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Улаанбаатар хот

Хэрлэн голын хөндийн дагуух газрын доорх усны хүнд металлын орон зайн тархалтын шинжилгээ
Analysis of the spatial distribution of heavy metals in drinking groundwater of the Kherlen River Valley, Eastern Mongolia

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Хураангуй

Хэрлэн голын ай сав нь гүний ус ашиглах цогцолбор төлөвлөгөөнд байнга тусгагдаж байдаг онцлог бүхий стратегийн өндөр ач холбогдолтой бүс нутаг юм. Энэхүү судалгааны ажлаар бид Хэрлэн голын хөндий дагуу газрын доорх усны сорьцод нийт 53 үзүүлэлтээр бичил элементийг тодорхойлсноос Mn, Ni, As, U, Cd, Cu болон Sr зэрэг элементүүд тодорхой хэмжээгээр бүх цэгт илэрсэн тул эдгээр элементүүдийг сонгож, агууламжийн тархалтын зураглалыг орон зайн интерполяцийн урвуу зайн жингийн аргыг ашиглан гаргасан. Судалгааны ажлыг 2021 оны хавар (5-р сар) болон 2022 оны намар (10-р сар) хийж гүйцэтгэлээ. Усны чанарын судалгааны хүрээнд нийт 60 сорьц цуглуулсан. Судалгаанд хамрагдсан уст цэгүүдэд манганы хамгийн өндөр агууламж (Mn 908 µg/L), кадми хамгийн бага агууламж (Cd 0.01 µg/L) илрэлтэй байна. Судалгааны үр дүнгээс харахад Mn, U, Ni, Sr болон As зэрэг элементүүд нь Монгол улсын ундны усны стандартын хэмжээнээс 31.6%, 16.6%, 15%, 8.3%, 3.3%-иар тус тус давсан агууламжтай байна. Харин газрын доорх усанд дахь Cu, Cd-ийн агууламж дээрх стандартаас давсан үзүүлэлтгүй байна. Энэ голын сав газрын бохирдлын эх үүсвэр нь байгалийн болон хүний үйл ажиллагаатай холбоотой болох нь тогтоогдсон.

Түлхүүр үгс: *Хэрлэн гол, газар доорх усны бохирдол, хүнд металл, орон зайн шинжилгээ*

Abstract

The Kherlen River Basin holds significant strategic importance and is often considered in the comprehensive groundwater utilization plan due to its unique characteristics. Our study focused on analyzing the concentration and spatial distribution of 53 heavy metals (HMs) in groundwater within the Kherlen river valley in East Mongolia. The findings revealed the presence of 5 heavy metals (Mn, Ni, As, U, Sr) out of the 53 in the collected groundwater samples. A total of 60 drinking groundwater samples were collected between 2021 and 2022, and the concentrations and spatial contributions of heavy metals such as manganese (Mn), strontium (Sr), nickel (Ni), arsenic (As), and uranium (U) were analyzed. The distribution of HMs along the river valley was determined using the IDW (Inverse Distance Weighting) interpolation method. The results indicated that manganese (Mn) had the highest concentration at 908 µg/L, while cadmium (Cd) had the lowest concentration at 0.01 µg/L. When compared to Mongolia's drinking water standard, the exceeding rates for manganese (Mn), uranium (U), nickel (Ni), strontium (Sr), and arsenic (As) concentrations were 31.6%, 16.6%, 15%, 8.3%, and 3.3% respectively. Copper (Cu) and cadmium (Cd) did not exceed the corresponding standards. The spatial distribution of heavy metals primarily originated from both natural and anthropogenic sources.

Keywords: *Kherlen river, Groundwater contamination, heavy metals, spatial analysis*

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Introduction

Groundwater serves as the most crucial source of water globally, particularly in arid and semi-arid regions, meeting water needs for drinking, irrigation and other economic purposes. It is imperative to acknowledge that any changes in its quality, leading to contamination, can undeniably have adverse effects on human health (Naomi et al., 2019; Tmava et al., 2013). Unfortunately, due to climate change and human activities, groundwater faces the risk of pollution and scarcity in numerous locations. Consequently, concerns regarding the quality of drinking water are progressively escalating due to unprecedented population growth, urbanization, and industrial expansion. Heavy metals, known for their toxic behavior, persistence, lack of biodegradability, and bioaccumulation, are significant environmental pollutants that necessitate stringent control measures (Fu et al., 2013; Batvari et al., 2013).

Heavy metals are extensively distributed in nature as a result of their broad use in a variety of industries and fields, including household, industrial, medicinal, and agricultural. According to Quyang et al. (2002), anthropogenic activities and geochemical reactions are the two primary sources of heavy metals in the environment. Anthropogenic sources, such as industrial discharge, agricultural chemicals, and municipal sewage discharge, contribute significantly to heavy metal contamination. Groundwater pollution, particularly caused by heavy metals, is considered one of the most significant environmental problems today (Voleda et al., 1997). Among the diverse range of contaminants affecting water resources, heavy metals are of particular concern due to their potent toxicity, even at low concentrations.

In Mongolia, groundwater plays a vital role as a water source for both drinking and economic sectors. Although the country possesses a total water resources of approximately 564.8 million m^3, only 1.8% constitutes groundwater, as reported by Jadambaa (2009). However, more than 70% of water consumptions in country relies on both renewable and non-renewable aquifers. Therefore, conducting comprehensive research and analysis on groundwater quantity and quality is crucial to safeguard water resources.

Groundwater contamination caused by heavy metals has emerged as a significant issue in Mongolia, particularly in rural areas. Research has shown that the most prominent compounds found in groundwater in Dornod, Baganuur and Khentii aimags are Mn, U, Fe, and Be. High concentrations of heavy metals in water have been linked to various health issues, including abdominal pain, heart disease, immune system, high blood pressure, and damage to the liver, and kidneys (Tokatlı, 2018). Only a few studies have measured the heavy metal content of ground- and surface water in KRB and evaluated water quality using the drinking water quality index and heavy metal pollution index (Gerelt-Od et al., 2023; Erdenetsetseg et al., 2022). Some studies have focused only on specific elements, such as uranium and arsenic (Tegshbayar, 2020). Even though Mongolia is still in the early stages of developing a thorough quality monitoring program for its ground-, surface and drinking water, recent researches already found elevated levels of heavy metals (HMs) in surface water, groundwater and soils/sediments in the center and settlement area of eastern Mongolia (Chinzorig et al., 2020; Amarsanaa et al., 2022;). Studies on heavy metals in drinking water in Kherlen river valley, Eastern Mongolia, are scarce. Tuv, Khentii, Dornod province and Ulaanbaatar are emerging centers of socio-economic development and industrialization in Mongolia, which requires moe researches to determine the extent of groundwater contamination linked to heavy metals in urban and industrial areas relative to large cities or settlements.

Protecting groundwater security necessitates a thorough analysis of the heavy metal distribution characteristics in groundwater. The primary goals of this study are to (1) identify the characteristics of HMs' spatial distribution; and (2) analyze the factors that influence HMs in groundwater. The findings of this study will provide policy makers a solid scientific foundation on which to build plans and strategies for protecting water resources and guarantee the safety of groundwater used for drinking.

Material and Methods

Study area

This research was conducted in the Mongolian section of the Kherlen River Basin (KRB), which is situated in the eastern Mongolian plain and eventually flows into China's Hulun Lake. The river basin covers an area of 94,629 km² in the country and includes a municipal district (i.e., Baganuur District, Ulaanbaatar City) and four provinces (i.e., Tuv, Khentii, Dornod and Sukhbaatar). A small portion of the basin also covers areas of the Gobisumber and Dornogovi provinces.

The KRB is known for its tin and gold deposits.The largest coal deposits of Baganuur coal mine located in the upstream part and the Aduunchuluun coal mine situated near Choibalsan city, Dornod province, in downstream part of the basin. The Kherlen River is geologically located beneath the layer of greenschist formed by Neo-proterozoic (Kim et al., 2017).

Annual air temperatures in the KRB tend increase from north to south, and from west to east. The annual average air temperature ranges from -3.1 to 0.6℃ degrees throughout thr basin, with colder air at higher land surfaces. The annual precipitation in the KRB is approximately 250 mm, but it varies depending on the geographical location and characteristics. The Khentii mountain ranges located upstream of the KRB receive around 350-400 mm of precipitation (Fai, Munkhjargal 2017).

The renewable resources of groundwater in a 1 km² area fluctuate between 20-200 mm/year and are changeable and compound along the valley of the river. The potential exploitable groundwater resources have already been studied for drinking water purposes in Baganuur district, Undurkhaan and Choibalsan cities.

Sampling and analysis

The concentration of heavy metals in groundwater was determined using a total of 60 groundwater samples (Figure 1), comprising of 8 shallow well water samples and 32 deep well water samples from locations along the Kherlen River valley (Tuv province-6, Baganuur district-13, Khentii province-20 and Dornod province-21). The majority of sampling wells, which range in depth from 2 to 100 m, are used to supply drinking water to the towns and centers of municipal district, provinces and soums. Every well was pumped for 10 min or until the water volume was discharged approximately twice and stable chemical conditions were reached. The sampling locations were recorded using global positioning system (GPS) equipment. The GIS based spatial distribution of samples and parameters were analyzed using ArcGIS 10.1. The concentrations of HMs (As, Mn, Cd, Cu, U, Ni, Sr and Mo) were measured by ICP-OES in the Société Générale de Surveillance laboratory.

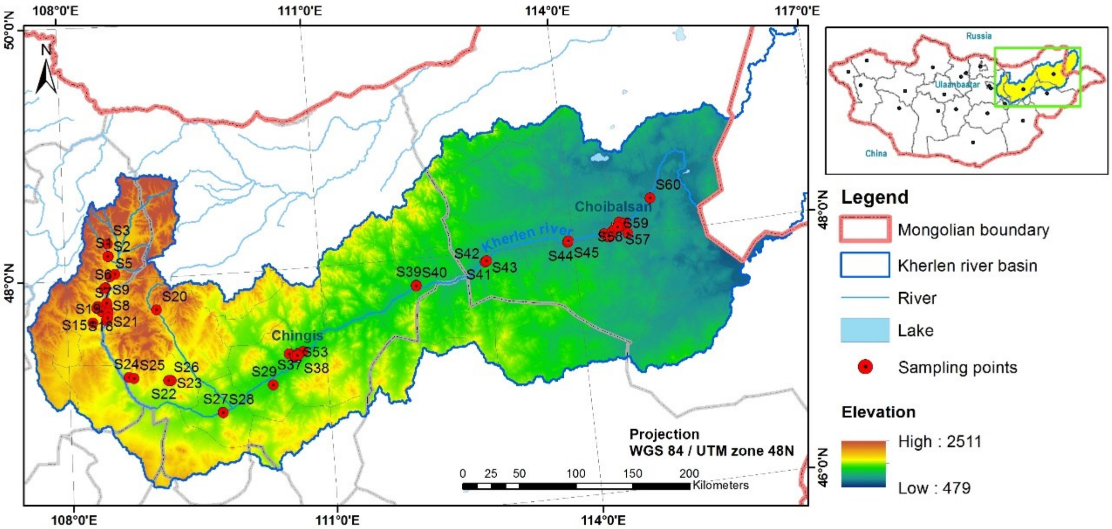

Figure 1. Location map and sampling points of study area.

Results and Discussion

Heavy metal concentration in groundwater: The heavy metal content in groundwater samples collected from a different section of the Kherlen river valley is presented in Table 1. The quality of the samples was assessed against the Mongolian drinking water (MNS 0900:2018) standard.

Table 1. Descriptive statistics of the heavy metals contamination in groundwater

Parameters	Min	Max	Mean	SD	MNS 0900:2018
Mn (µg/L)	5.0	908.0	138.2	226.7	100
Cd (µg/L)	0.01	1.2	0.1	0.2	3
Cu (µg/L)	5.0	13.0	5.4	1.5	2000
Ni (µg/L)	0.3	42.5	12.6	10.7	20
As (µg/L)	0.21	41.9	4.0	6.8	10
U (µg/L)	0.02	206.0	19.3	34.7	30
Sr (µg/L)	132.0	3627.0	755.8	753.6	2000

According to Table 1, the mean concentrations of Mn, Ni, As, U, and Sr were 138.2, 12.6, 4.0, 19.3, and 755.8 µg/L, respectively. The concentrations of Cu and Cd in samples were below the permissible limit given by MNS.

The concentration of arsenic in groundwater ranges from 0.21 to 41.9 µg/L, with a mean concentration of 4.0 µg/L, which is lower than the permissible limit given by MNS. Most of the samples (97%) have a lower As concentration. Only two samples concentrations exceeded the standard limit (10 µg/L). The highest concentration of As was measured (41.9 µg/L) at sites S59 sampling sites located in the downstream part, and the lowest level of As (0.21 µg/L) was recorded at sites S15 located in the midstream part of the study area. The present mean concentration of As in groundwater was found to be very low compared to the reported study conducted in Baganuur (Baldandorj et al., 2016; Tegshbayar, 2020). Arsenic cannot only be observed by humans through drinking water; as Mongolian coal has a high arsenic content (Mongolian Ministry of Health, 2004), and coal firing results in high air pollution during the harsh winters, the arsenic concentration in the soil of Ulaanbaatar is unusually high (Batjargal et al., 2010).

The concentration of manganese ranged from 5.0 to 908.0 µg/L, with a mean concentration of 138.2 µg/L. 20 of 60 samples (33%) exceeded the MNS standard limit for Mn in drinking water (100 µg/L). The highest concentrations were measured at sites S29 and middle, and the lowest level of Mn (5 µg/L) was recorded at the upstream and midstream parts of the study area. Comparing this study result, the mean concentration of Mn was found to be little higher than those reported in Baganuur (Baldandorj et al.,2016; Chinzorig et al., 2020), and much higher than those studies results conducted in Khentii (Chinzorig et al., 2022) and Dornod (Amarsanaa et al., 2022).

Concentrations of Ni varied from 0.3 to 42.5 µg/L. The mean concentration was 12.6 µg/L. Compared with the MNS standard (20 µg/L), 11 samples (17%) exceeded the standard limit. The highest level of Ni (42.5 µg/L) was recorded at the S46 sampling point in downstream valley and lower values of Ni are located in the midstream part of the study area. The current mean concentration of Ni was found to be little higher than those reported study conducted in Khentii (Chinzorig et al., 2022).

The mean concentrations of Sr were 132 µg/L. Only 5 samples (83%) were higher than the MNS limit (2000 µg/L). A high concentration of Sr was noticed in samples S1 (Sr 3627 µg/L), S46 (Sr 3114 µg/L), S55 (3114 µg/L) and lower level of Sr (148 µg/L) was observed at sites S18 and S19, respectively.

Concentrations of U ranged from 0.019 µg/L to 206 µg/L, with mean concentrations of 19.3 µg/L. Only 10 samples (16%) were higher than the desired limit of the standard (30 µg/L). The highest level of U was observed at the S59 sampling point, and the lowest level of U (0.019 µg/L) was recorded at the S6, which is located in the midstream part. Comparing this study result, the mean concentration of U was found much higher than the reported study conducted in Dornod, Khentii, and Tuv provinces (Tegshbayar, 2020).

Spatial distribution of the heavy metals and their concentration: Groundwater contamination by heavy metals is a result of human activities, specifically the introduction of chemicals from agricultural, industrial, and municipal waste into water bodies without proper treatment. While these heavy metals are essential for the human body in small quantities, their high concentrations lead to water pollution and pose risks to human health. Heavy pollution of As, Mn, Ni, U, and Sr was found in samples that were located in the upstream and downstream parts of the Kherlen river valley. This pollution can be attributed to coal mining activities in the region, which have made a substantial contribution to the contamination of groundwater with heavy metals in bith the upstream and downstream parts of study area.

The distribution of Ni and Mn concentrations in the study region can be observed in figure 2 and 3, respectively.

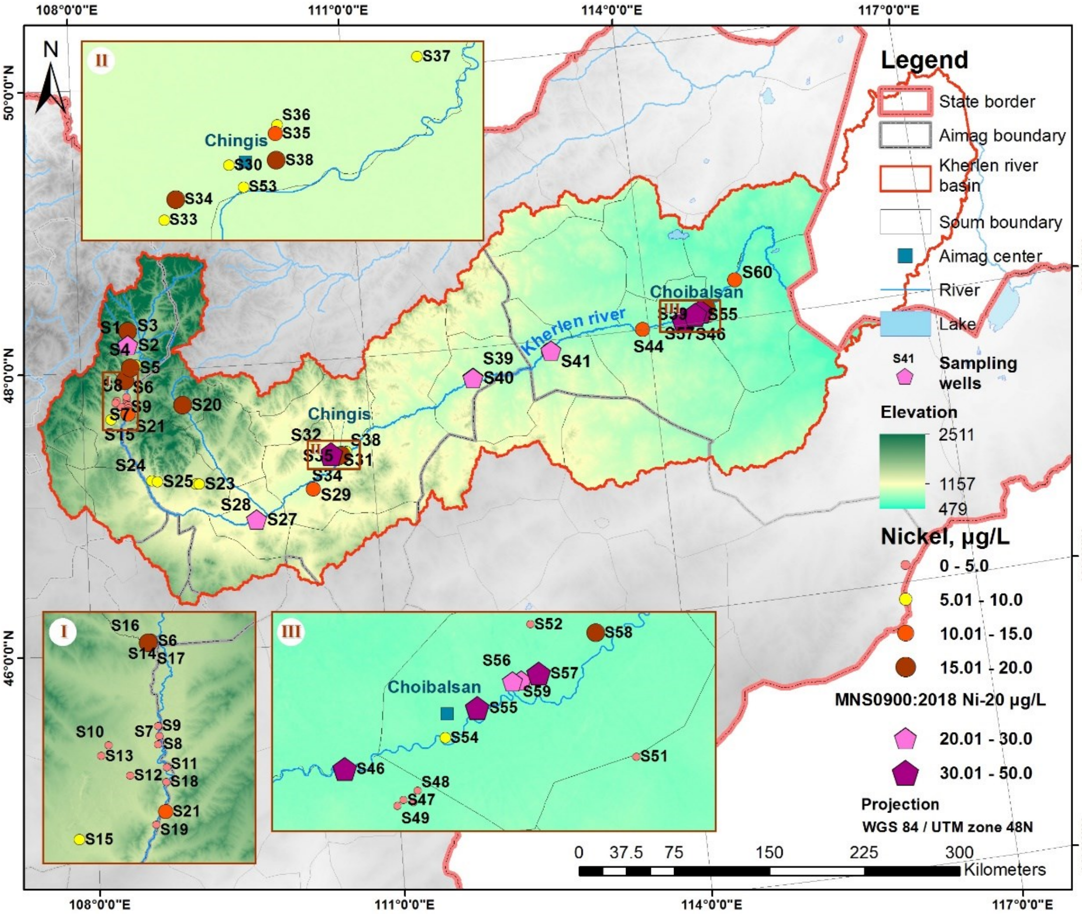

Figure 2. Ni concentration spatial map

The Ni concentration map presented in figure 2 depicts that the Ni content of the groundwater increased from the upstream part to the downstream part of the Kherlen river valley, with the maximum Ni value observed in the water samples collected from downstream parts of the study area, while the concentration was relatively low in the groundwater samples collected from upstream and middle parts of the study area (Chinzorig et al., 2022).

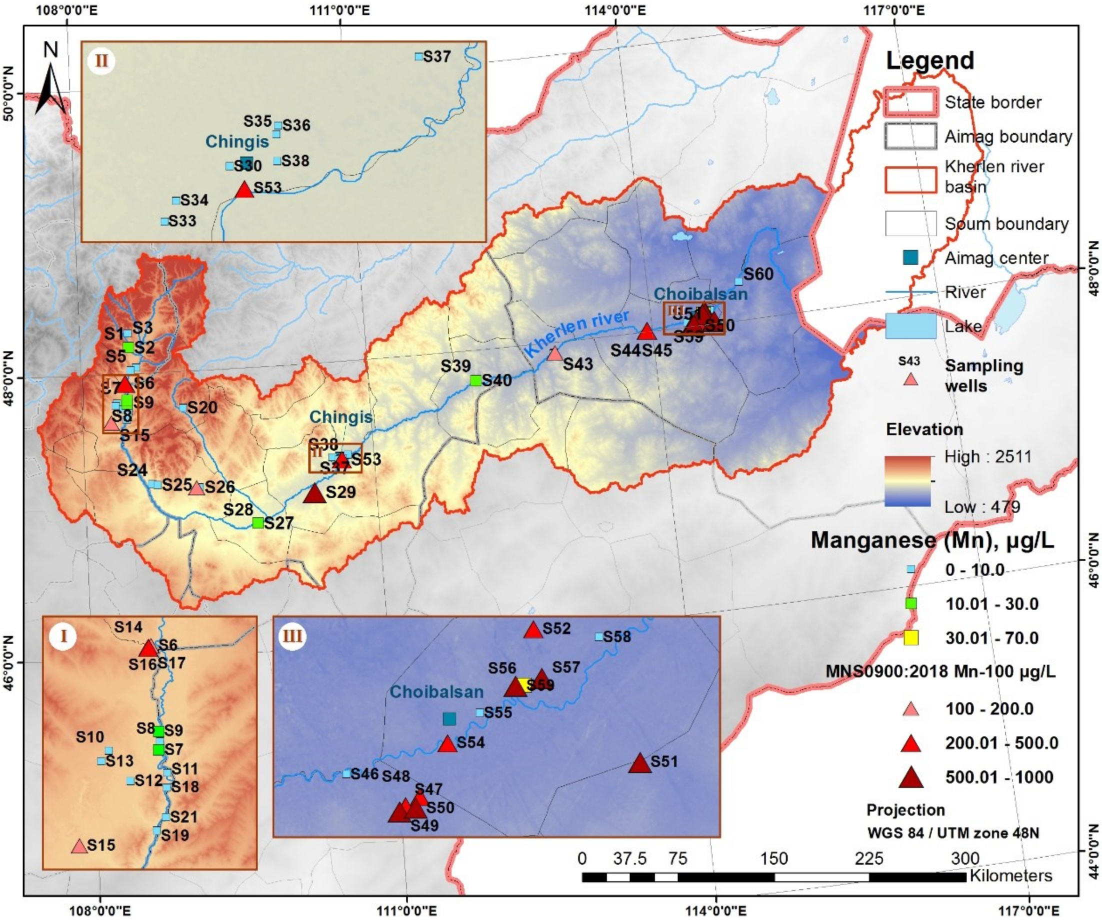

Figure 3. Mn concentration spatial map

The Mn concentration varied widely throughout the region, with the maximum Mn value observed in the water samples collected from downstream parts of the study area, while the concentration was relatively low in the groundwater samples collected from upstream and midstream parts (Figure 3). The concentration of Mn in groundwater increases from upstream to downstream. It is rich in resources, including coal, oil, and mixed metal deposits, as well as large coal deposits in the Khoot and Aduunchuluun areas of the region. The high levels of these metals mainly indicate the anthropogenic role of these metals in the groundwater of the Kherlen River valley.

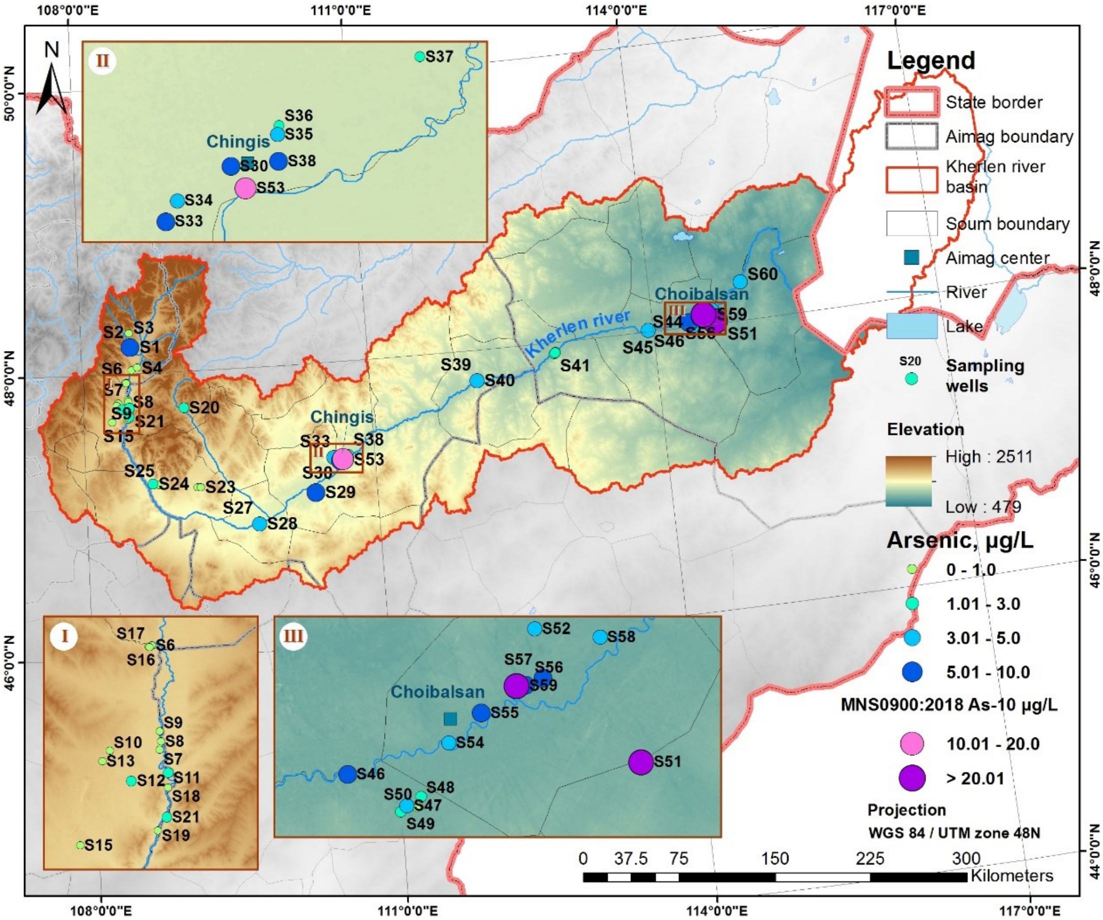

Figure 4. As a concentration spatial map

The spatial distribution of As, U, and Sr concentrations throughout the study area is depicted in figures 4, 5, and 6. As shown in figure 4, the upper and downstream parts of the study area tend to have lower As levels when compared to the other parts. It was also noted that most of the groundwater had a low As concentration, with the downstream part having the lowest groundwater As concentration.

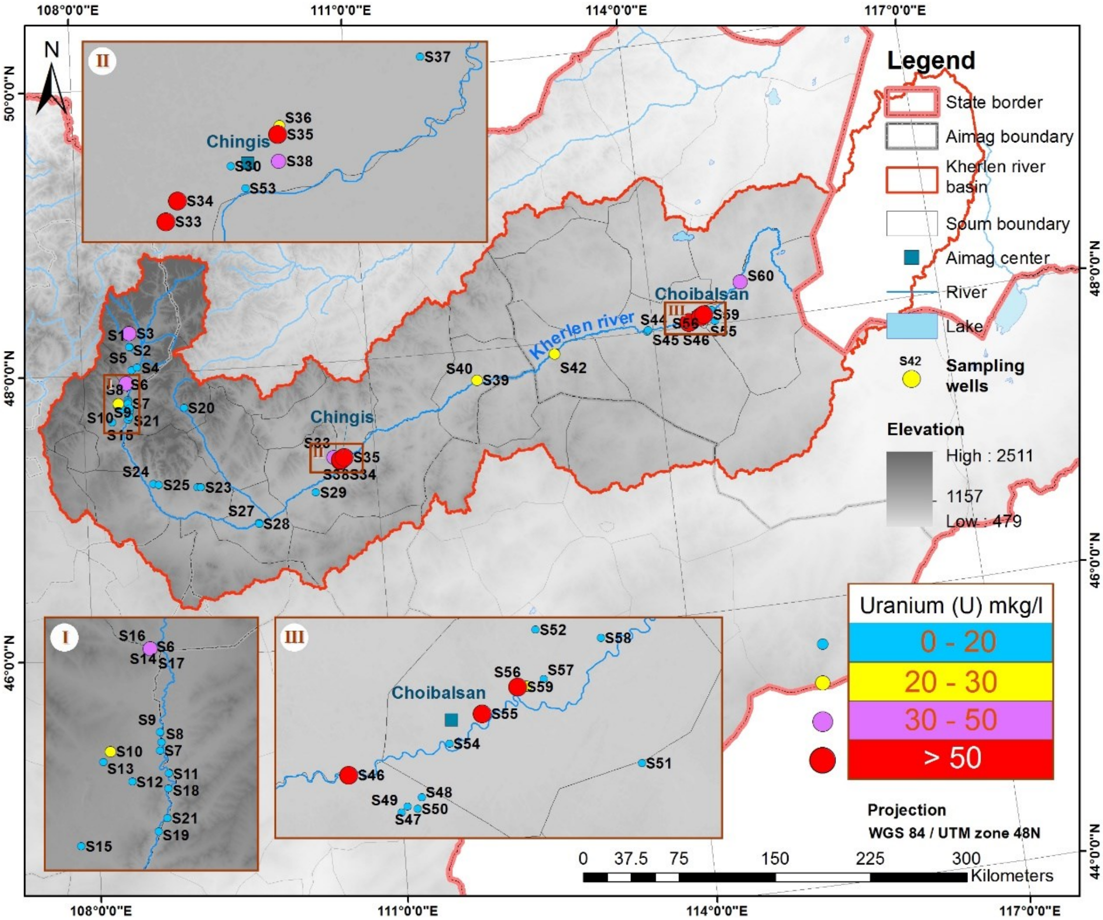

Figure 5. U concentration spatial map

The water map of U levels in the groundwater of the Kherlen River valley is shown in figure 5. As shown in Fig. 5, the middle and downstream parts of the study area tend to have higher U levels when compared to the other parts, while the concentration was relatively low in the groundwater samples collected from upstream parts.

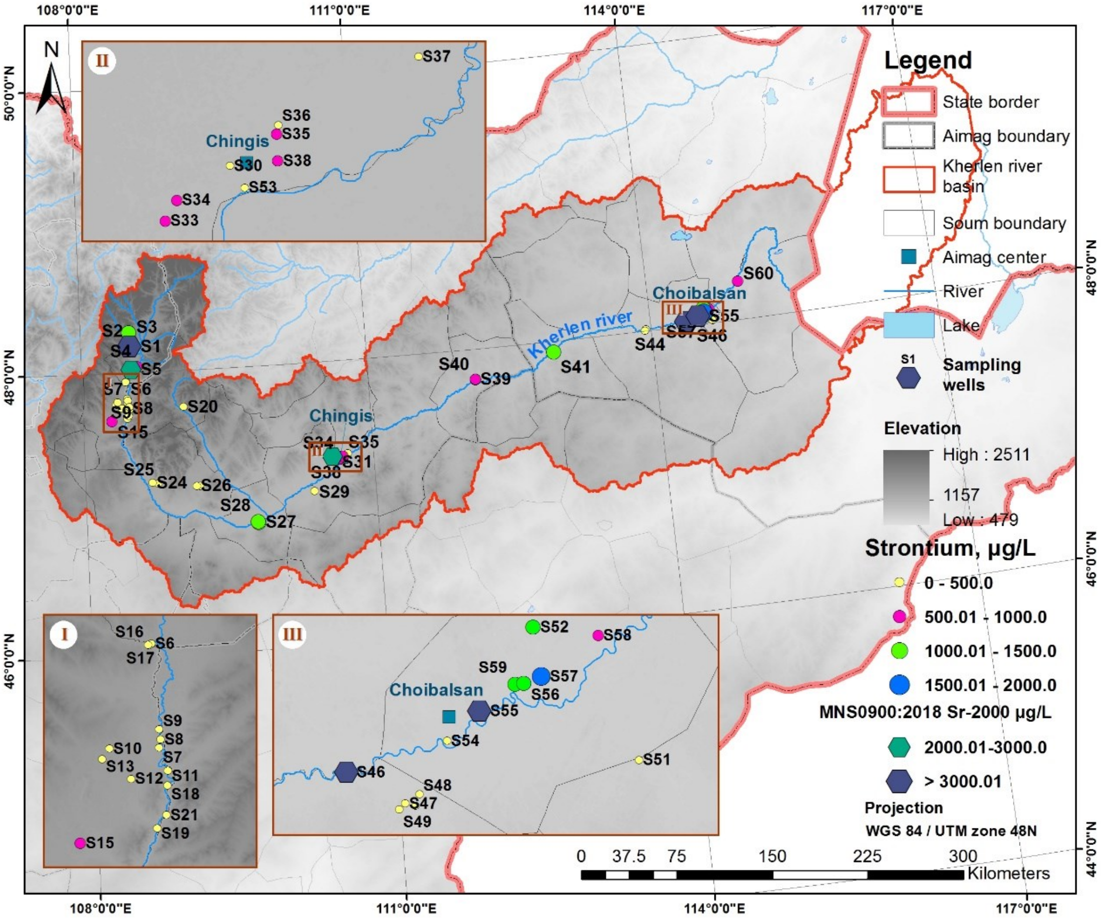

Figure 6. Sr concentration spatial map

The concentration of Sr in the groundwater varied unevenly from upstream to downstream of the study area, with the upstream part having the maximum Sr level (Figure 6). The Baganuur mine is located east of Ulaanbaatar, upstream of the study area. The spatial distribution map further revealed that most of the groundwater has a moderate Sr concentration. It was noted that the spatial distribution of Sr is similar to the Mn distribution, with the major difference being that Sr had the maximum concentration in the upstream water as against the lowest As and U content recorded in the upstream water.

Conclusion

The element concentration in the study area shows the following order: Mn>Ni>U>Sr>As. The contents of Mn, U, Ni, As, and Sr exceeded the corresponding permitted limits of the MNS for drinking water at some sites. Although the concentrations of Cu and Cd in the sampled groundwater were lower than the MNS standard limits, from the seven metals investigated, Mn had the highest concentration, while As had the lowest concentration in the groundwater.

Mn, Ni, As, U, and Sr displayed identical patterns, indicating that the pollution sources of these heavy metals may be identical. These distribution patterns are insufficient to demonstrate that the pollution sources are indeed the same, and further study is required to determine whether these heavy metals are associated in order to confirm that they share the same pollution sources.

Generally, anthropogenic sources were the predominant factors influencing heavy metal pollution in this area. Furthermore, the groundwater from the region should be subjected to cheap and effective treatments like adsorption and ion exchange in order to reduce the concentration of heavy metals to permissible levels.

Acknowledgment

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Reference

1. Naomi, C., Tim, F., & Juliet, W. (2019). Groundwater as a source of drinking water in southeast Asia and the Pacific: A Multi-Country review of current reliance and resource concerns. *Journal of Water, 11(8),* 1605.
2. Tmava, A., Avdullahi, S., & Fejza, I. (2013). Assessment of heavy metal study on groundwater in the mining area in Stan Terg, Kosovo. *Journal of Biodiversity and environmental sciences, 3,*53-60.
3. Fu, J., Hu, X., Tao, X. C., Yu, H. X. & Zhang, X. W. (2013). Risk and toxicity assessments of heavy metals in sediments and fshes from the Yangtze River and Taihu Lake, China. *Journal of Chemosphere, 93,* 1887–1895.
4. Batvari, D., Sivakumar, B.P., Shanthi, S.K., Lee, J., Krishnamoorthy, Oh, T., & Kamala-Kannan, S. (2013). Heavy metals accumulation in crab and shrimps from Pulicat lake, north Chennai coastal region, southeast coast of India. *Journal of Toxicology and industrial health*.
5. Quyang, Y., Higman, J., Thompson, J., Toole, T., & Campbell, D. (2002). Characterization and spatial distribution of heavy metals in sediment from Cedar and Ortega rivers subbasin. *Journal of Contaminant Hydrology, 54,* 19-35.
6. Vodela, JK., Renden, JA., Lenz, SD., Meelhenney, WH., Kemppainen, BW. (1997). Drinking water contaminants. *Journal of Poultry Science, 76*, 1474-1492.
7. Jadambaa, N. (2009). The Geology and Mineral Resources of Mongolia, *8*.
8. Tokatlı, C. (2018). Essential and toxic element bioaccumulations in fishes of Gala and Siğirci Lakes (Meriç River Delta, Turkey). *Journal of Acta Alimentaria, 47(4)*, 470-478.
9. Gerelt-Od, D., Enkhjargal, T., Bingbo, Gao., Byambasuren, z., & Chinzorig, S. (2023). Groundwater quality along the Kherlen River valley, Mongolia, Hydroscience and Engineering-2023, *Commemorative international conference proceedings.*
10. Erdenetsetseg, Ts., Byambasuren, Z., Gao, B., Enkhtuya, M., Renchinbud, Badrakh., Chinzorig, S. (2023). Surface water quality assessment in the Kherlen river basin, a semi-arid region in eastern Mongolia, Hydroscience and Engineering-2023, *Commemorative international conference proceedings.*
11. Chinzorig, S., Javzan, Ch., Ouyn-Erdene, B., Renchinbud, B., Gan-Erdene, E. (2020). Institute of Geography and Geoecology, Drinking water quality in center and settlements of the Baganuur district, *Joint work between MAS and the Water service regulatory commission of Mongolia.*
12. Chinzorig, S., Gerelt-Od, D., Renchinbud, B., Uuriintuya, G., Ouyn-Erdene, B., Gan-Erdene, E., Burnee. (2022). Institute of Geography and Geoecology, Drinking water quality in center and settlements of the Khentii province. *Joint work between MAS and the Water service regulatory commission of Mongolia.*
13. Amarsanaa, B., Oyuntsetseg, D., Odontuya, G., Tsiiregzen, A., Dulamsuren, G., Dariimaa, B, Icchinnorov, A., Buyanjargal, Z. (2022). Institute of Chemistry and Chemistry Technology, Drinking water quality in center and settlements of the Dornod province. *Joint work between MAS and the Water service regulatory commission of Mongolia.*
14. Kim, S., Tanaka, Yu., Kashima, K. (2017). The history of palaeoflood and palaeoclimate recorded in the flooddeposits of the Kherlen River, Mongolia. *Journal of Quaternary International, 1-11*.
15. Fai, K., Lo, A., & Munkhjargal, A. (2017). Rainwater harvesting in kherlen river basin, east Mongolia. *Journal of International Development Research, 7,* 01.
16. Baldandorj, Ts., Oyunbaatar, D., Javzan, Ch., & Narangerel, Z. (2016). Integrated water resources management plan of the Kherlen River Basin, 1st phase 2016-2020 and 2nd phase 2021-2030. Ministry of Environment and Tourism.
17. Batjargal, T., Otgonjargal, E., Baek, K., & Yang, JS. (2010). Assessment of metals contamination of soils in Ulaanbaatar, Mongolia. *Journal of Hazard Mater, 184*, 872-876.