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Research on Establishing Tritium Concentration Model of Precipitation in Northeast of Tarim Basin Based on Factor Analysis

Zhenhua Zhao*, Dongqing Wang, Youliang Bai, Changhong Yan, Xiaofeng Xu
Northwest Institute of Nuclear Technology, Xi’an, Shanxi 710024 China
*Corresponding author’s e-mail: 64802442@qq.com

Abstract. In the study of groundwater quantitative dating with tritium isotope, the establishment of tritium concentration model in precipitation is the key link, which provides the input function value for the calculation of groundwater tritium age. The Global Network of Isotopes in Precipitation (GNIP) jointly established by the international atomic energy agency (IAEA) and the world meteorological organization (WMO) provides a lot of data for the study of tritium isotopes in precipitation. Factor analysis is able to reduce variables with complex relations into a few comprehensive factors based on the internal dependence of variables. Therefore, factor analysis has obvious advantages in establishing tritium concentration model of precipitation based on a large number of tritium data in precipitation. In this paper, a tritium concentration model of precipitation in northeast Tarim basin had been established using factor analysis method, and calibrated with real data. The calculated results of model were in a good agreement with real data, showing that the model is reasonable. Meanwhile, considering the influence of nuclear test in the 20th century on the tritium concentration in the atmosphere of the study area, some previous research results were adopted, and the tritium concentration data in precipitation from 1960 to 2009 were finally recovered. In order to further verify the reasonability of the model, the recovered tritium concentration data in precipitation in northwest of Tarim basin were put to piston flow model and mixed flow model to date four groundwater samples in Kuketag, and the results showed that the tritium age of groundwater was consistent with the hydrogeological condition of study area. Therefore, it was considered that the tritium concentration model of precipitation in northeastern Tarim basin was reasonable and reliable.

1. Introduction
Tritium (³H or T) is an unstable isotopes of the element hydrogen and has a half-life of 12.32±0.02 years [1]. Tritium exists in the form of HTO molecules in the atmosphere and enters groundwater through atmospheric precipitation to participate in the groundwater circulation, and therefore is a kind of ideal tracer and dating technology of tracking various hydrology process. The concentration of tritium in atmospheric precipitation is less than 10 tritium units before 1952(TU) [2]. However, after 1952, the concentration of tritium in atmospheric precipitation greatly increased because of the nuclear test. In the early 1960s, tritium in precipitation in the mid-latitude region of the northern hemisphere exceeded 1000TU[3], especially the peak of tritium in 1963 which has become an obvious feature of the distribution of tritium concentration in atmospheric precipitation in many hydrogeological studies[4].
Tritium is usually used for groundwater dating in two ways. One is to qualitatively infer whether it is modern groundwater or ancient groundwater based on the concentration of tritium. Another is to calculate the groundwater age by mathematical physical model based on the tritium input and output functions. In recent decades, tritium has been widely used in groundwater age calculation and circulation studies\(^5\)\(^-\)\(^8\). The recovery of tritium concentration in meteoric precipitation is a key point in quantitative study of the groundwater circulation. Since 1985, with the support and cooperation of the international Atomic Energy Agency (IAEA), China has established the meteoric precipitation isotope observation station, and recorded only the data after 1985 in other regions except for Hong Kong. Therefore, the restoration of tritium concentration in meteoric precipitation of the years after 1952 has become an important research topic in this field. At present, the main recovery methods applied in China are Guan Bingjun method\(^9\)\(^-\)\(^11\), interpolation method\(^12\), double reference curve method\(^11\), unary linear correlation method of with different influencing factors\(^12\), artificial neural network method\(^13\) and factor analysis method\(^14\)\(^-\)\(^15\). The study area of this paper is located in the northeast of Tarim basin, where monitoring data of atmospheric precipitation tritium concentration are scarce. At the same time, due to the influence of atmospheric nuclear tests in the 1960s and 1970s, a large amount of tritium is generated in the atmosphere, which makes it difficult to recover the tritium concentration of atmospheric precipitation in Tarim basin. Based on the model established using factor analysis method, combined with the tritium concentration of atmospheric precipitation recorded by IAEA monitor station, and the previous research of tritium concentration in Thor wood peak glaciers of the Tianshan mountains and sedimentary rock in Bosten lake, and the measured data in this study, this article recovered the tritium concentration in atmospheric precipitation in the northeast of Tarim basin between 1960 and 2009. Taking this result as the input, the age of four groundwater samples in the study area is calculated. The result is consistent with the result of regional hydrogeological conditions analysis, which shows that the result of calculation is reasonable and the method effective.

2. Method

2.1 Principle of factor analysis method

Factor analysis method is the extension and development of principal component analysis method, and also a method of dimensionality reduction in multivariate statistical analysis. Factor analysis method is used to study the internal dependence of correlation matrix or covariance matrix. It synthesizes multiple variables into a few factors to reproduce the correlation between original variables and factors. The main idea of factor analysis method is to classify observation variables, which is classify those with high correlation or those closely related variables into same category, but the correlation between different types of variables is low. Thus, each class of variables actually represents a basic structure, i.e., the common factor. For actual problem, the most important is to try to describe each component of the original observation with the sum of the least number of unmeasurable linear functions of the common factors and the special factors. The most critical parameter in factor analysis method is the common factor score, that is, the estimated value of the common factor.

The orthogonal factor model is the most commonly used factor analysis mathematical model, a brief introduction are as follows, suppose there are m correlated observation random variables \(Z_1, Z_2, Z_3, \ldots, Z_m\) and mean value of them is \(\mu_1, \mu_2, \mu_3, \ldots, \mu_m\), with \(p\) independent common factors \(F_1, F_2, F_3, \ldots, F_p\) \((m \geq p)\) and \(m\) special factors \(U_i\) \((i = 1, 2, 3, \ldots, m)\). Each \(Z_i\) can be expressed linearly by \(p\) common factors and their corresponding special factors \(U_i\), as follows,

\[
\begin{align*}
Z_1 - \mu_1 &= a_{11}F_1 + a_{12}F_2 + \cdots + a_{1p}F_p + U_1 \\
Z_2 - \mu_2 &= a_{21}F_1 + a_{22}F_2 + \cdots + a_{2p}F_p + U_2 \\
&\quad \vdots \\
Z_m - \mu_m &= a_{m1}F_1 + a_{m2}F_2 + \cdots + a_{mp}F_p + U_m \\
\end{align*}
\]

(1)

Or it can be written as a matrix,
Which satisfy the following conditions,

(1) \( p \leq m \).

(2) \( \text{COV}(F, U) = 0 \) (means \( F \) is independent of \( U \)).

(3) \( \text{E}(F) = 0, \text{COV}(F) = (1_{p \times p}) \), that is \( F_1, F_2, \ldots, F_p \) is not related, and the variance is 1, the mean value is 0, thus is a normalized vector.

(4) \( \text{E}(U) = 0, \text{COV}(U) = I_m \), that \( U_1, U_2, \ldots, U_p \) is not related, and also a normalized vector.

In formula (2), \( A \) is called factor loading matrix, and its element \( a_{ij} \) represents the loading of the \( i \) variable \( Z_i \) on the \( j \) common factor \( F_j \), which is short for factor loading. If \( Z_i \) is regarded as a vector in \( p \)-dimension factor space, then \( a_{ij} \) represents the projection of \( Z_i \) on the coordinate axis \( F_j \). In factor analysis method, there is a special orthogonal factor analysis model, which is set up specifically for standard variables, namely those random variables whose mean value is 0 and variance is 1. Because the absence of the mean value \( \mu \) compared with formula(2), makes the application conditions of the two models different.

2.2 Tritium concentration features in global Precipitation

The IAEA in collaboration with the world meteorological organization (WMO), has established the Global Network of Isotopes in Precipitation (GNIP) to monitor the concentration of tritium in global Precipitation. The network, which initially collected data from 100 weather stations in 60 countries, has expanded to more than 1,000 sites around the world by now and providing a wealth of data for research. Relevant studies shows that the curve of tritium concentration changes over the years in global atmospheric precipitation has similar characteristics \cite{22-24}. It also shows that there was correlation with the data. In the northern hemisphere, tritium peak in atmospheric precipitation appeared in 1963, and observation data showed that it had a significant latitude effect \cite{22,25}. But in the southern hemisphere, the average concentration of tritium in atmospheric precipitation is two to three orders of magnitude lower than that in the northern hemisphere, and the duration curve is relatively gentle \cite{26}. There are correlations between the concentration of tritium in meteoric precipitation, and the factor analysis method is used to simplify and study the law of tritium concentration in meteoric precipitation by finding common factors.

2.3 The development of factor analysis method used for establish tritium concentration of atmospheric precipitation

Doney first established a global tritium concentration of atmospheric precipitation model from 1960 to 1986 using factor analysis method in 1992 \cite{14}. Based on the correlation between global tritium concentration in atmospheric precipitation data and tritium concentration of latitude effect, Zhang Y H et, al. using the factor analysis method study the tritium concentration data in 1960-2005 that collected from all sites distributed around the world at 50° south to 70° north. Then she extracted two common factors and established a mathematical model of global atmospheric precipitation tritium concentration, which shown in formula (3). The cumulative variance contribution rate of two common factor was 94.99%. The value of two common factor are shown in Table 1 \cite{15}.

\[
Z - \mu = A F + U
\]  

Where: \( b \) is constant, \( f_1 \) and \( f_2 \) is regression coefficients of common factor \( c_p(t, 1) \) and \( c_p(t, 2) \), \( \varepsilon \) is random error.

| year | common factor 1 | common factor 2 | year | common factor 1 | common factor 2 |
|------|----------------|----------------|------|----------------|----------------|
| 1960 | 0.00390        | -0.93470       | 1983 | -0.29454       | -0.35384       |
| 1961 | 0.06080        | 0.34152        | 1984 | -0.22078       | -0.48899       |
| 1962 | 1.97690        | -0.03799       | 1985 | -0.20207       | -0.52399       |
3. Establishing tritium concentration model of precipitation in northeast of Tarim basin

The study area is located in the northeast of Tarim basin (Figure 1). It has a typical arid continental climate. The average annual precipitation is 25mm, and the annual evaporation is 2900mm. The terrain is generally high in the northwest and low in the southeast, with an altitude range of 900 ~ 1800m. The recharge source of groundwater in the study area is mainly the atmospheric precipitation infiltration in the northern mountainous area, and the groundwater flows roughly from the north to the south. There are some structural springs in the central runoff area, and the water overflow throughout the year. The groundwater in this area is finally discharged to the lacustrine alluvial plain in the south. The recharge, runoff and discharge law of groundwater in the study area and the distribution of hydrochemical types are typical characteristics of basin groundwater system[16].

The latitude of the groundwater recharge area of the study area is about 41 ° 20 'N. The atmospheric precipitation isotope observatory closest to the study area in Urumqi station (the latitude is 43 °46 '48 "N) and Zhangye station (the latitude is 38 ° 55' 48" N). In this article, the directly and indirectly method were used to calculated the parameter, and finally the atmospheric precipitation tritium concentration model of the study area was obtained. The calculation process is as follows.

![Figure 1. Sketch map of the study area](image_url)

3.1 The tritium recovery model of Urumqi station and Zhangye station
Using the tritium concentration data of atmospheric precipitation from Urumqi station and Zhangye station and the common factors \( c_p(t, 1) \) and \( c_p(t, 2) \) of the year in which the data located, the parameters \( f_1 \) and \( f_2 \) were obtained by the least square method. Due to the data collected from Urumqi station and Zhangye are the year from 1986 to 2002, lack of 1963 "tritium peak" data, therefore, the result obtained by direct parameter calculation will produce a larger deviation. In order to ensure the accuracy, the Jiao P C's achievements on tritium concentration in atmospheric precipitation in Lop Nur, Xinjiang\(^\text{[17]}\) were adopted, and the data from 1961 to 1966 were taken to participate mode parameter calculation of Urumqi and Zhangye station tritium concentration in atmospheric precipitation. Because "tritium peak" of the world in 1961-1966 are universal, therefore, the geographical location difference between luobubo and Urumqi or Zhangye can be ignored. The Urumqi and Zhangye tritium concentration data required for direct parameter extraction are shown in Table 2. According to the data in Table 2 and the common factors \( c_p(t, 1) \) and \( c_p(t, 2) \), the multivariate linear regression analysis was carried out by using the regression function LINEST in Excel.

Tritium recovery model of Urumqi station is shown in formula (4).

\[
c_p(t) = 196.31 + 417.01 \times c_p(t, 1) + 137.47 \times c_p(t, 2)
\] (4)

Tritium recovery model of Zhangye station is shown in formula (5).

\[
c_p(t) = 216.70 + 412.55 \times c_p(t, 1) + 128.34 \times c_p(t, 2)
\] (5)

The fitting degree of the two equations was 0.99 and both of them passed the F test. The regression equation was significant.

Table 2. Tritium concentration in precipitation of urumqi and Zhangye station\(^\text{[17]}\)

|     | Urumqi  |     | Zhangye |
|-----|---------|-----|---------|
| year | 3H/TU   | year | 3H/TU   |
| 1961 | 212.80  | 1961 | 212.80  |
| 1962 | 892.20  | 1962 | 892.20  |
| 1963 | 2586.20 | 1963 | 2586.20 |
| 1964 | 1372.10 | 1964 | 1372.10 |
| 1965 | 702.00  | 1965 | 702.00  |
| 1966 | 508.90  | 1966 | 508.90  |
| 1986 | 51.24   | 1986 | 100.90  |
| 1987 | 39.65   | 1987 | 69.48   |
| 1988 | 43.38   | 1988 | 71.82   |
| 1989 | 54.73   | 1989 | 74.91   |
| 1990 | 43.33   | 1990 | 48.72   |
| 1991 | 43.65   | 1991 | 74.84   |
| 1992 | 66.90   | 1992 | 88.36   |
| 1996 | 31.91   | 1995 | 83.33   |
| 1997 | 27.66   | 1996 | 54.29   |
| 1998 | 25.18   | 2001 | 66.45   |
| 2001 | 24.99   | 2002 | 40.28   |

Note: the monthly tritium concentration data of IAEA Urumqi station and Zhangye station from 1986 to 2002 were averaged by year in the Table

3.2 Tritium concentration model of meteoric precipitation in northeast Tarim basin

Since the tritium concentration data of atmospheric precipitation have obvious latitude effect\(^\text{[18]}\), based on the latitude relationship between the study area and Urumqi station and Zhangye station, the parameters \( f_1 \) and \( f_2 \) of the study area are obtained by linear interpolation. Then the parameters are substituted into the tritium concentration recovery model and the annual average precipitation tritium concentration recovery model of the study area were obtained, see formula (6).

\[
c_p(t) = 206.53 + 414.77 \times c_p(t, 1) + 132.90 \times c_p(t, 2)
\] (6)

By substituting the common factors \( c_p(t, 1) \) and \( c_p(t, 2) \) in Table 1 into equation (6), the calculated tritium concentration of atmospheric precipitation in the study area from 1960 to 2005 was obtained, as shown in Table 3.
Table 3. Calculated results of Tritium concentration in precipitation of study area

| year | values calculated using model | calculated values after model correction | year | values calculated using model | calculated values after model correction |
|------|-------------------------------|-------------------------------------------|------|-------------------------------|-------------------------------------------|
| 1960 | 83.93                         | 98.70                                     | 1983 | 37.33                         | 50.13                                     |
| 1961 | 277.13                        | 285.89                                    | 1984 | 49.97                         | 63.21                                     |
| 1962 | 1021.44                       | 1027.46                                   | 1985 | 53.08                         | 66.44                                     |
| 1963 | 2471.10                       | 2468.76                                   | 1986 | 55.13                         | 68.78                                     |
| 1964 | 1493.84                       | 1491.97                                   | 1987 | 42.96                         | 56.91                                     |
| 1965 | 695.53                        | 694.16                                    | 1988 | 52.36                         | 66.10                                     |
| 1966 | 411.23                        | 412.21                                    | 1989 | 52.48                         | 66.73                                     |
| 1967 | 303.49                        | 305.49                                    | 1990 | 62.00                         | 76.66                                     |
| 1968 | 235.62                        | 238.39                                    | 1991 | 55.80                         | 70.10                                     |
| 1969 | 194.79                        | 196.61                                    | 1992 | 52.42                         | 66.72                                     |
| 1970 | 157.84                        | 160.93                                    | 1993 | 45.47                         | 59.65                                     |
| 1971 | 142.78                        | 147.88                                    | 1994 | 47.14                         | 61.49                                     |
| 1972 | 120.23                        | 127.82                                    | 1995 | 52.06                         | 66.16                                     |
| 1973 | 93.21                         | 101.94                                    | 1996 | 63.19                         | 77.28                                     |
| 1974 | 118.67                        | 128.00                                    | 1997 | 47.94                         | 62.09                                     |
| 1975 | 126.16                        | 136.55                                    | 1998 | 27.38                         | 41.05                                     |
| 1976 | 98.97                         | 110.06                                    | 1999 | 35.88                         | 50.11                                     |
| 1977 | 98.40                         | 109.88                                    | 2000 | 23.86                         | 37.35                                     |
| 1978 | 111.52                        | 123.24                                    | 2001 | 5.38                          | 18.46                                     |
| 1979 | 79.04                         | 90.95                                     | 2002 | 23.34                         | 37.52                                     |
| 1980 | 69.97                         | 82.85                                     | 2003 | 26.48                         | 40.89                                     |
| 1981 | 71.22                         | 84.17                                     | 2004 | 30.19                         | 44.71                                     |
| 1982 | 48.64                         | 61.45                                     | 2005 | 33.61                         | 48.30                                     |

3.3 Model calibration

During 2000-2009, tritium concentration of summer precipitation in the study area was sampled and tested. Considering the seasonal effect of tritium concentration of atmospheric precipitation, tritium concentration of summer precipitation in the study area was converted into annual mean value (as shown in Table 4) according to the ratio relationship between the summer tritium concentration of atmospheric precipitation in Urumqi monitoring station of IAEA and annual mean value. By comparing with the data in Table 3 and Table 4, it can be seen that the model calculation value is low, which maybe the result of nuclear tests in the 20th century in China. In order to keep the model in accordance with the actual situation, the model were calibrated using the measured data. The method used in model calibrate is still regression function LINEST in Excel. The model after correction see formula (7).

\[ c_p(t) = 217.00 + 412.43 \times c_p(t, 1) + 128.2947353 \times c_p(t, 2) \]  

(7)

The common factors \( c_p(t, 1) \) and \( c_p(t, 2) \) in Table 1 were substituted into equation (7), and the calculated values of tritium concentration of atmospheric precipitation from 1960 to 2005 in the study area after model correction were obtained, as shown in Table 3. Draw the calculated values of the tritium concentration after the model calibrate, the atmospheric tritium concentration data from 1960 to 1996 restored Jiao P C et al., and the measured data of the author into a graph (see Figure 2). The curves were in good agreement with each other, which proved that the recovered tritium concentration value of atmospheric precipitation in the study area was reliable.

Table 4. Average value of Tritium concentration in precipitation of study area from 2000 to 2009

| year | \(^{3}H/\text{TU}\) | year | \(^{3}H/\text{TU}\) |
|------|----------------|------|----------------|
| 2000 | 47.19         | 2005 | 47.27         |
| 2001 | 34.96         | 2006 | 39.71         |
2002 39.93 2007 30.36
2003 42.66 2008 37.12
2004 39.06 2009 32.66

Figure 2. Recovery curve of tritium concentration in precipitation of study area by model

3.4 Discussion of Tritium concentration in atmospheric precipitation from 1960 to 1974

Lin R F studies the tritium concentration in the rock of the Tormu peak glacier in tianshan mountain and the Tosten lake sedimentary rocks in Xinjiang and inferred that due to the influence of local nuclear tests in some areas of Xinjiang, the tritium concentration of atmospheric precipitation not only peaked in 1963, but also in 1967 and 1969. Therefore, the relative relationship of tritium concentration in precipitation between the study area and Ottawa should be considered when establishing the process line of tritium concentration in the precipitation of Xinjiang, as well as the influence of local nuclear tests and the elevation effect of the tritium concentration in the precipitation [19~20]. Because the model used in this paper unable take into account the effect of nuclear test in China, by using the Lin R F’s results the author modified the tritium concentration value of atmospheric precipitation from 1960 to 1974 calculated by the model (Table 5). The tritium concentration after 1974 calculated by the model was consistent with that calculated by Lin R F.

Table 5. Tritium concentration in precipitation of study area from 1960 to 1974 [19~20]

| year | 3H/TU   | year | 3H/TU   |
|------|---------|------|---------|
| 1960 | 235.00  | 1968 | 1958.75 |
| 1961 | 312.50  | 1969 | 3118.75 |
| 1962 | 1506.25 | 1970 | 1193.75 |
| 1963 | 4400.00 | 1971 | 700.00  |
| 1964 | 2337.50 | 1972 | 235.00  |
| 1965 | 1175.00 | 1973 | 165.00  |
| 1966 | 843.75  | 1974 | 165.00  |
| 1967 | 2793.75 |

4. Model verification

4.1 Mathematical model of tritium dating

Using the method of centralized parameter model, the tritium age of groundwater in the study area can be calculated. Given an input function, the theoretical output value was calculated by use the transfer function.

$$C_{\text{out}} = \int_0^\infty C_{\text{in}} (t - \tau) \cdot g(\tau) \cdot e^{-\lambda \tau} d\tau$$

(8)
Where $C_{out}$ is concentration of tritium in groundwater, $C_{in}$ is concentration of tritium in atmospheric precipitation, $g(\tau)$ is system response function, or age distribution function of water within the system, $t$ is time series for tritium output, $\tau$ is tritium stays time in groundwater, $\lambda$ is decay constant of tritium. 

According to the difference of system response function, the mathematical model of tritium dating can be divided into piston flow model, exponential model, exponential - piston flow model and dispersion model. Due to the low degree of hydrogeological research of the study area and lack of hydrogeological, the tritium age was calculated by using the piston flow model and exponential model which only a few parameters are required.

1) piston flow model

The model describes a non-mixed system, in which the tracer moves downstream in a piston type, and the output concentration depends only on the radioactive decay of the input concentration. $\tau$ is the only parameter of the model, and if given this parameter, the output concentration can be calculated. The system response function is $g(\tau) = \delta(t-\tau)$, where $\delta$ is Dirac function. The output relation of tracer is shown in formula (9)

$$C_{out} = C_{in}(t - \tau) \cdot e^{-\lambda \tau} \quad (9)$$

2) exponential model, also known as fully mixed model

It is assumed that the water of different ages in the groundwater system reaches uniform mixing at any time, and the isotope concentration output at any time is equal to the average isotope concentration of the groundwater in the groundwater system at that time. System response function is $g(\tau) = (1/\tau_m) \cdot e^{-\tau/\tau_m}$, where $\tau_m$ is tracer average residence time. The output relation of tracer is:

$$C_{out} = \int_0^{\infty} C_{in}(t - \tau) \cdot \left(\frac{1}{\tau_m}\right) \cdot e^{-t(\frac{1}{\tau_m} + \lambda)} \, d\tau \quad (10)$$

This model can be rewritten as the sum of the two parts before and after 1952. Since tritium in atmospheric precipitation before 1952 is less than 10 TU(tritium units), which is the natural background value of tritium. As the calculation result is very small, usually within the range of measurement error, so it can be ignored. Therefore, in general, formula (10) can be simplified to formula (11)

$$C_{out} = \int_0^{1952} C_{in}(t - \tau) \cdot \left(\frac{1}{\tau_m}\right) \cdot e^{-t(\frac{1}{\tau_m} + \lambda)} \, d\tau \quad (11)$$

### 4.2 Groundwater tritium age calculation

The hydrogeological conditions in the study area are relatively simple. The groundwater supply comes from the infiltration of atmospheric precipitation, and there is no lateral recharge and artificial exploitation around the area, thus the groundwater system is in a natural state. Due to the low degree of hydrogeological early research in the study area, many parameters are unknown. Therefore, this paper simplifies the calculation and generalizes it into a single input and single output system. It is assumed that the groundwater input is equal to the output in the calculation. Then, the tritium age of groundwater was calculated by using the tritium dating model. The tritium concentration of atmospheric precipitation from 1952 to 1959 in the input value sequence quoted the data published by Jiao P C in 2004[19], and the rest used the results of this study. Equations (9) and (11) are programmed and calculated in MATLAB software, which can give a concentration-time curve. The tritium output value of the piston flow model was shown in Figure 3-a. The tritium output value of the full-mixed model was shown in Figure 3-b with the year 2009 as the "zero" year and take $\tau_m=1-1000a$. The tritium age of 4 groundwater samples in the study area was calculated by using the established model and tritium concentration output curve, and the calculation results are shown in Table 6. Because the piston flow model and the full mixing model are two extreme situations of groundwater mixing, so the retention time of groundwater should be between the two.
Figure 3. Curve of output data by tritium piston and tritium mixed flow model

Table 6. The tritium age results of groundwater in study area

| Samples number | Samples type  | \(^3\text{H}/\text{TU}\) Result calculated by piston flow model /year | Result calculated by exponential model /year |
|----------------|---------------|---------------------------------------------------------------|---------------------------------------------|
| S1             | Spring sample | 32.30                                                          | 3-48                                        |
| S2             | Borehole sample | 25.20                                                        | 9-52                                        |
| S3             | Borehole sample | 8.70                                                          | -                                           |
| S4             | Spring sample | 3.90                                                          | -                                           |

4.3 The rationality analysis of calculation results

Among the tritium concentration data of the 4 underground water samples, the tritium concentration of S1 and S2 water samples is relatively high, which is determined by the characteristics of atmospheric precipitation recharge at the locations of S1 and S2 (see Figure 4). The point where S1 located is a natural water source, and the groundwater circulation rate is relatively fast, which is greatly affected by the direct infiltration of atmospheric precipitation. While the dynamic monitoring results of water level in the borehole at position S2 show that the water level rise and fall of the borehole are correlated with rainfall events, indicating that atmospheric precipitation infiltration has a certain impact on the aquifer at position S2. Therefore, the concentration of tritium in groundwater at the sampling points S1 and S2 is relatively high. For the sample S3 and S4, the location of them is far away from the meteoric precipitation area, and their TDS can reach 20456 mg/L and the runoff speed is slow \[^{16,21}\]. Therefore, it can be considered that S3 and S4 have a strong mixing effect in the runoff process, so the tritium age of these two water samples is calculated using the full mixing model. It can be seen from Table 6 that the age of sample S1 and S2 are 1 ~ 48 years and 3 ~ 70 years respectively, which means the groundwater age is relatively new. The age of sample S3 and S4 are 291 years and 695 years respectively, indicating that the groundwater runoff speed in the central and southern part of the study area was relatively slow. According to the preliminary estimation of the groundwater age, the average groundwater flow rate in the study area was 50 ~ 100 m/a. Based on the calculation of tritium age of the above four water samples and the rationality analysis of the results, it is concluded that the tritium age of groundwater obtained conforms to the hydrogeological conditions of the region.
5. Conclusions

(1) By using the factor analysis method, the tritium concentration model of meteoric precipitation in northeast Tarim basin was established, and was corrected with the measured data of recent years in the study area. The results calculated using model after correction is consistent with measured data and the predecessors' research results. Considering the influence of nuclear test on the tritium concentration in atmospheric precipitation in the study area, the tritium concentration in atmospheric precipitation from 1960 to 1974 calculated by Lin R F were adopted, and the tritium concentrations in atmospheric precipitation of Tarim basin were finally obtained. The method in this paper can be used in areas where monitoring data are relatively scarce, and a relatively reliable tritium concentration in atmospheric precipitation can be obtained from little measured data.

(2) Based on the piston flow model and the fully mixed model of tritium dating, and taking tritium concentration value of atmospheric precipitation recovered in this paper as the model input value, the tritium age of 4 underground water samples in the study area was calculated. The results show that the groundwater age near the recharge area in the north is within a range of several years to several decades, and the groundwater age toward the south is gradually aging, about 291 and 695 years respectively, indicating that the groundwater runoff speed in the study area is relatively slow, which is consistent with the previous research results of the region's hydrochemistry. Therefore, the tritium age of groundwater calculated by the model is in line with the hydrogeological conditions of this region, which also proves that the tritium concentration of atmospheric precipitation recovered in this paper is reasonable. The results can be used as a reference for the calculation of tritium age of groundwater in the northeast Tarim basin in the future.

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