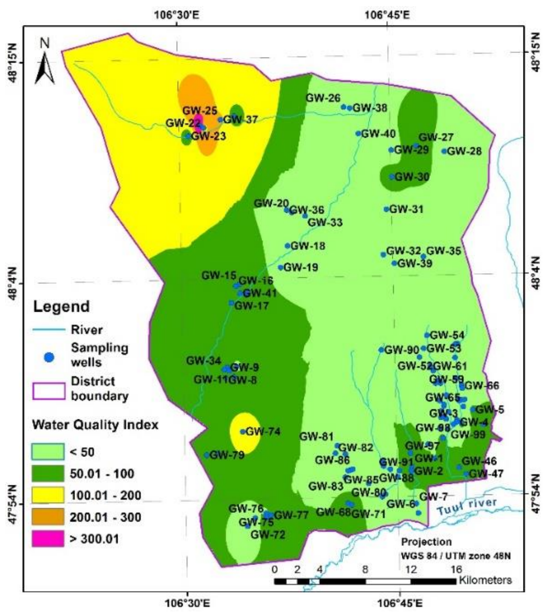

Fig 6. The Water Quality Index Spatial Distribution Map

Figure 6 illustrates the spatial distribution of the WQI. The WQI values ranged from 22 to 501.7 (average of 53). Consequently, groundwater quality was classified into excellent (66%), good (27%), poor (4.5%), very poor (1.8%), and unsuitable for drinking purposes (0.9%). The WQI map indicates that the high-risk zone is in the northwest part of the study area (see Fig. 6). From heavy metals, a high concentration of arsenic was detected at some points in the northwestern part of the study area, which affected the WQI value. Therefore, the WQI values differed from the TDS distribution and total hardness.

4 Conclusions

This article has highlighted an assessment of groundwater quality for drinking purposes using the WQI in the study area. Spatial distribution maps of the main parameters of groundwater quality (TDS, TH) and water quality indices were prepared and analyzed using ArcGIS software. This spatial distribution map was used to determine the distribution of water contaminants in detail and helped to provide a comprehensive overview of groundwater pollution control and remediation measures.

In general, around 80% of the samples were suitable for drinking water standards. Groundwater in the Emelt, Tolgoit, and Bayankhoshuu areas has relatively high mineralization and hardness. Calcium and magnesium exceeded the maximum permissible levels in many samples. Also, approximately 42.3% of the samples do not meet drinking water standards (F 0.7-1.5 mg/L) by fluoride ion. The higher values are related to the complex hydrogeological conditions and the predominance of weathered fissure water.

According to the water quality index (WQI), 7.2% of groundwater in the study area was classified as poor water, very poor, and unsuitable.

To protect human health, parameters (minerals, total hardness, calcium, magnesium, uranium, arsenic, and strontium) that are not suitable for drinking purposes should be purified using membrane filters (reverse osmosis, nano filters). It is necessary to connect the settlement area around Emelt to the centralised clean water network and provide reliable clean water to the people who live there to protect their health. In addition, families living in Ger use traditional pit latrines not connected to a centralised sewage system. Therefore, there is a risk of contamination of the surface and groundwater with bacteria through pit latrines, so a detailed bacteriological monitoring study is recommended in the study area.

5 References

1. Ministry of Environment and Green Development, Mongolia.: National integrated water management assessment report. Volume 2. Groundwater resources. ISBN. 978-99962-4-538-1, Ulaanbaatar (2012).
2. Yin, S., Xiao, Y., Han, P., Hao, Q., Gu, X., Men, B., Huang, L.: Investigation of Groundwater Contamination and Health Implications in a Typical Semiarid Basin of North China. Water Journal 12(4), 1137 (2020). https://doi.org/10.3390/w12041137
3. Sadat-Noori, S.M., Ebrahimi, K., & Liaghat, A.M.: Groundwater quality assessment using the Water Quality Index and GIS in Saven-Nobaran aquifer Iran, Environmental Earth Sciences 71 (9), 3827-3843 (2014). https://doi.org/10.1007/s12665-013-2770-8
4. Batdelger, O., Tsujimura, M., Tran, D.A., Zorigt, B., Thuc, P.T.B.: Identification of Hydrogeochemical Processes and Controlling Factors in Groundwater and Surface Water Using Integrated Approaches, Tuul River Basin (Ulaanbaatar, Mongolia). In: Vo, P.L., Tran, D.A., Pham, T.L., Le Thi Thu, H., Nguyen Viet, N. (eds.) Advances in Research on Water Resources and Environmental Systems. GTER 2022. Environmental Science and Engineering. Springer, Cham (2023). https://doi.org/10.1007/978-3-031-17808-5_12
5. Togtokh E., Dashdondog G., & Zorigt B.: Hydrochemical characteristics and groundwater quality: A case study in the Emeelt area. Environment and Sustainable Development of the Mongolian Plateau and surrounding territories, XIII International Conference, Proceeding, p. 152-162, Ulaanbaatar (2020).
6. Olasoji, S.O.; Oyewole, N.O.; Abiola, B.; Edokpayi, J.N.: Water Quality Assessment of Surface and Groundwater Sources Using a Water Quality Index Method: A Case Study of a Peri-Urban Town in Southwest, Nigeria. Environments (2019). https://doi.org/10.3390/environments6020023
7. National Statistics Office, https://www.1212.mn/mn/statistic/statcate/573051/table-view/DT_NSO_0300_067V2, last accessed 2023/05/15.
8. Dang, A.T., Tsujimura, M., Ho, H.L et al.: Groundwater quality evaluation and health risk assessment in coastal lowland areas of the Mekong Delta, Elsevier. Volume 15, 100679 (2021). https://doi.org/10.1016/j.gsd.2021.100679

9. Bahar, M.M., Reza, M.S.: Hydrochemical characteristics and quality assessment of shallow groundwater in a coastal area of Southwest Bangladesh. Environ Earth Sci 61, 1065–1073 (2010). https://doi.org/10.1007/s12665-009-0427-4
10. World Health Organization (WHO).: Guidelines for Drinking-Water Quality. Vol. 4th edn. Recommendations. Geneva: World Health Organization, (2011).
11. Mongolian Standard Metrology Agency. Environment.: Health protection. Safety. Drinking water. Hygienic requirements, assessment of the quality and safety" MNS 0900:2018.
12. Choijil, J., Badrakh, R., Togtokh, E., Bold,O., Dashdondog, G., et al.: Study of water quality in drinking water and economy of Ulaanbaatar city and development of recommendations to protect human health from water pollution, Grant project report, Ulaanbaatar. Mongolia (2019).