Interaction of ground and surface waters revealed by stable isotopes in the Tuul river basin, Mongolia

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Key words: Deuterium, oxygen-18, storage ratio, drainage factor, meteoric line, hydrograph separation

Introduction

Ulaanbaatar is Capital City of Mongolia, which is fully dependent on groundwater resources hydraulically connected with the Tuul river.

The rapid population growth of the Ulaanbaatar has led to a sharp increase in water demand. According to projection present water demand of Ulaanbaatar will increase by 1,6 times in 2020 level and would face a serious water shortage problem. At present, seasonal water scarcity by the end of winter and spring happened nearly every year.

One of possible solution of the improvement of water supply state is considered as construction of reservoirs to increase recharge rate in upper Tuul river basin. However, physical properties of the basin, surface and groundwater interaction are very little known.

Hydrological changes occurring in the Tuul river basin

Hydrological station was operating on Tuul River at Ulaanbaatar since 1945. There are 4 other stations operating in relatively short period of time in upper basin of the river.

Analysis of annual storage ratio series of the basin, expressed as ratio of hydrograph area below annual average flow to the total area of annual hydrograph, reveal change in water regime regulating ability of the basin. While, analyses of series of drainage factor of the exponential function /Maillet, 1905/, derived from recession curves after the flood peak in every year reveal changes in storage rate of the basin.

Drainage factor of the Tuul River at Ulaanbaatar has clearly increasing trend in last 56 years. Therefore, underground retardation decreases due to change in natural characteristics of the river basin. Drainage factor value range from 0,040 to 0,071. Its highest values in last years indicate that size of active drainage decreases in the basin.

As consequence of change in drainage factor, water regime, regulating ability of the basin decreases. If calculate the storage ratio rate by trend equation, and compare the ratio rate in 1945 and in 2000 then it decreases by 7,6 % in comparison with the ratio in 1945. It was 0.44 in 1945-th and 0.40 in 2000-th. In connection with occurrence of these changes, duration of low flow period is increasing and flood recesses shortly than in previous years /G. Davaa and N. Sharkhuu, 2001/.

Therefore, it is urged to apply isotope techniques, which allow revealing groundwater recharge rate and zone, source identification, age and mixing rate of various water sources etc.

Isotopic composition of waters in the basin and results of analysis

Samples from all water bodies and precipitation were taken on monthly basis in 1999. In 2000 year, totally over 1300 samples from different water bodies have been collected by the 8 hydrological posts and Institute of Meteorology and Hydrology. Considering water and climate regimes were selected 716 samples and analyzed by the Isotope Hydrology laboratory, IAEA. Sampling points were shown in fig. 1. Samples for stable isotopes as ^{18}O and ^{2}H and radioactive isotope as ^{3}H was taken in all water bodies and in precipitation. In addition to that CFC samples were taken from water of springs and ground water wells. Samples for chemical analysis was taken on monthly basis from all water bodies in project area and analysis made at the Central Environmental Laboratory, Ministry of Nature and the Environment, Mongolia.

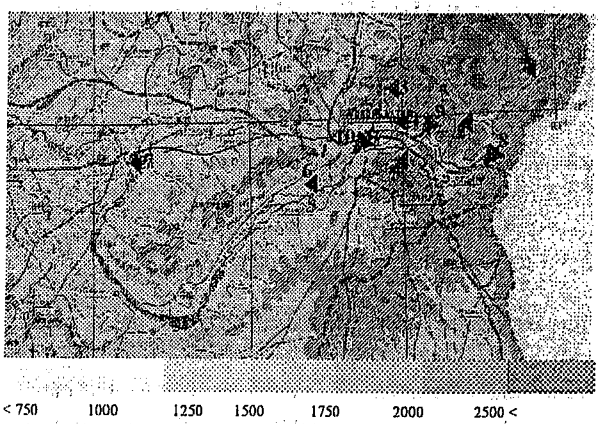

Fig. 1. Location of sampling points in the Tuul river basin

1. Tuul river at Bosg bridge (TBG), 2. Terelj river at Rest house "Terelj" (TRJ), 3. Selbe river at Sanzai (SES), 4. Selbe river at Dambadarjaa (SED), 5. Tuul river at Ulaanbaatar (TUB), 6. Tuul river at Altanbulag (TAL), 7. Tuul river at Lun (TLU), 8. Upper water supply well (UPW), 9. Bayanzurkh water supply well (BZW), 10. Yarmag water supply well (YAW)
Notes: Sampled springs are located in Selbe river /3 and 4/ basin. Names of sampling stations are abbreviated with three relevant letters and fourth letter indicates type of sampled water like river water (R), precipitation (P), and well water (W) and spring (S).

The penetration of the surface temperature into the soil is characterized by an exponential decrease of the maximum-minimum difference. Amplitude of the ground temperature is about 42 °C at surface and it decreases to about 6 °C at a depth of 3.2 m in Ulaanbaatar. The little snow fallen in this period from November to the end of April or beginning of May is either evaporated or run off at the surface before it theoretically could enter the soil zone and replenish the groundwater.

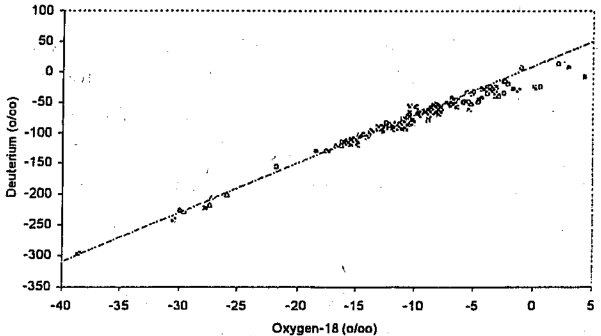

Fig. 2. δ^2H- δ^{18}O plot for all precipitation stations temporarily operational in the study area

Therefore, the isotope concentration in contemporary groundwater should be represented by the respective concentration of precipitation fallen in the period of about April/May to October/November.

The stable isotope composition of the precipitation collected at the 6 stations operational during the project period in 1999 and 2000 (TGBP, TRJP, SESP, TALP, and TLUP) is shown in the δ^2H- δ^{18}O diagram of Fig. 2. Most of the data represent individual samples collected on daily base in the year 2000. In 1999, only monthly composite samples have been collected from each station in the period 1999 to May 2000. All values with δ^{18}O below –27 ‰ represent snow samples. The summer data show an evaporation effect. There is a considerable scatter of the values and an increase of the deuterium excess with increasing δ^{18}O values.

The δ^{18}O values of the precipitation at all stations show a high temporal variability (Fig. 3).

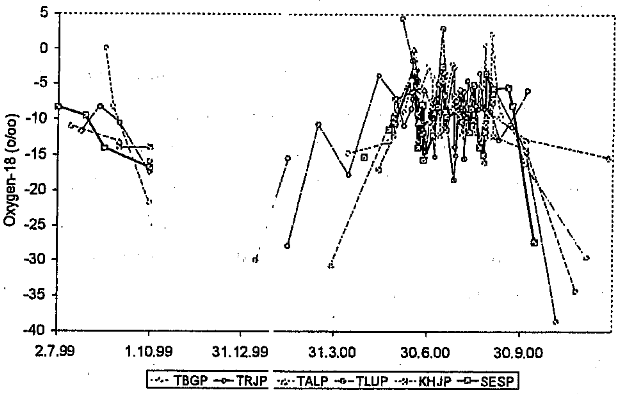

Fig. 3. Temporal variation of δ^{18}O in precipitation in the study area collected in 1999 and 2000 at the various stations

For a more quantitative comparison of the results for the various stations the average δ^{18}O and deuterium excess values have been calculated for the summer as well as winter period separately. The results show that there is now remarkable difference in the average summer values of ^{18}O of the various stations. *An altitude effect, which is expected to exist, appears to be masked by the high statistical spread of the data obtained so far.* The averages for the three stations characterising precipitation in the Tuul river catchment area upstream of Ulaanbaatar for ^{18}O and the d-excess has been found to be:

δ^{18}O (summer) = -9,0 ± 4,6 ‰, d-excess = 6 ± 9 ‰
δ^{18}O (winter) = -27,7 ‰, d-excess = 6 ‰

This result shows that a considerable spread exists in both the ^{18}O and the d-excess values, which is certainly due to strong natural variations of these values in daily precipitation samples. Varying degree of evaporation of the falling raindrops under the dry conditions and evaporation in the funnel of the precipitation sampler may also cause this scatter. The latter two effects can cause a shift of ^{18}O towards higher values and values of d-excess towards lower values. This shift in ^{18}O could be in the order of a permille, and thus, it would have a strong impact on the hydrograph separation by the isotopic method.

The ^{2}H-^{18}O diagram of water samples collected in 1999 and 2000 from springs in the study area is shown in Fig. 4. All springs except the spring at Selbe-Sanzai (SZS) clearly show evaporation effects. The evaporation could occur in meadow area of discharge zone of springs.

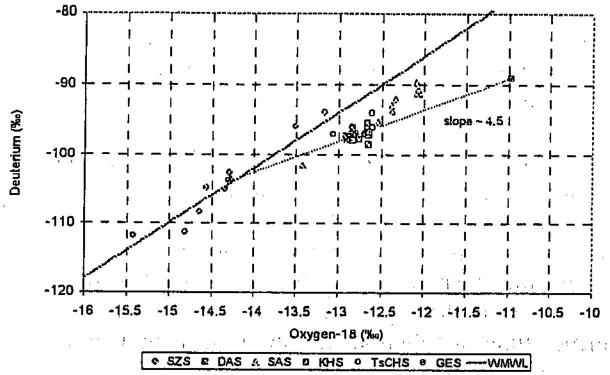

Fig. 4. δ^2H-δ^{18}O diagram of the sampled springs of the study area

Since the water of the spring at Selbe-Sanzai represents subsurface runoff to the Selbe river, the isotope composition of this water can be considered as reference for the groundwater isotopic composition in this area. The average δ^{18}O value of the Selbe spring for the observation period is (−14.3 ± 0.2) ‰ (without correction for evaporation in early summer 2000) and (-14.5 ± 0.3) ‰ (with correction), respectively. Thus, the slight shift of the average δ^{18}O content can be disregarded.

Maloszewski et al. (1992) have shown that the mean residence time (T) of spring water can be estimated from the attenuation of the amplitude of the annual ^{18}O (or ^{2}H) variation in spring water (A) relative to local precipitation (B) by the expression

$$T = \frac{1}{2\pi}\sqrt{\left(\frac{B}{A}\right)^2 - 1};\ \text{year} \qquad (1)$$

Adopting the values A = 2.3 ‰ (difference between maximum and minimum value of SZS in Fig.4 and B = 18.7 ‰ (difference between summer and winter average ^{18}O value of the precipitation) the estimated mean residence time is 1.3 years.

The measured δ^{18}O values of water collected from the wells UPW, BZW, and YAW cover a rather narrow range between about −15.5 ‰ and −13.3 ‰, and the data points are spread along the World Meteorological Water Line (Fig. 5). Most of the d-excess values are between 8 ‰ and 12 ‰

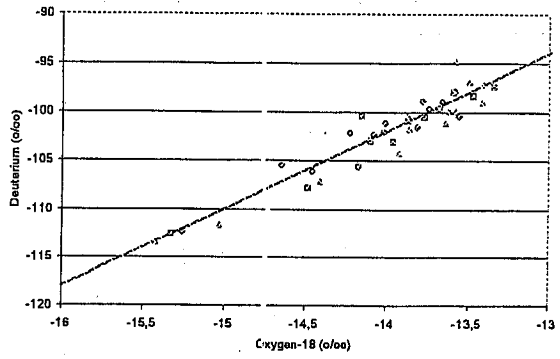

Fig. 5. ^{2}H-^{18}O diagram of the sampled groundwater wells in the study area

Also the temporal change of the δ^{18}O values of the three wells UPW, BZW and YAW (Fig. 5) is rather consistent and largely mirrors the behaviour of the groundwater of the Selbe spring (SZS). The lower values in late spring/early summer indicate spring-meltwater, and in the following summer months there is an increase due to higher contribution of river water through bank filtration to groundwater. In this connection it should be noted that wells UPW, BZW, and YAW have been selected from a series of production wells along the bank of the Tuul river used for the drinking water supply of Ulaanbaatar. Since the water extracted from the wells UPW, BZW, and YAW is supposed to be a mixture between locally formed groundwater and water infiltrated from the Tuul river, the temporal δ^{18}O change of the well water is compared with the δ^{18}O change of the river water .

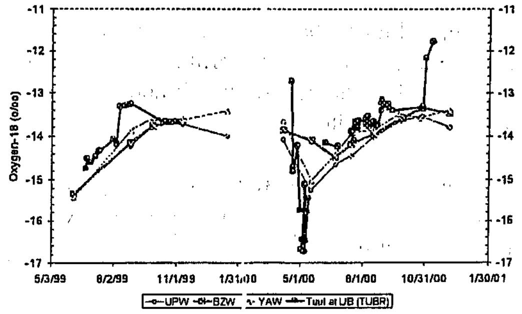

Fig. 6. Temporal change of δ^{18}O in groundwater of the investigation area and of the Spring SZS near Ulaanbaatar

In Tuul river at Ulaanbaatar (Fig. 6) appears to be a fast response of wells UPW and YAW to the isotopically depleted meltwater transported by the adjacent Tuul river. It can be assumed that the minimum δ^{18}O in well UBZ occurs at about end of May 2000, which would be equivalent to a delay time with respect to the river Tuul minimum of about 3 weeks. The delay time can be considered as transit time of the infiltrated water from the riverbank to the respective well. The delay time for the other two wells is less than 2 weeks.

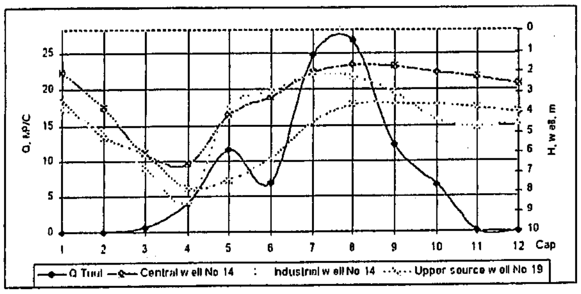

Fig. 7. Monthly mean water table (H in m) of different wells and monthly mean discharge (Q in m^3/s) of the Tuul river at Ulaanbaatar

To determine the isotopic composition of the groundwater during the winter months it is useful to examine the water table fluctuations of these wells and the change of the Tuul river flow (Fig. 7). At the beginning of the winter when the river is frozen, the water table is still high, but gradually decreases with increasing abstraction of groundwater because of the missing river water contribution. The water table starts to rise again during the spring meltwater phase and recovers during the summer due to increasing river flow. Despite a considerable decline of the water table between January and April (Fig.6) there is no remarkable change of the $\delta^{18}O$ values. Therefore, the well water of this period can be considered as pure groundwater. For the winter months 1999/2000 the following average values have been obtained:

UPW: $\delta^{18}O = -13.94‰$
BZW: $\delta^{18}O = -13.78‰$
YAW: $\delta^{18}O = -13.56‰$

They are slightly higher than the average groundwater concentration represented by the spring SZS (-14.3‰), which seems to reflect an accordingly higher meltwater content in the spring water.

It should be noted that the average d-excess values and the standard deviation for individual d-excess values during the observation period 1999 and 2000 are as follows:

UPW: d-excess = (10.3 ± 1.1)‰
BZW: d-excess = (9.8 ± 1.3)‰
YAW: d-excess = (9.5 ± 1.7)‰

The δ^2H-$\delta^{18}O$ diagram of the river water samples (Fig.8) reveals that the water collected from the Tuul at Lun (TLUR) and the Selbe-Damba (SEDR) was subject to evaporation. At Tuul-Bosgo, Terelj-Terelj, Tuul-Ulaanbaatar and Tuul-Altanbulag the isotope values do not show effects of evaporation from the water surface.

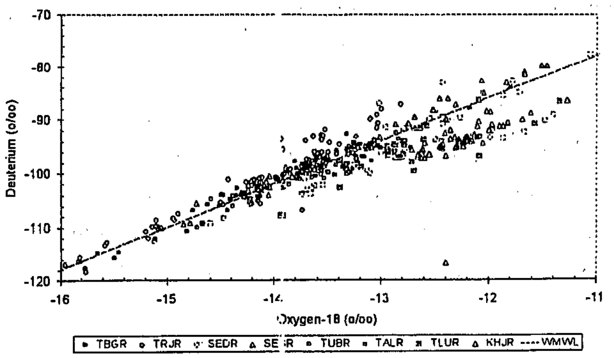

Fig. 8. δ^2H-$\delta^{18}O$ diagram of the water samples collected during 1999 and 2000 from various rivers in the study area

With regard to the residence time determination it was very fortunate those CFC measurements on some spring and well water samples have been carried out. Since the samples are from unconfined shallow aquifers, the mean residence time (MRT) has been calculated using the exponential model of groundwater residence time distribution. It appears that the CFC12 data provide a useful estimate of the MRT of the investigated groundwater. Since this parameter is a direct measure of the groundwater recharge rate R for an unconfined aquifer with the thickness H and porosity p the relation follows as:

$$R = \frac{pH}{MRT} \qquad (2)$$

It appears that MRT=30 years, the recharge rate is R=100 mm/yr.

Conclusion and discussions

The results of stable isotopic composition analysis indicate that spring at Selbe-Sanzai represents subsurface runoff and it's isotope composition of this area. MRT of the spring is 1.3 year. While MRT = 30 years and R= 100 mm in shallow aquifers in the Tuul river basin. The lower values $\delta^{18}O$ in well water in late spring/early summer indicate spring-meltwater, and in the following summer months there is an increase due to higher contribution of river water through bank infiltration. High temporal and spatial variations of isotope composition in precipitation in such semi arid basin require special sampling procedures for future studies.

References

Davaa G. Sharkhuu N. Interrelations of permafrost and water regime of the upper Tuul river basin, Mongolia, Extended abstracts of International symposium on mountain and arid land permafrost, Ulaanbaatar, 16-20pp, 2001.

Maloszewski, P., Rauret.W., Trimborn.P., Hermann.A., Rau.R., Isotope hydrological study on mean transit times in an Alpine basin., J.Hydrol.140, 343-360 pp., 1992.