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Des défis du Nord au Sud

Hydrologic connections in the Source Area of the Yellow River as inferred by hydrogen and oxygen isotopes

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ABSTRACT
Analyses of stable (^{2}H and ^{18}O) and radioactive (^{3}H) isotopes of different waters are applied here to investigate the potential changes in hydrologic connections of the surface and subsurface water in the Source Area of the Yellow River (SAYR), in northeast of Qinghai-Tibet Plateau. A record of tritium in historical precipitation from 1956 to 2003 in the SAYR has been reconstructed and the results show that groundwater with tritium concentration less than 3.05 TU had a pre-1956 age. The spring water could be recognized as former years precipitation and had around 10 years ages while the ages of well water in Madoi Town reflect recent precipitation. The variations of $\delta^{2}H$ and $\delta^{18}O$ of the water system suggest that the Yellow River and its tributaries were mainly recharged by the shallow ground water in the continuous permafrost areas, while in seasonal permafrost regions, surface water recharged the groundwater.

RÉSUMÉ
Afin d'étudier les changements potentiels des connexions hydrologiques entre la surface et la sous-surface de l'eau, les analyses d'isotopes stables (^{2}H et ^{18}O) et radioactifs (^{3}H) de différentes eaux sont effectuées dans la zone de la Source du Fleuve Jaune (SAYR), nord du Plateau Qinghai-Tibet. Un dossier historique concernant la précipitation de tritium entre les années 1956 et 2003 dans le SAYR, a été reconstruit ; les résultats montrent que la concentration en tritium de l'eau souterraine était inférieure à 3,05 TU, et que l'eau avait un âge de pré-1956. L'eau de source pourrait être reconnue comme étant la précipitation des années précédentes, et elle aurait un âge d'environ 10 ans; mais l'âge de l'eau de puits, dans le district de Madoi, reflète les récentes précipitations. La variabilité de $\delta^{2}H$ et de δ18O du système d'eau suggère que le fleuve Jaune et ses affluents ont été principalement rechargés par la nappe phréatique peu profonde dans le pergélisol continu ; Par contre, dans la région du pergélisol saisonnière comme Madoi, l'eau de surface recharge la nappe phréatique.

1 INTRODUCTION

The effects of global climate warming during the recent decades is best recognized in cold systems such as polar and permafrost regions. Permafrost (frozen ground) regions respond rather rapidly to the climate change and are environmental-sensitive causing significant ecological changes that are associated with permafrost degradation (Harris et al. 2002; Jin et al. 2007; Marchenko et al. 2007; Jin et al. 2009). Especially, it had been observed that the local water cycle processes in these permafrost areas were extensively influenced by the degradation process (Wang et al. 2000; Walker et al. 2003; Wang et al. 2009).

The Qinghai-Tibet Plateau (QTP) houses the large area of permafrost (1.26 × 106 km^2) extending from mid to high altitude and is characterized by arid and semi-arid plateau-climate. The plateau has been the focus of international concern due to geographic location and unique high elevation thus forming a source of cold air system separating the Himalaya climatic front boundary from inner China. The southern part of QTP is mainly influenced by the Indian summer monsoon invasion, while the northern part of QTP is mainly influenced by the continental climate (Kang et al. 2002). QTP is also called as the water tower of Asia as many important large streams and their tributaries (the Ganges River, the Indus River and the Yangtze, Yellow river) originated from QTP. The air temperature had increased by 0.45°C over the last 40 years as suggested by the IPCC (2013) and climatic projection suggests that the temperature in QTP would increase by 3.8°C at the end of this century (2100). This temperature change will lead to a degradation of

58% of the total area of permafrost (Li & Cheng, 1999).

The Source Area of the Yellow River (SAYR) is situated in the northeastern part of QTP. The SAYR is the headstream basin of the Yellow River, and is also the key area of runoff-yield and storage. The regional hydrogeology is extremely complex, including continuous and discontinuous permafrost, seasonally frozen ground and lake shore taliks which are associated with crisscross surface and subsurface water that were related to each other. Jin et al. (2007) suggested that the delicate thermal balance and the intense monsoon influence make the SAYR basin highly sensitive to climate warming when compared with the other cold regions. The Source Area of the Yellow River (SAYR) is situated in the northeastern part of QTP. The SAYR is the upstream basin of the Yellow River, and is also the key area of runoff-yield and storage. Jin et al. (2007) suggested that the delicate thermal balance and the intense monsoon influence make the SAYR basin highly sensitive to climate warming when compared with the other cold regions.

Research has been conducted on the SAYR regarding the challenging influences on regional ecological environments under the background of permafrost degradation which was caused by climate change and human activities. Zhang et al. (2004) reported the permafrost degradation in the SAYR had resulted in lowing or even disappearing of local shallow groundwater. Cao et al. (2006) found that during 38 years period between 1961 and 1999 the annual average temperature in the SAYR increased at the rate of 0.25°C/10 years, which had caused imbalance in water quantity, shrinking of lakes and desertification of land. Chang et al. (2007) used data from Madoi Meteorological Station, which is located in the center of the SAYR, during the period of 1955-2005 to analyze the change trend of climate and frozen ground and revealed the discharge of the Yellow River (annual runoff) had showed a declining trend. They suggested that many changes in temperature, sharp increase of evaporation, change in thickness of active layer could have contributed to the reduction of runoff from the precipitation. But the most determined factor remained to be disclosed. Wang et al. (2009) showed soil freezing and thawing of the upper active layer in this area played the most important role in controlling local river runoff discharge (35% reduction in the annual runoff). This feature could well explain the early findings of the shrinkage of taliks, the lowering of groundwater tables which also brought in the lowing of lake levels and the disappearance of wetlands (Wang et al. 2000). The water resources and water environment in the SAYR have been faced with serious crisis and show a deteriorating development tendency. The hydrologic processes in the SAYR are, however, still poorly understood because of the demanding field work environment for human and measuring instruments, which has hindered the proper evaluation for regional water resources (Jin et al. 2007, 2009; Wang et al. 2009). Consequently any effort to contributing to the investigation of the hydrological processes in the SAYR is strongly needed task in order to understand the current situation of local water resources and environment and to reach reasonable water management for the ecological sustainable development.

Although traditional hydrological observations, such as flow tests were carried out in the extreme climate regions such as the SAYR (Gibson et al. 1993), there is the potential of utilizing stable and radioactive isotopes tracers that have proved efficient and presently widely applied in the understanding of hydrological processes (Kendall and McDonnell, 2012). The different fractionation of the stable isotopes (^{18}O and ^{2}H) in water under variable conditions and processes (evaporation, condensation, desorption and dissolution) permits tracing of sources and thereby potential monitoring of changes in the hydrological system (Dansgaard,1964; Macumber, 2003; Murad, 2010). Tritium (^{3}H or T) a radioisotope of hydrogen is another interesting isotope that has been used for tracing transport and ages of water systems. The isotope was primarily enriched in atmosphere through production from above surface atomic weapon tests with a major peak in precipitation during mid-1950s and 1963 (Ingraham, 1998). The half-life of ^{3}H is 12.43 years and thus the radioactivity signals have been strongly reduced since the times of anthropogenic production. However, high accuracy measurements can still produce detectable values of ^{3}H in natural water such as rain and groundwater.

Investigations of the QTP using the isotopes (^{18}O, ^{2}H and ^{3}H) have mainly concentrated on precipitation in order to identify origin of moisture (Tian et al. 2001, 2007; Yu et al. 2006), compositions in ice core for palaeoclimatic reconstruction (Yao et al. 1996), or identification of runoff generation and concentration in small watersheds (Yang et al. 2012). Also, the locations of areas used to collect isotope data from river water, lake water and spring water are allocated in the middle and southern part of the QTP (Wake et al. 1995; Tian et al. 2001). These areas are covered with ice and snow year around in contrast, to the SAYR area which is combined by continuous, discontinuous permafrost and seasonally frozen ground have rarely been investigated using ^{18}O, ^{2}H and ^{3}H isotopes.

In 2014, a scientific investigation started in the SAYR with the purpose to identify potential changes between the hydraulic connections of the surface and subsurface water flow systems in representative permafrost zone, to resume and to protect the region's ecological environment. Isotope techniques were applied in order to better clarify and understand the hydrological process in the SAYR as reported here. The major goals of the investigation were (1) to reconstruct the historical ^{3}H precipitation record of SAYR; (2) to characterize t ^{3}H, ^{18}O and ^{2}H isotope fingerprints in water from rivers, lakes, springs and wells.

2 THE STUDY AREA

2.1 Topography

The SAYR is located in the northeastern QTP and surrounded by the Bayan Har Mountains in the south, which is the watershed divide between the Yellow River system and the Yangtze River system (Figure 1), the

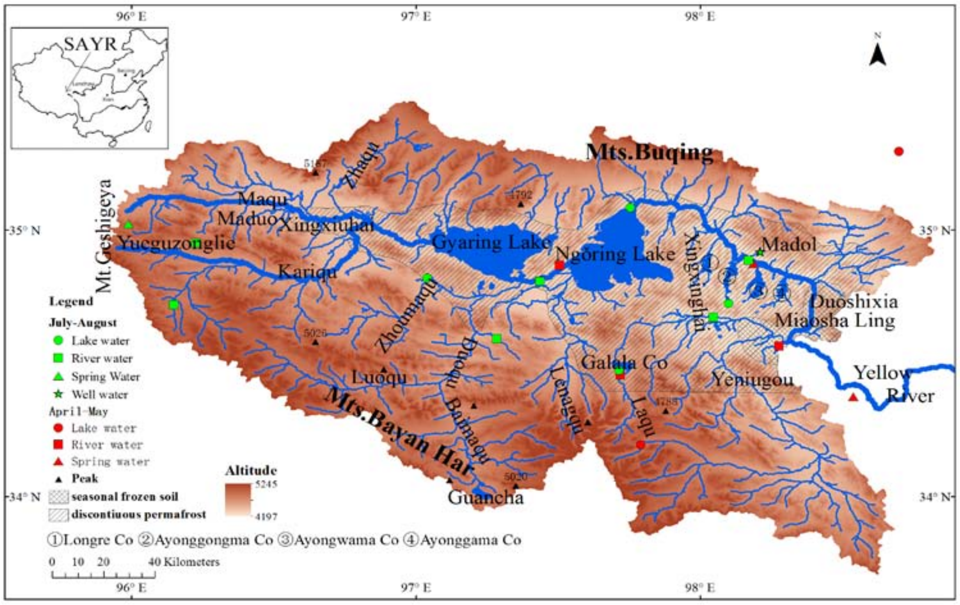

Figure 1.The geographic information of the SAYR and distribution of sampling points in the study area

SAYR is between 95°55'-98°41'E, 33°56'-35°31'N, with a total catchment area (the whole upstream basin above the Duoshixia reservoir) of around 2.47×10^4 km^2. The elevation of the SAYR increases southwards and northwards, with a range from 4100 m amsl to 5442 m amsl. The Yellow River in SAYR runs generally in NW-SE direction along the tectonic structures. The Yellow River floodplains which include the two largest lakes (the Gyaring and Ngǒring Lakes) and small river tributaries also occurs the flat at lower elevation, which is surrounded by frost mound and mountains. The vegetation types are primarily alpine swamp meadow, alpine meadow and alpine steppe meadow. In the higher elevation area, the soil type is alpine meadow, while in the lowlands and wetlands near the lakes and rivers, the soil type is the swamp meadow.

2.2 Climate and Hydrology

The dominated climate pattern of the SAYR is of the sub-frigid zone semi-arid climatic conditions. The rain and heat are over the same period, where wet and dry season are divided clearly. The mean annual air temperature is around -4°C, leading to freeze up of rivers and lakes for 7 months every year. The mean rainfall varies between 300 and 400 mm yr^{-1} (70-80 percentages of the precipitation in warm seasons) and the changing trends of mean annual precipitation are not evident compared with the changes of mean annual temperature. Generally speaking, this region had noticeably become warmer and the frequently seasonal variations of rainfall can be observed during 1960-2006, mostly in the form of snow (solids) or storms (liquid). In recent 50 years (until 2007) the mean annual runoff decreased and high and low flows fluctuated frequently. There majority of lakes are distributed, besides the main stream or southern branches of the Yellow River, along the southern part of SAYR. The two largest lakes are the Ngǒring (surface area 610.7 km^2 in 2000) and Gyaring (surface area 526.1 km^2 in 2000).

The other main lakes are Xingxiuhai Lake, west of the Gyaring lake, the Galala Co, south of the Ngǒring Lake and Xingxinghai Lake, east of the Ngǒring Lake and the four lakes in the east besides Xingxinghai Lake.

The Yellow River runs across most of the lakes. In recent years, the surface area of the lakes has reduced and the lake water levels of the Gyaring and Ngǒring Lakes declined by at least 2 m (Zhang et al. 2004). Due to the permafrost degradation, the intensive freezing-thawing process in or near the river and lake tailks, decreased soil moisture content has caused grassland degeneration and desertification. Furthermore, the lower ground water table and less soil moisture content implied obstruction of the evapotranspiration which together with constant precipitation rate and decreasing runoff imposed difficulties in estimating the actual water balance in the SAYR.

2.3 Frozen ground

The distribution of frozen ground and manners of seasonal freeze-thaw zones are complicated in the SAYR because they are influenced by location of lakes and rivers, the warming climate, the topography and altitude. The continuous and discontinuous permafrost, seasonally frozen ground and lake shore taliks are distributed with frequent transitions in SAYR. The seasonally frozen ground only appears in river valleys in the east of Ngǒring Lake, from Duoshixia to Miaosha Ling along the Yellow River. In these places, taliks form around the lake shore due the high ground temperature and influences of lakes and rivers. These taliks extend from

Xingxiuhai to Xingxinghai lakes, from the west to the east, along the Yellow River and across the two lakes. There are also areas of discontinuous permafrost, westward, southward and northward of the two largest lakes with the increasing elevation. Transition can be found from lake shore taliks to the isolated patches of permafrost, and then to discontinuous permafrost. The remaining large zone of the SAYR at elevations higher than 4400 m asl are continuous permafrost. It is worth noting that glaciers were found in this area.

3 SAMPLING AND METHODS

Field works covering most of the SAYR was carried out during 14th April—1st May and 21st July—15th August in 2014. Samples for isotopic analyses were collected from 7 lake water, 10 river water, 3 springs and 4 wells along the the Yellow River (main stream), and from its tributaries, lakes, springs and wells in Madoi Town (Figure 1). All the sampling bottles were filled with water samples and tightly capped to prevent the potential evaporation or moisture exchange with the atmosphere. They were stored in at 4°C until being measured in laboratory.

The ^{3}H concentration measurements were completed by using a liquid scintillation counter (Tri-Carb 3170 TR/SL). The measurement precision was ± 1 TU. The stable oxygen and hydrogen isotope compositions (^{2}H and ^{18}O) of April's samples were measured on a water isotope spectrometer analyze (Model Picarro, L2120-i).

Every sample was measured six times average and we use the standard liquid as calibration when measuring every three samples to eliminate the 'memory effect'. Hydrogen and oxygen isotopes ratios are expressed by the $\delta^{2}H$ and $\delta^{18}O$, respectively. Delta (δ) is the conventional notation (Craig, 1961) in per mil (‰) relative to VSMOW (Vienna Standard Mean Ocean Water) (Gat & Gonfiantini, 1981).

$$\delta = (R_{Sample}/R_{VSMOW} - 1) \times 1000 (‰) \quad [1]$$

Where the R_{Sample} and R_{VSMOW} are the isotopic ratios of the sample water and the standard mean ocean water (VSMOW), respectively.

The measurement precision was ± 1‰ for $\delta^{2}H$ and ± 0.1‰ for $\delta^{18}O$, respectively.

4 RESULTS AND DISCUSSION

4.1 Tritium

The natural concentration of tritium in precipitation was in steady state of (0-15 TU) before 1952. Since 1952, the thermonuclear tests increased the tritium concentration in precipitation by 3 orders of its natural value and the maximum addition was recorded in 1963 reaching about 2000 TU in northwestern part of China. This anthropogenic signal was a useful tool for dating of groundwater because the 1963 tritium concentration peak in rainfall was just an input of tracer. Tritium concentration of groundwater depends on the concentration of initial atmospheric precipitation recharge as an input, and the radiogenic decay which begins from that time.

However, the record of tritium concentration in precipitation in SAYR was lacking, and the data from nearby stations were not continuous series or long time record, in order to study the historic tritium concentration of precipitation in the SAYR, it was necessary to reconstruct the annual mean tritium value in precipitation. Guan (1986) used detailed historical information to build up model and found that tritium concentration in precipitation had linear relationship with latitude and annual precipitation in China. By considering time and location factors in his model, the tritium concentration in precipitation record from 1963-1978 could be reconstructed. The 1956-1962 data were borrowed from Pingliang which has the same latitude area near the SAYR and share similar meteorological characteristics (Li et al. 2011). The 1992-1994 data were from Luobupo station and Lhasa station, using the spatial interpolation (Jiao et al. 2004). The data of 1988, 1990, 1991, 1996 and 2001-2003 came from the actual observation record (Wang et al. 1989; Su et al. 2003). All this data were in good agreement with observation data from stations nearby. The reconstructed tritium values in precipitation from 1956 to 2003 in the SAYR are shown in Figure 2.

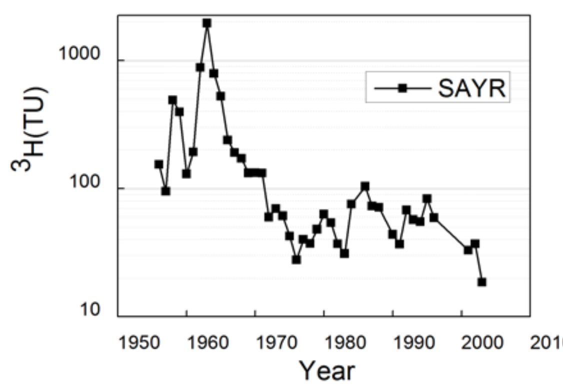

Figure 2. The record of reconstructed tritium values in precipitation from 1956 to 2003 in the SAYR

A basic decay equation is used to modify the residual tritium concentration in historical precipitation and to represent the concentration in recharge of groundwater.

$$N = N_0 \times e^{-\lambda t} \quad [2]$$

Where N is the current residual tritium concentration in the historical precipitation assuming preservation until 2014; N_0 is the original tritium concentration in historical precipitation; λ is the decay constant, and t is the time from historical precipitation to 2014.

The decayed precipitation record of tritium concentration has been showed in Figure 3. The measured data from our study and data of tritium concentration in water samples from previous published paper were put in Table 1, also, the previous data were modified by Eq.2 to make comparison and discussion possible.

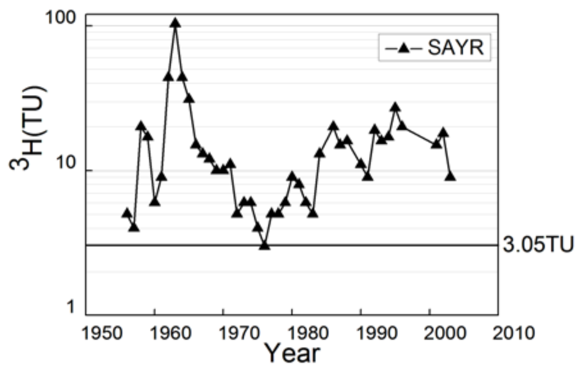

Figure 3. The decayed precipitation record of tritium concentration in the SAYR, using 2014 as the reference year

Table 1. The previous data compared with data in this study, the historical tritium concentration of water had been modified to show the residual concentration in 2014 caused by the decay.

Type	Date	Tritium (TU) Max	Min	Average	Description	Reference
Rainfall	1980-1984	101.4	40		Fresh snow	Wang et al.(1989)
	Modification	17.6	7			
	06, 1988	80	66	73	In Madoi	Wang et al.(1990)
	Modification	17	14	16		
River water	1980-1984	88.3	62		Surface water	Wang et al.(1989)
	Modification	15.3	10.7			
	Jun, 1988			183	In Madoi	Wang et al.(1990)
	Modification			40		
	Aug-Sep, 2000			41.1	Mon soon	Su et al.(2003)
	Modification			17.6		
	Mar-Apr, 2001			43.7	Dry season	
	Modification			19.8		
	Apr, 2014	16.74	8.27	10.63		This study
	Jul-Aug, 2014	11.91	7.94	10.53		
Lake water	May, 1988			183		Wang et al.(1990)
	Modification			40		
	Apr, 2014	13.19	8.88	9.89		This study
	Jul-Aug, 2014	11.99	9.82	11.03		
Spring water	May, 1988	116	80	92	suprapermafrost water, 0-0.8m depth	Wang et al.(1990)
	Modification	25	17	20		
	Jun,1988-Sep,1989	113	69	91	In Madoi	
	Modification	24	15	20		
	Apr, 2014	10.19	9.63	10.54		This study
	Jul, 2014			14.44		
Well water	Aug, 2014	9.13	7.7	8.36	In Madoi	This study

Generally speaking, the mean tritium concentration for water samples is 10.37 TU, with a range of 7.70 TU – 16.74 TU. For river water, the mean value is 10.77 TU and the range is 7.94-16.74 TU while for lake water, the mean value is 10.42 TU and the range is 8.88-13.19 TU. There were only three samples from spring water and their values were 10.19, 9.63 and 14.40 TU. The four well water samples had values for of 8.40, 8.20, 9.13, 7.70 TU.

4.2 Stable isotopes

Values of δ^2H and δ^{18}O in precipitation have near-linear relationship, and this behavior has been successfully used to determine source of water. The GMWL (Global Meteoric Water Line) was published by using data of weighted isotopic ratios of numerous samples of meteoric water (Craig, 1961). It was later modified by Rozanski et al. (1993), and the isotopic compositions of the majority of meteoric waters fall on the following expression which is abbreviated simply as GMWL (Figure 4):

$$\delta^2H = 8.17\delta^{18}O + 10.35;\ n=206,\ r^2 = 0.98 \qquad [3]$$

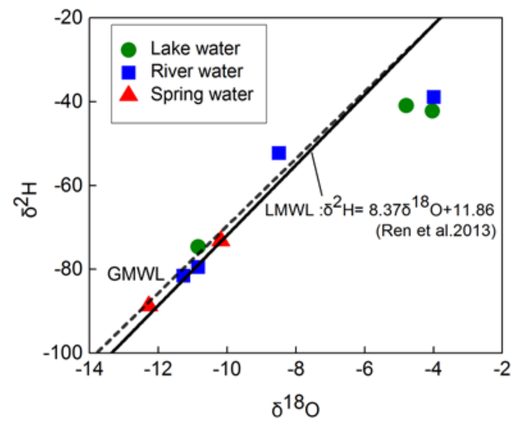

Figure 4. δ^2H and δ^{18}O in water samples in the SAYR, the LWML defined by Ren et al.(2013) was also plotted

Ren et al. (2013) collected event-based rain and snow samples from May, 2009 to April, 2010 (175 samples in total) and published the LWMLs based on individual samples and monthly weighted means. The LMWL based on individual samples (Figure 4) is expressed as:

$$\delta^2H = 8.37\delta^{18}O + 11.86;\quad n=175,\ r^2 = 0.97 \qquad [4]$$

The slope and intercept of LMWL may be similar with the GMWL, but in arid and semiarid regions the slopes of LMWLs are usually near 5-6 and less than 8 due to the kinetic isotope effects which depend on local conditions of humidity, isotopic composition of water vapor, and fraction of water evaporated. However, Liu et al. (2012) revealed that the LMWL in Fenghuoshan permafrost watershed (N34°40'-N34°34', E92°52'- 93°02') expressed as: $\delta^2H = 9.04\ \delta^{18}O + 18.77$ (r^2=0.87, n=85). Yao et al (2009) found that the LMWL in the Manasarovar basin of western part of QTP had a slope of 7.37 near around 8 and the intercept is 6.26 (r^2= 0.99). Kumar et al (2010) reported that the slope of LMWL in the Kumaon Himalaya in India is about 7.5, fairly similar to the Ganges River Headwaters (Ramesh and Sarin, 1992). The similarity in the slope values for the three closely-related regions implies the same large scale moisture transport -Monsoon and westerlies alternating control- that shares the same vapor mass origin. Also less secondary evaporation and isotope exchange in precipitation should accompany low ambient temperature, which was inverse for regions with high temperature at lower latitudes (Krishnamurthy and Bhattacharya, 1991).

The values $\delta^{18}O$ and $\delta^{2}H$ in the river water ranged between -3.99‰ and -11.27‰ and -38.9‰ and -81.5‰ with the average values of -7.96‰ and -60.1‰, respectively. For lake water, the values ranged between -4.03‰ and -10.84‰ for $\delta^{18}O$ and -42.2‰ and -74.6‰ for $\delta^{2}H$, with the average values of -8.29‰ for $\delta^{18}O$ and -63.8‰ for $\delta^{2}H$. The spring water had the lowest values, the two samples each were -12.28‰ and -10.19‰ for $\delta^{18}O$, -88.7‰ and -73.2‰ for $\delta^{2}H$, respectively.

4.3 Isotopic features and local hydrological processes

Figure 4 shows that most water clusters follow the LMWL, and only three clusters are located below the LWML suggesting the river and lake water are primarily recharged by precipitation. Evaporation is a non-equilibrium process, in the surface water of rivers and lakes, as it becomes enriched in heavy isotopes ($\delta^{2}H$ and $\delta^{18}O$), and the lines of isotope compositions of surface water usually does not follow the LMWLs (Meredith et al. 2009). From Figure 4, it clearly indicated that the two lake water samples (L1 and D2) and one river water sample (M2) were isotopically heavier than the rest of the river water samples suggesting extensive evaporation from the lake surface. The other water samples had depleted isotopic values and higher d-excess which may imply snow-ice melt and soil moisture from thawing of frozen soil as the primary supply of water to the rivers. The ice melt water was mainly from the moisture in upper active layer of frozen soil. The permafrost serves as an impermeable layer for water infiltration and provides high moisture content in the vadose zone. There were complicated freezing-thawing processes accompanied the retained water in the upper active layer of frozen soil. During warm periods, with the thawing of active topsoil layer, interflow and shallow groundwater discharge increase, leading to spring's flood runoff to increase as a result (Wang et al. 2009). This process can also reflect the good hydraulic connection between the streams and shallow groundwater.

From the decayed precipitation record of tritium concentration, it was accepted that groundwater with tritium concentration > 3.05 TU was of post-1956 age, but using this unique record to determine ages of groundwater was not possible due to multiplicity instances where one tritium concentration of groundwater could correspond to many ages (Ma et al. 2008). The tritium concentration of river, lake, spring, well water analyzed here were similar, and all were lower than 15TU, shared the same value with data of 2003. This feature may suggested that the river water and precipitation in 2003 was preserved to 2014, and the tritium concentration of river water mainly depended on its recharge. The recent changes of tritium concentration of precipitation indicated the decreasing trend which started to be lower than 10 TU since 2003, pointing the value of 10 TU as a discrimination threshold. Spring water's tritium concentration which was more than 10TU shared an old age more than 12 years if not mixed by the recharge of modern precipitation infiltration. But the springs were mainly recharged by the supra-permafrost water, which had residence time and received supply from precipitation (Han et al. 2009). So the spring water could be recognized as recharge of former years precipitation which had age of 10 years. River water had large range of tritium concentration and showed different recharge of possibilities. River water that had high tritium concentration could be explained by the recharge of shallow groundwater along its path, especially in the northern and southern part of SAYR where continuous permafrost occurs. Low tritium concentrations of river water can be connected to discontinuous permafrost and isolated patches of permafrost area. Soil moisture from thawing of frozen soil as the form of snow-ice melt water was the primary supply of rivers, and it originated from recent precipitation which had lower tritium concentration. Lake water also showed a similar distributing characteristic. It was notable that all the well water had narrow variation of tritium concentration at lower than 9.2 TU. All the wells distributed in Madoi Town, where the seasonal permafrost occurs, showed decreasing soil moisture content and low ground water table likely caused by degradation of permafrost which resulted in decreasing runoffs (Wang et al. 2000; Wang et al. 2009). So combined with the tritium concentration data, we inferred that the well water originates mainly from surface water and current precipitation.

5 Conclusions

The oxygen and hydrogen isotope ratios of the rivers, lakes springs and wells in the SAYR, located in the northeastern of QTP suggested that:

(1) Residual tritium concentration in historical precipitation pointed out that groundwater with tritium concentration less than 3.05 TU had a pre-1956 age.

(2) The spring water could be recognized as the former years precipitation and had 10 years age, while the well water in Madoi Town were of much recent precipitation.

(3) River and lake water in continuous permafrost had different isotopic features from those in discontinuous permafrost and seasonal permafrost suggesting different regional patterns of hydrological characteristics. During the warm season in April, the Yellow River and its tributaries were mainly recharged by the shallow ground water in northern and southern part of SAYR where the continuous permafrost conditions occur. In discontinuous permafrost and isolated patches of permafrost area, soil moisture from thawing of frozen soil in the form of snow-ice melt water was the primary supplier of rivers, and it originated from precipitation. In seasonal permafrost regions, evaporation and melt water from active layer of frozen ground was negligible, there were decreasing trend of runoffs, surface water and precipitation recharged to the groundwater.

6 Acknowledgements

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