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Isotope Hydrology in Mongolia: Progress, Challenges and Opportunities for Water Resources Management

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Summary

Environmental isotope techniques have been applied in Mongolia for nearly four decades through five national IAEA TC projects and five RCA projects. These studies have significantly improved the understanding of groundwater recharge and residence time, surface water and groundwater interactions in Mongolia's diverse hydrogeological conditions. Environmental isotopes ($\delta^{18}O$, $\delta^{2}H$, ^{3}H, ^{14}C and, more recently, ^{222}Rn), combined with hydrochemical investigations, have provided valuable complementary scientific evidence for groundwater assessment in arid regions, mining areas, and major river basins.

International cooperation has also strengthened national laboratory infrastructure, technical capacity, and human resources through the establishment of isotope and hydrochemical laboratories, regional training, and collaborative research. Despite these achievements, the routine application of isotope hydrology in groundwater resource assessment and water resources management remains limited. Greater integration of isotope techniques into groundwater investigations, long-term monitoring programmes, technical guidelines, and decision-making processes is therefore needed. Continued investment in advanced analytical capacity, university education, long-term isotope monitoring, and collaboration between research institutions and water management agencies will be essential for supporting sustainable groundwater management in Mongolia.

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1. Introduction

Groundwater is the principal source of water supply in Mongolia, supporting domestic consumption, livestock, agriculture, mining and industrial development, particularly in the country's arid and semi-arid regions. Ensuring the sustainable use of groundwater has therefore become an increasingly important challenge as water demand continues to grow under the combined pressures of climate variability, economic development and population growth.

Conventional hydrogeological investigations provide essential information on groundwater occurrence, aquifer characteristics, hydraulic properties and water quality. Environmental isotope techniques provide complementary information on groundwater origin, recharge processes, residence time, aquifer renewability, and hydraulic connectivity between surface water and groundwater. Together, these approaches can strengthen the scientific basis for groundwater resource assessment and management.

Since 1988, Mongolia has cooperated with the International Atomic Energy Agency (IAEA) through national Technical Cooperation (TC) projects and, since 2012, through the Regional Cooperative Agreement (RCA), to introduce and apply isotope hydrology in surface and groundwater investigations (Table 1). Over nearly four decades, these activities have supported scientific research, analytical capacity development and training.

This Issue Brief summarizes the development of isotope hydrology in Mongolia from 1988 to 2026, highlights its major scientific contributions and applications, and discusses future opportunities for integrating isotope techniques into groundwater assessment and sustainable water resources management.

2. Water Resources and Water Use in Mongolia

Mongolia is a landlocked country characterized by an extreme continental, cold arid and semi-arid climate. Water resources are distributed very unevenly both spatially and temporally, reflecting the country's pronounced climatic and physiographic contrasts. Most rivers, freshwater lakes and areas of relatively high runoff are concentrated in the northern mountainous and central forest-steppe regions, whereas the southern steppe and Gobi regions possess very limited renewable surface water resources and depend predominantly on groundwater. In addition to this strong spatial variability, water availability is also highly seasonal. Approximately 85–95% of the annual river runoff occurs during the warm season, whereas winter runoff is extremely low because of limited precipitation, prolonged freezing conditions, and the partial or complete freezing of many rivers, resulting in pronounced seasonal water shortages. January temperatures frequently fall below −40°C, while summers are short and relatively warm. Consequently, the mismatch between the spatial and temporal distribution of water resources and the location of water demand has become one of the principal challenges for sustainable water resources management in Mongolia.

Based on available estimates for the principal components of the country's water resources, the country's total water resources are currently estimated at approximately 596.8 km^3 (Batbayar, 2026). Earlier assessments by Tsedensodnom (2000) estimated that about 500.0 km^3 of water was stored in lakes, while the updated assessment by Davaa et al. (2025) revised this figure to approximately 532.0 km^3. In addition, an estimated 19.4 km^3 is stored in glaciers and permanent snow (Davaa et al., 2012), 34.6 km^3/year is represented by river water resources (Ministry of Water Management, 1975), and approximately 10.8 km^3 is attributed to groundwater resources (Jadambaa, 2003).

Although groundwater accounts for only about 1.8% of Mongolia's estimated water resources, it supplies approximately 80% of total water use. This contrast reflects the difference between total water stored in the hydrological system and water that is practically accessible for human and economic use. Much of the national water volume is stored in lakes and glaciers, often far from major users, while groundwater is more widely distributed and provides the principal source for drinking water, livestock, industry, energy production and mining, especially in arid and semi-arid regions.

National water use increased from 594.8 million m^3 in 2021 to 679.1 million m^3 in 2023, and 682.5 million m^3 in 2025. National projections indicate that total water demand will rise to approximately 1,397.5 million m^3 by 2030 and 1,833.6 million m^3 by 2040, corresponding to approximately 2 and 2.7 times the 2025 water use, respectively. The projected increase is expected to be driven primarily by growing demand from the agricultural, mining, domestic water supply, energy, and industrial sectors (Batbayar, 2026).

The imbalance between water availability and demand is most pronounced in the South Gobi. Approximately 96.6% of the Galba–Uush–Doloogiin Gobi basin project area lies within one of Mongolia's driest climatic zones, where renewable water resources are very limited and unevenly distributed in both space and time (Prestige Engineering LLC, 2021). Annual precipitation generally ranges from about 70 to 150 mm across most of the basin, increasing to 160–200 mm in its eastern part (Ganzorig, 2024). In this region, groundwater is the principal source of supply for communities, livestock, mining and industrial development.

Water demand within the South Gobi study area was estimated at approximately 25.2 million m^3/year in 2019 and is projected to reach 69.2–104.5 million m^3/year by 2030 and 73.3–109.9 million m^3/year by 2040, depending on the development scenario. Mining accounts for the dominant share of this increase, with demand projected to rise from approximately 18.7 million m^3/year in 2019 to between 54.5 and 89.7 million m^3/year by 2030 (Prestige Engineering LLC, 2021). Available assessments identify approximately 48.0 million m^3/year of groundwater currently in use and an additional 31.6 million m^3/year of potentially usable groundwater within the evaluated supply scheme, indicating that groundwater alone may not be sufficient to meet medium- and high-demand scenarios over the long term.

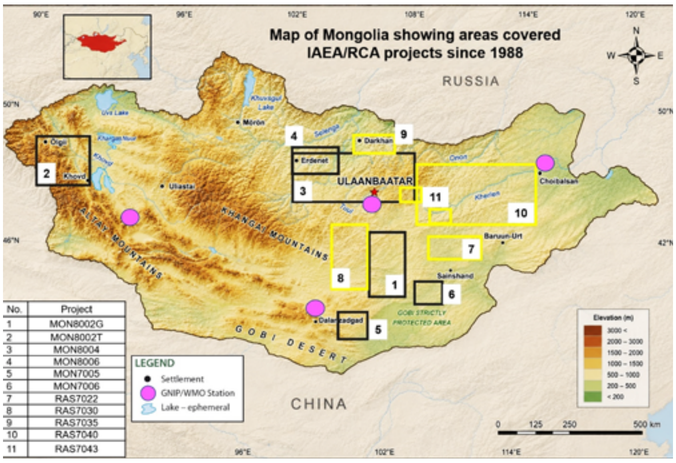
These figures show that Mongolia's water challenge is not simply the total quantity of water resources. The key issue is the mismatch between where water is stored, where demand is concentrated, and how rapidly groundwater resources are renewed. This is particularly important in the South Gobi, where recharge may be limited, episodic or associated with earlier climatic conditions. Therefore, sustainable groundwater management requires information not only on aquifer storage and abstraction, but also on recharge sources, groundwater residence time, flow pathways and surface water and groundwater connectivity. These are important questions for which isotope hydrology can provide valuable complementary evidence.

3. Development of Isotope Hydrology in Mongolia under IAEA and RCA Cooperation

The first isotope hydrology studies in Mongolia were conducted in the mid-1980s by Russian researchers led by V.V. Romanov. They collected isotope samples from precipitation, surface water, and groundwater in the eastern and central parts of Mongolia, estimated the groundwater age in the Khalkh River area to be approximately 1,000 years, and concluded that the groundwater was recharged by precipitation (Romanov at al., 1989).

The development of isotope hydrology in Mongolia began in the late 1980s through cooperation with the IAEA. During the initial stage, the primary focus was on introducing isotope techniques and establishing national analytical and research capacity. Between 1990 and 2000, isotope applications expanded to identify groundwater recharge sources, determine groundwater age, and investigate surface water and groundwater interactions under various hydrogeological conditions.

Since 2010, the IAEA TC and RCA projects have significantly strengthened research capacity, laboratory and field monitoring equipment, and international collaboration in the country. Through these projects, environmental isotope techniques have been applied to studies of snow and ice in glaciers, groundwater origin and age, surface water and groundwater interactions, deep confined groundwater in the Gobi region, water resources in river basins affected by mining and other human activities, and water quality. At present, isotope hydrological techniques are also being applied to evaluate the effectiveness of Managed Aquifer Recharge (MAR) under RCA RAS7043 project (2024-2027).



(Fig. 1) Map showing the locations of national IAEA TC and RCA project study areas in Mongolia (1988–2026).

4. Strengthening National Capacity for Isotope Hydrology

Since the beginning of IAEA cooperation in 1988, one of the most significant achievements has been the establishment of national human resources and analytical infrastructure for isotope hydrology in Mongolia. Over these past years, continuous support through IAEA TC and RCA regional projects has enabled Mongolia to develop a sustainable national capability rather than relying solely on individual research projects.

More than 30 Mongolian scientists have participated in international training courses, fellowships and regional workshops organized under TC and RCA projects. These activities covered isotope hydrology, groundwater age

(Fig. 2) National capacity for isotope hydrology in Mongolia (1988–2026)

dating, data interpretation, groundwater modelling, MAR, environmental isotope techniques and laboratory operation. In parallel, more than 20 international expert missions have been conducted in Mongolia, providing technical guidance on project implementation, field investigations, laboratory quality assurance, groundwater monitoring and data interpretation.

Laboratory infrastructure has expanded substantially through successive IAEA TC and RCA projects. Major laboratory equipment has been installed, including Liquid Water Isotope Analyzer (LGR DLT-100), auto-injector system, ion chromatograph (ICS6000), groundwater level loggers, multiparameter water quality meter, groundwater detector, rain gauges, radon monitor (RAD8), and other analytical accessories. These investments have transformed isotope hydrology from a project-based activity into a sustainable national analytical capability.

Since 2021, Mongolia has re-established the GNIP monitoring network with four precipitation isotope (^{2}H, ^{18}O and ^{3}H) stations representing the central, eastern, western and southern regions of the country. Together with the national isotope laboratory, this network provides continuous isotope data that support groundwater investigations, recharge assessment and evidence-based integrated water resources management.

5. Key Applications and Scientific Contributions of Isotope Hydrology

Since 1988, Mongolia has implemented five national IAEA TC projects and five RCA regional projects in isotope hydrology (Table 1). Through these projects, isotope techniques have been applied to investigate groundwater recharge, age and renewability, surface water–groundwater interactions, water-quality changes, and MAR across the country (Fig. 1).

The **MON8002G** component applied stable isotopes ($\delta^{18}O$ and $\delta^{2}H$), tritium (^{3}H), and radiocarbon (^{14}C) to investigate groundwater recharge and renewability in Dundgobi Province. Groundwater close to active recharge zones was estimated to be approximately 200–6,000 years old, whereas groundwater in parts of the Olziit and Undurshil areas and the Mandalgovi–Olgoin Gobi system in the province was found to be more than 35,000 years old. The occurrence of relatively high tritium concentrations, reaching approximately 25.5–100 TU in some wells near recharge areas, indicated localized infiltration of

No	Project	Study area	Period	Main focus
1	MON8002G	Eastern Dundgovi, Gobi aquifers	1988–1990	Groundwater recharge and sustainability
2	MON8002T	Tsambagarav, western Mongolia	1991–1996	Snow and ice glacier isotopes
3	MON8004	Tuul and Khangal River basins	1999–2000	Groundwater dynamics and SW–GW interaction
4	MON8006	Orkhon River Basin	2005–2006	Isotope and hydrochemical assessment of water quality
5	MON7005	Southern Gobi	2017–2018	Confined groundwater dynamics
6	MON7006	Zuunbayan and Tavan Tolgoi	2024–2026	Sustainable groundwater management in mining region
7	RAS7022	Dornogovi	2012–2015	Groundwater recharge and movement
8	RAS7030	Dundgovi	2016–2019	Deep groundwater sustainability
9	RAS7035	Shariin gol River Basin	2020–2023	Groundwater management
10	RAS7040	Kherlen River Basin	2022–2025	Environmental isotopes for water management
11	RAS7043	Baganuur and Kherlen riverine reach	2024–2027	Managed aquifer recharge

(Table 1) IAEA TC and RCA projects supporting the development of isotope hydrology in Mongolia since 1988.

modern precipitation through permeable sediments and fractured rocks. In contrast, negligible tritium and low radiocarbon activity in deeper aquifers demonstrated weak present-day recharge and very limited renewability (Sanjdorj, 1996).

The **MON8002T** project represented Mongolia's isotope investigation of a high-altitude glacier. An 11 m ice core was drilled from the Tsast Uul ice cap (4193 m a.s.l.) in western Mongolia and analysed for stable isotopes. The ice core preserved clear seasonal variations in $\delta^{18}O$ (approximately −24‰ to −10‰), demonstrating that glacier ice records changes in the isotopic composition of precipitation. Borehole temperatures remained close to −18°C below 5 m depth, confirming that the glacier was a cold glacier with minimal meltwater percolation. Subsequent interpretation of the isotope record showed that summer precipitation in western Mongolia was strongly influenced by re-evaporated continental moisture rather than oceanic sources, providing isotope-based evidence of regional atmospheric moisture circulation and establishing an important baseline for paleoclimate in Mongolia (Sandjordj and Baast, 1996; Schotterer et al., 1997).

The **MON8004** project (1999–2000) applied isotope techniques to estimate groundwater residence time and recharge in the Tuul River Basin. The results showed that groundwater in the Tuul River alluvial aquifer has an apparent residence time of approximately 30 years and an average recharge rate of about 100 mm/year. In the Selbe River alluvial aquifer, a tributary of the Tuul River in Ulaanbaatar, groundwater residence time was estimated at approximately 1.3 years, indicating rapid groundwater renewal (Janchivdorj et al., 2013).

Building on these studies, research conducted under the UNESCO Chair on Sustainable Groundwater Management by Tsujimura, Janchivdorj and colleagues integrated stable isotopes, hydrochemical tracers, groundwater-level observations and End Member Mixing Analysis (EMMA) to investigate groundwater–surface water interactions in the Tuul River alluvial aquifer. The study demonstrated that the Tuul River is the principal recharge source for the floodplain aquifer supplying drinking water to Ulaanbaatar, contributing approximately 44–94% of groundwater recharge. Groundwater from the northern mountain area contributed 1–54%, while contributions from the southern mountain area and winter precipitation were estimated at 0–16% and 0–12%, respectively. These findings substantially improved the understanding of recharge mechanisms and provided a scientific basis for protecting both the quantity and quality of the Tuul River to sustain Ulaanbaatar's groundwater resources (Tsujimura et al., 2013).

The **MON8006** project (2005–2006) expanded the application of isotope hydrology to assess the impacts of mining activities on surface water and groundwater quality in the Orkhon and Tuul River basins. A total of 52 water samples were collected and analyzed for major hydrochemical parameters, heavy metals, stable isotopes ($\delta^{18}O$ and $\delta^{2}H$), tritium (^{3}H), carbon-13 (^{13}C), and radiocarbon (^{14}C). The investigations covered different mining-affected areas. In the Zaamar area, isotope and hydrochemical analyses indicated water-quality changes associated with gold mining activities, while a separate investigation in the Erdenet area identified hydrochemical and isotopic evidence of seepage influence from the mining tailings pond. These findings demonstrated the value of combining environmental isotopes with hydrochemical analyses for identifying contaminant sources, and supporting environmental monitoring in mining-affected regions.

The **MON7005** project (2017–2018) expanded isotope hydrology applications in Mongolia by combining groundwater investigations with national capacity development. Hydrochemical analyses, together with $\delta^{2}H$, $\delta^{18}O$, ^{3}H, and ^{14}C, were applied to investigate groundwater dynamics in the Naimant Valley and Balgas Red Lake depressions of the South Gobi (Umnugobi province). In the Naimant Valley, isotope results indicated pre-modern groundwater in deep production wells, with corrected ^{14}C results suggesting groundwater ages of several thousand years and the possibility of substantially older groundwater in parts of the aquifer system. In the Balgas Red Lake depression, isotope and hydrochemical results indicated that young groundwater can percolate through the shallow unsaturated zone, while much of the groundwater recharge originates in the surrounding mountainous areas (Gusyev et al., unpublished manuscript).

Beyond its scientific findings, the project established Mongolia's first national stable isotope laboratory equipped with an LGR laser water isotope analyser, enabling routine isotope analysis and supporting subsequent IAEA TC and RCA projects.

(Fig. 3) Project team members, including Dr. Lunten Janchivdorj (Project Coordinator) and Dr. Muhammad Azam Tasneem (IAEA expert, Pakistan), during groundwater investigations for the IAEA TC project MON7005 in the South Gobi Region, Mongolia.

The ongoing TC Project **MON7006** (2024–2026) has further expanded isotope hydrology applications from regional groundwater assessment to sustainable groundwater management in Mongolia's arid mining regions. Building upon the isotopes δ^2H and $\delta^{18}O$, ^3H and ^{14}C investigations initiated under previous projects, MON7006 extends groundwater studies by introducing ^{222}Rn as a complementary environmental tracer to improve the characterization of groundwater flow, recharge processes, and aquifer interactions in selected mining areas of the South Gobi.

Beyond scientific investigations, MON7006 has substantially strengthened national analytical capacity. An Ion Chromatography System (ICS-6000) laboratory at the institute was established to enable high-precision analysis of major ions and trace constituents, complementing isotope investigations with comprehensive hydrochemical characterization. In parallel, national researchers received specialized training through scientific visits, expert missions and laboratory courses, while international experts introduced applications of radon-222 techniques and laboratory quality assurance. These activities have significantly enhanced Mongolia's capability to conduct integrated isotope-hydrochemical investigations for groundwater resource assessment.

The first RCA **RAS7022** (2012–2015) project for isotope hydrology, focused on investigating groundwater dynamics and recharge in the Sain-Us and Bor Khuuvur depressions of the South Gobi using environmental isotopes and hydrochemical techniques. Isotopes δ^2H and $\delta^{18}O$, ^3H and ^{14}C, hydrochemical analyses and conventional hydrogeological investigations were integrated to evaluate groundwater origin, recharge processes, groundwater age and sustainability. The results indicated that groundwater in the deep confined aquifers was generally 11,000–25,900 years old, with an estimated recharge rate of only 0.7–2.1 mm/year (average 1.3 mm/year), indicating long groundwater residence times and very limited modern recharge to the deep confined aquifers (Janchivdorj, 2015).

The **RAS7030** project (2016–2019) expanded isotope investigations of deep groundwater resources in the South Gobi region and Dundgobi province to support sustainable groundwater management in water-scarce areas. Three field campaigns were conducted between 2016 and 2018, during which number of water samples were collected and analysed for δ^2H and $\delta^{18}O$, ^3H and ^{14}C isotopes and hydrochemical parameters. The study indicated that groundwater recharge in the study area is primarily derived from local precipitation, while estimated recharge to the deep confined aquifers ranged from 0.7 to 2.1 mm/year, with an average of 1.3 mm/year. Groundwater ages ranging from approximately 2,000 to more than 40,000 years indicated long groundwater residence times and limited modern recharge in the deep aquifer systems (Janchivdorj and Odontsetseg, 2019). In addition, Mongolia hosted the Final Project Assessment Meeting of RAS7030 in Ulaanbaatar in September 2019, bringing together representatives from RCA Member States to review project achievements and share research findings (Fig. 4).

(Fig. 4) Participants at the IAEA/RCA RAS7030 Final project assessment meeting, Ulaanbaatar, Mongolia, 23–27 September 2019.

The **RAS7035** project (2020–2023) applied isotope techniques in the Shariin Gol River Basin, a representative catchment in northern Mongolia characterized by diverse anthropogenic pressures along its longitudinal profile. The upper reaches are affected by gold mining, the middle reaches by coal mining, urban settlements and wastewater discharge, while irrigated agriculture and livestock production dominate the downstream areas. This catchment therefore provided an ideal setting for evaluating the influence of different land-use activities on surface water and groundwater systems.

Isotope $\delta^{18}O$ and δ^2H analyses showed that both river water and groundwater plot close to the Local and Global Meteoric Water Lines, indicating that groundwater is primarily recharged by local precipitation and river infiltration with limited evaporative enrichment. Tritium analyses estimated groundwater residence times ranging from approximately 14 to 43 years, indicating relatively young and renewable groundwater within the alluvial aquifer. Mixing analyses further demonstrated that river water contributed approximately 14–31% of groundwater in the investigated wells, confirming active hydraulic connectivity between the Shariin Gol River and the adjacent aquifer (Chinzorig and Enkhjargal, 2023).

The **RAS7040** project (2022–2025) expanded the application of isotope hydrology to the Kherlen River Basin, one of Mongolia's major transboundary river systems. Seasonal investigations conducted throughout the upstream, midstream, and downstream reaches integrated stable isotopes $\delta^{18}O$ and

δ^2H with hydrochemical analyses to evaluate groundwater recharge, river–groundwater interactions, and groundwater quality under contrasting hydrogeological conditions. Stable isotope results demonstrated that both surface water and groundwater are predominantly of meteoric origin, with groundwater recharge mainly controlled by warm-season precipitation. Most groundwater samples plotted close to the Global Meteoric Water Line, indicating limited evaporation prior to recharge (Gerelt-Od and Chinzorig, 2025).

(Fig. 5) IAEA Lecture by IAEA International Expert and Co-Chair of the UNESCO Chair on Sustainable Groundwater Management, Professor Maki Tsujimura, under the RCA RAS7035 project, with participation from project team members and students of the Mongolian University of Science and Technology.

The isotope data further demonstrated that river–groundwater interactions are spatially heterogeneous rather than uniform throughout the basin. Shallow alluvial aquifers exhibited isotopic compositions similar to river water, indicating active hydraulic connectivity and river recharge, whereas deeper boreholes showed weaker isotopic connectivity, reflecting differences in aquifer depth, residence time, and local hydrogeological conditions. Hydrochemical and isotope investigations also identified localized groundwater vulnerability associated with agricultural activities, particularly elevated nitrate concentrations in shallow groundwater. These findings are consistent with earlier isotope studies in the Kherlen River Basin (Tsujimura et al., 2005; Tsujimura et al., 2007), while providing updated basin-wide evidence that integrates isotope hydrology with groundwater quality assessment to support sustainable management of Mongolia's transboundary water resources.

The ongoing **RAS7043** project (2024–2027) has expanded the application of isotope hydrology to the evaluation of MAR. The Baganuur MAR pilot site, Mongolia's first demonstration site for MAR, was selected to investigate recharge processes, interactions between Nariin Spring, the recharge channel, and the local groundwater system, and the effectiveness of MAR using integrated hydrochemical and isotope techniques ($\delta^{18}O$, δ^2H, ^3H and, more recently, ^{222}Rn). Preliminary results suggest a potential hydraulic connection between Nariin Spring, the recharge-channel water, and groundwater within the study area; however, this recharge pathway is still under investigation (Chinzorig, 2026).

The project has also contributed to strengthening national capacity through the establishment of an integrated MAR monitoring system, installation of precipitation isotope collectors and automatic rainfall gauges, introduction of ^{222}Rn as an additional environmental tracer, and regional training of researchers. In June 2026, Mongolia hosted the IAEA/RCA RAS7043 Regional Technical Meeting in Ulaanbaatar, providing an opportunity for participating Member States to exchange experiences and discuss the application of isotope techniques for MAR evaluation (Fig. 6).

(Fig. 6) Participants of the IAEA/RCA RAS7043 Regional Technical Meeting and specialists from the Kherlen River Basin Authority during a field visit to the Baganuur MAR pilot site, Mongolia (18 June 2026).

The results of isotope investigations in Mongolia since 1988 indicate that groundwater management should be planned according to the recharge characteristics and residence time of individual aquifers. In northern Mongolia, studies of river alluvial aquifers have identified relatively young groundwater and active recharge associated with river systems. These characteristics indicate greater groundwater renewability than in many deep aquifers of the South Gobi, while sustainable abstraction still requires consideration of aquifer response, river–groundwater interactions, and environmental requirements.

In contrast, groundwater in the South Gobi region is characterized by extremely low recharge rates (generally less than 2 mm/year) and residence times ranging from thousands to tens of thousands of years, indicating that most of these resources represent slowly renewable or fossil groundwater.

These findings highlight the importance of considering groundwater residence time, recharge conditions, and aquifer renewability when planning long-term groundwater abstraction for increasing water demands in the Gobi region.

Groundwater systems characterized by long residence times and limited modern recharge require careful management because their recovery from intensive abstraction may occur over very long timescales. Long-term water resources planning in the Gobi region should therefore consider aquifer renewability, projected water demand, environmental requirements, and the potential contribution of multiple water-supply options within an integrated water resources management framework.

6. Integrating Isotope Hydrology into Water Resources Management in Mongolia

A key principle of sustainable groundwater management is to balance groundwater abstraction with long-term aquifer recharge and aquifer response, while ensuring the protection of groundwater-dependent ecosystems. This principle is consistent with international policies on sustainable water resources management (European Union, 2000; Australian Government, 2022; Gleeson et al., 2020). It is also reflected in Mongolia's regulatory framework, which requires groundwater resources to be assessed through hydrogeological investigations while identifying recharge sources and groundwater replenishment processes (Ministry of Nature, Environment and Tourism of Mongolia, 2012).

Groundwater abstraction planning should consider groundwater age, recharge sources and rates, aquifer renewability, and long-term aquifer response, together with conventional hydrogeological assessment.

The IAEA TC and RCA projects have established a scientific foundation for determining groundwater age, recharge processes, water origin, and surface water–groundwater interactions. In northern Mongolia, studies of alluvial aquifers have identified relatively young groundwater and active recharge associated with river systems, providing important information for integrated management of surface water and groundwater. In contrast, studies in the South Gobi have identified deep groundwater with residence times ranging from several thousand to tens of thousands of years, indicating limited modern recharge (Janchivdorj, 2013). Information on groundwater origin, recharge sources and rates, residence time, and hydraulic connectivity between aquifers can complement conventional hydrogeological investigations and strengthen the scientific basis for evaluating the long-term sustainability of groundwater abstraction.

In recent years, environmental isotope techniques have moved beyond the framework of IAEA TC and RCA projects and are increasingly being applied independently in nationally funded and international collaborative research projects. The Water Agency of Mongolia has also begun incorporating isotope investigations into the terms of reference for selected water resources studies where identifying groundwater recharge and water origin is essential. One example is the investigation of the restored Ganga Lake, where isotope techniques were applied to identify the lake's water sources using stable isotopes. These developments demonstrate that isotope hydrology is gradually being integrated into water resources assessment and management in Mongolia.

To move from project-based applications toward routine use in water resources management, isotope hydrology should be integrated as a complementary tool in groundwater resource assessment in Mongolia. Conventional hydrogeological investigations provide information on aquifer geometry, hydraulic properties, groundwater levels, and groundwater availability, while isotope and hydrochemical techniques provide additional evidence on recharge sources, groundwater residence time, aquifer renewability, and hydraulic connectivity. Integrating these datasets can strengthen the conceptual understanding of groundwater systems and, where appropriate, support groundwater modelling, thereby improving the scientific basis for evaluating sustainable groundwater abstraction under different development scenarios.

To facilitate the routine application of isotope hydrology in water resources management, practical national guidelines should be developed for the collection, analysis, interpretation, and use of isotope data in groundwater investigations. These guidelines should clarify when isotope investigations are needed, which isotope techniques are appropriate under different hydrogeological conditions, and how isotope results can be incorporated into groundwater resource assessments and, where appropriate, groundwater models. Continued strengthening of national laboratory capacity, long-term isotope monitoring networks, and professional training will also be essential to ensure that isotope information can be effectively translated into practical water management decisions.

7. Conclusions and Recommendations

Over nearly four decades of cooperation with the IAEA, Mongolia has made significant progress in developing human resources, laboratory infrastructure, and research capacity in isotope hydrology. Building on the knowledge, capacity, and experience developed through IAEA TC and RCA projects, the next step is to move from primarily project-based applications toward the more systematic use of isotope hydrology as a complementary tool in water resources assessment and management. Strengthened collaboration among the Water Agency of Mongolia, research institutions, universities, and other relevant organizations will be important for translating isotope-based scientific information into practical water management applications.

Priority actions should include developing practical national guidelines for the application and interpretation of isotope techniques in groundwater investigations; progressively integrating isotope information into groundwater resource assessment, river basin planning, environmental impact assessment, and long-term monitoring; strengthening national analytical capacity and isotope monitoring networks; and expanding professional and university-level education and training in isotope hydrology. Particular attention should be given to strategically important aquifers and groundwater systems where recharge conditions, hydraulic connectivity, or long-term renewability remain uncertain. These actions would help establish isotope hydrology as a practical complementary tool for decision-making and sustainable water resources management in Mongolia.

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