Asian Agricultural Research 2016, 8(6): 75 – 79, 86

# Evaluation on Potential Ecological Risk of Heavy Metals in Soil from Penglai Fairyland Park

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**Abstract** This study aims at evaluating the heavy metals pollution in soil collected from Penglai Fairyland Park in Guiyang, and predicting the harm of heavy metals to human health. Based on the background value of soil in Guizhou and *Soil Environment Quality Standard* (GB15618 – 1995), by using the geoaccumulation index method and Hakanson potential ecological risk assessment method, we research pollution characteristics and ecological risk of heavy metals in soil from the study area. The results show that from the index of geoaccumulation, the pollution level of heavy metals in agricultural soil from Penglai Fairyland Park is in the order of Ni > Cu > Hg > Cd > As > Zn > Cr > Pb. From the potential ecological harm index evaluation, soil is at slight ecological risk level in the park and the potential ecological hazard degree is in the order of Hg > Cd > Ni > As > Cu > Cr > Pb > Zn. The soil ecological environment in research area is only mildly damaged. Thus, the soil in research area is at the level of security, and it is suitable for cultivation of crops and less harmful to human health.

**Key words** Soil, Heavy metals, Ecological damage, Evaluation

## 1 Introduction

Soil is the means of production for human survival and development, and is also one of the most important natural resources in human society[1]. Among all the pollutants in the soil, the heavy metal brings the greatest harm to human body, and heavy metal pollution of the soil has captured more and more attention of scholars at home and abroad[2-6]. Heavy metal is a kind of important pollutant with potential hazards, and it is hidden and irreversible[7]. It can lead to human cancer and chronic toxicity, mutagenicity and teratogenicity. Heavy metals can enter the food chain[8-9] through the water-soil-crop ecosystem. The heavy metals in the soil can be absorbed by plants and can not be degraded by biological degradation. When the heavy metal content is too high, it will affect the normal growth, development and reproduction and other physiological activities of the plant[10-11]. In order to understand the pollution situation of heavy metals in soil, it is necessary to predict the harm of heavy metals to human health and the impact on the ecosystem. This paper takes the soil from Penglai Fairyland Park in Baiyun District of Guiyang City as the research object, and based on the soil background value of Guizhou Province and *Soil Environment Quality Standard* (GB15618 – 1995), this paper analyzes the content of 8 kinds of heavy metals in the soil from Penglai Fairyland Park, and uses the method of accumulation index and potential ecological risk index to evaluate and analyze. It aims to provide scientific basis for the safe use of soil and the safety of agricultural products in the park.

Received: March 14, 2016 Accepted: May 25, 2016

Supported by Agricultural Science and Technology Achievement Transformation Fund Project of the Ministry of Science and Technology (2013F-2001007); Project of Edible Fungus Engineering Center of Guizhou Province (G20144002); Guiyang Science and Technology Project (201410014); Project of Baiyun District Science and Technology Bureau (201419).

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## 2 Materials and methods

**2.1 Soil sampling** Global positioning system (GPS) is used for the positioning of soil sampling points in Penglai Fairyland Park of Baiyun District, and the quincunx sampling method is used for collecting 1 kg of soil samples (0 – 20cm) in sampling bag. After the soil samples are brought back to the lab, soil samples are cooled and put on white paper for indoor natural air drying. Then some stones and residual plant roots are removed to retain about 200 g. The air dried soil sample is ground and sifted with a mortar and 100 nylon mesh, then it is packaged for later use.

**2.2 Sample handling and monitoring** The total amount of Pb, Cr, Cd, Cu, Zn, Ni elements is digested by $HNO_3 - HClO_4 - HF$ wet method, Hg, As as elements with 1:1 aqua regia digestion. Heavy metal Cd is determined by atomic absorption spectrometry and graphite furnace method. Zn, Cu and Ni are determined by atomic absorption spectrometry. Hg is determined by Atomic Fluorescence Spectrometry, and Pb, Cr and As are determined by inductively coupled plasma atomic emission spectrometry. All reagents are GR, and ultra pure water is used for water analysis in determination process. The samples include blank sample, and the second parallel samples, coupled with national soil standard reference material in accordance with GBW – 070010 and GBW – 07430 quality control. The relative deviation of second parallel kind is less than 5%, the samples with the recovery are in 96.4% – 115.1% and standard sample determination results are within the allowable error range. EXCEL software and SPSS18 software are used for analysis and processing.

## 2.3 Evaluation methods

**2.3.1** Cumulative pollution index method. Land accumulation index method is an environmental assessment method widely used in the assessment of heavy metal pollution in soil or sediment[12-15], proposed by scientist Muller from Sediment Research Institute of German University of Heidelberg in 1969. The method not only reflects the characteristics of natural changes in the distribution of heavy metals, but also intuitively reflects the exogenous heavy metals in the sediment concentration. The formula is as follows:

$$I_{geo} = \log_2\left[\frac{C_j}{1.5 \cdot BE_j}\right]$$

where $I_{geo}$ represents the value of element $j$ in the product; $BE_j$ represents the background concentration of element $j$; $C_j$ represents the measured value of element $j$ in the sample; 1.5 is modified exponential, which takes into account element background values change caused by diagenesis and human activities[16].

**Table 1 The evaluation criterion classification of geoaccumulation index**

| Grade | Geoaccumulation index | Class of pollution |
|---|---|---|
| 0 | $I_{geo} < 0$ | Non-pollution |
| 1 | $0 \leq I_{geo} < 1$ | Slight pollution |
| 2 | $1 \leq I_{geo} < 2$ | Moderate pollution |
| 3 | $2 \leq I_{geo} < 3$ | Moderate to heavy pollution |
| 4 | $3 \leq I_{geo} < 4$ | Heavy pollution |
| 5 | $4 \leq I_{geo} < 5$ | Heavy to extreme pollution |
| 6 | $I_{geo} \geq 5$ | Extreme pollution |

Geoaccumulation index has the advantages of comprehensive consideration of the sedimentary rock and other natural geological processes and human activities, and geochemical background values will have a greater impact on the geological accumulation index[17]. Integrated pollution index method is used for embedding Igeo. Based on the index of Geoaccumulation advantages, combined with the geological structure features of Penglai Fairyland Park, Nemerow comprehensive pollution index formula and cumulative index are used to replace the single factor index. The embedded formula of the comprehensive pollution index of Geoaccumulation ($I_{geo}$) is as follows:

$$P_j = \sqrt{\frac{(I_{max})^2 + (I_{ave})^2}{2}}$$

where $P_j$ represents the comprehensive pollution index of element $j$; $I_{\max}$ indicates the maximum value of the ground accumulation index; $I_{\text{ave}}$ indicates the average value of the cumulative index. The integrated pollution index of the embedded $I_{geo}$ is shown in Table 2.

**Table 2 The evaluation criterion classification of embedded $I_{geo}$ composite index**

| Grade | Embedded $I_{geo}$ comprehensive pollution index | Class of pollution |
|---|---|---|
| 0 | $P_j < 0$ | Non-pollution |
| 1 | $0 \leq P_j < 0.5$ | Slight pollution |
| 2 | $0.5 \leq P_j < 1$ | Mild to moderate pollution |
| 3 | $1 \leq P_j < 2$ | Moderate pollution |
| 4 | $2 \leq P_j < 3$ | Moderate to heavy pollution |
| 5 | $3 \leq P_j < 4$ | Heavy pollution |
| 6 | $4 \leq P_j < 5$ | Heavy to extreme pollution |
| 7 | $P_j \geq 5$ | Extreme pollution |

**2.3.2** Hakanson potential ecological risk assessment method. Swedish scholar Lars Hakanson's potential ecological risk index is used to evaluate heavy metal potential ecological hazard in soil from Penglai Fairyland Park. The potential ecological risk index reflects the heavy metal content, species, toxic level and the sensitivity to heavy metal pollution in the soil of the cultivated layer.

$$Er^i = T_f^i \times C_f^i \quad (1)$$

where $Er^i$ is the potential ecological risk coefficient in the soil of a certain region; $Tf^i$ is the toxic coefficient of heavy metal $i$, which reflects the level of toxicity and the sensitivity of biological to the pollution.

$$R_j = \sum_{i=1}^{n} Er^i \quad (2)$$

where $R_j$ is a potential ecological risk factor for a variety of heavy metals in sediment.

The potential ecological hazard classification standards of $Er^i$ and $R_j$ are shown in Table 3, and the toxicity coefficient of heavy metal in soil is shown in Table 4.

**Table 3 Classification standard of potential ecological risk of heavy metals in soils**

| Potential ecological risk | Light | Moderate | A bit strong | Very strong | Extremely strong |
|---|---|---|---|---|---|
| $Er^i$ | <40 | 40-80 | 80-160 | 160-320 | >320 |
| $R_j$ | <150 | 150-300 | 300-600 | 600-1200 | >1200 |

**Table 4 Coefficient of heavy metal toxicity in soil**

| | Pb | Cd | Cr | Cu | Zn | Hg | As | Ni |
|---|---|---|---|---|---|---|---|---|
| Toxicity Coefficient $Tr^i$ [18] | 5 | 30 | 2 | 5 | 1 | 40 | 10 | 5 |

# 3 Results and discussions

**3.1 Soil heavy metal content** The content of heavy metals in the soil from Penglai Fairyland Park is shown in Table 5. Table 5 shows that the average content of Cu, Hg, Ni is slightly higher than that of Guizhou's soil background value, while the average content of the remaining heavy metals is lower than that of the background value. The average values of Cu, Hg and Ni are 2.82, 3.82 and 2.05, respectively, and the average content is in the order of Hg > Cd Cu > Cr > Ni > Zn > Pb > As > Hg > Cd. It shows that the content of Cu, Hg and Ni in the soil of this area has been affected by human activities.

**Table 5 The content of heavy metals in soil from Penglai Fairyland Park (mg/kg)**

| Heavy Metals | Range | Average value | Standard deviation | Coefficient of variation | Soil background values in Guizhou Province[19] | Multiple of mean value | Exceeding standard rate//% |
|---|---|---|---|---|---|---|---|
| Pb | 11.05 – 35.09 | 30.66 | 6.94 | 22.64 | 35.20 | 0 | 0 |
| Cd | 0.12 – 0.63 | 0.37 | 0.17 | 45.95 | 0.66 | 0 | 0 |
| Cr | 48.25 – 96.90 | 84.42 | 12.21 | 14.46 | 95.90 | 0 | 0 |
| Hg | 0.26 – 0.49 | 0.42 | 0.07 | 16.67 | 0.11 | 3.82 | 100 |
| As | 12.63 – 19.59 | 16.30 | 2.20 | 13.50 | 20.00 | 0 | 0 |
| Cu | 75.80 – 99.70 | 90.08 | 6.80 | 7.55 | 32.00 | 2.82 | 100 |
| Zn | 34.47 – 98.09 | 73.78 | 18.40 | 24.94 | 99.50 | 0 | 0 |
| Ni | 54.48 – 96.96 | 80.04 | 12.94 | 16.17 | 39.10 | 2.05 | 100 |

**3.2 Correlation of heavy metal content in soil** From Table 6, we can see that the correlation coefficient of Zn and Cd is 0.433, there is a very significant positive correlation; the correlation coefficient of Zn and Cr, Cu is 0.443, and there is a significant positive correlation at 5% level; the correlation coefficients of Ni and Cr and Zn are 0.424 and 0.428, respectively, and there is a significant positive correlation at the 5% level. The results show that Zn, Cr, Cd, Cu, Ni in the park soil may have the same source of pollution, and have similar geochemical behavior.

**Table 6 The correlation matrix of heavy metal content in soil from Penglai Fairyland Park** mg/kg

| | pH | Pb | Cd | Cr | Hg | As | Cu | Zn | Ni |
|---|---|---|---|---|---|---|---|---|---|
| pH | 1 | | | | | | | | |
| Pb | –0.109 | 1 | | | | | | | |
| Cd | .0.620** | –0.371 | 1 | | | | | | |
| Cr | –0.199 | –0.231 | 0.095 | 1 | | | | | |
| Hg | –0.307 | –0.157 | 0.007 | –0.182 | 1 | | | | |
| As | –0.028 | 0.330 | –0.188 | –0.395 | 0.305 | 1 | | | |
| Cu | –0.076 | –0.090 | 0.345 | 0.214 | –0.035 | –0.248 | 1 | | |
| Zn | 0.119 | –0.415 | 0.433* | 0.443* | 0.164 | –0.033 | .0.443* | 1 | |
| Ni | 0.311 | 0.018 | –0.031 | 0.424* | –0.297 | –0.221 | 0.072 | 0.428* | 1 |

Note: ** $p < 0.01$, * $p < 0.05$.

**3.3 Principal component analysis of heavy metal elements in soil** Principal component analysis (PCA) can be used to determine the source of trace elements in soil[20–21]. Principal component analysis is performed on heavy metal element content in soil, and multiple factors can be selected from correlation factors, so as to provide a basis[22].

**Table 7 The decomposition of total variance for heavy metals in soil**

| Principal component factor | Initial eigenvalue and contribution rate | | |
|---|---|---|---|
| | Total characteristic value | Contribution rate//% | Cumulative contribution rate//% |
| 1 | 2.600 | 32.501 | 32.501 |
| 2 | 1.589 | 19.865 | 52.366 |
| 3 | 1.113 | 13.914 | 66.281 |
| 4 | 0.955 | 11.939 | 78.219 |
| 5 | 0.697 | 8.709 | 86.928 |
| 6 | 0.479 | 5.984 | 92.912 |
| 7 | 0.414 | 5.178 | 98.090 |
| 8 | 0.153 | 1.910 | 100.000 |

Table 7 shows that the total variance value of first three principal components accounts for 66.281% of cumulative contribution rate, and the first three principal components have the feature information of 8 kinds of heavy metals contained in the soil. The first principal component includes 32.501% of general information; the second principal component contains 19.865% of general information; the third principal component contains 13.914% of general information. So, we choose the first three factors as the main components, to represent the 8 kinds of heavy metals in the soil characteristic index. Based on the principal component analysis principle, the load value is a reflection of the principal component and variable correlation coefficient of heavy metal elements in the soil. The greater the load value, the stronger the correlation between the variable and the principal component. The element is the main component of the important characteristic index[23]. The principal component matrix of soil heavy metal content is shown in Table 8.

**Table 8 The matrix of principal component loading for heavy metals in soil**

| Principal component factors | Pb | Cd | Cr | Hg | As | Cu | Zn | Ni |
|---|---|---|---|---|---|---|---|---|
| First principal component | −0.555 | 0.556 | 0.691 | −0.154 | −0.553 | 0.569 | 0.774 | 0.503 |
| Second principal component | −0.414 | 0.456 | −0.334 | 0.747 | 0.349 | 0.175 | 0.299 | −0.546 |
| Third principal component | 0.294 | −0.283 | 0.166 | 0.316 | 0.597 | −0.045 | 0.467 | 0.494 |

Table 8 shows Cd, Cr, Cu load, and Zn, Ni value in 8 kinds of heavy metal elements, and this indicates that the sources of 5 kinds of heavy metals are similar. By the variation coefficient of Cd, Zn in Table 5, we can see that the source is not stable, and may be influenced by people. Zn also can be used as identification element of traffic pollution, and the first principal component is mainly human activity and traffic pollution. Cd and Hg load is highest in 8 kinds of heavy metal elements of the second principal components, and it indicates that the sources of 2 kinds of heavy metals are similar, the variation coefficient of Hg is higher, and Guizhou is a typical karst province, affected by the topography and soil factors[24]. The background values of heavy metals in soil are generally high. The second principal components may be subject to a combined effect of soil parent material and human activities. As, Zn, Ni load value is largest in 8 principal components of the third heavy metal elements, and it indicates that the sources of 3 kinds of heavy metals are similar, probably from soil parent material, less affected by human activities. It can be seen that the result of principal component analysis and correlation analysis are consistent.

**Table 9 The geoaccumulation index value of heavy metals in soil**

| Detection itemorder | Evaluation index range | Number of test points | Geo-accumulation index $I_{geo}$: $I_{geo}<0$ Non-pollution | | $0\leqslant I_{geo}<1$ Slight pollution | | $1\leqslant I_{geo}<2$ Moderate pollution | | $2\leqslant I_{geo}<3$ Moderate to heavy pollution | | $3\leqslant I_{geo}<4$ Heavy pollution | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Number | Percentage % | Number | Percentage % | Number | Percentage % | Number | Percentage % | Number | Percentage % |
| Pb | −5.08 − −3.42 | 22 | 22 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cd | −1.91 −0.49 | | 15 | 68.18 | 7 | 31.82 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cr | −2.96 − −1.95 | | 22 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Hg | −0.79 −0.12 | | 12 | 54.55 | 10 | 45.45 | 0 | 0 | 0 | 0 | 0 | 0 |
| As | −1.83 − −1.20 | | 22 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cu | 0.01 −0.41 | | 0 | 0 | 22 | 100 | 0 | 0 | 0 | 0 | 0 | 0 |
| Zn | −3.12 − −1.61 | | 22 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Ni | −0.14 −0.69 | | 1 | 4.55 | 21 | 95.45 | 0 | 0 | 0 | 0 | 0 | 0 |
| $P_j$ Integrated pollution index of embedded $I_{geo}$ | | Number of test points | $P_j<0$ (non-pollution) | | $0\leqslant P_j<0.5$ (Slight pollution) | | $0.5\leqslant P_j<1$ (Mild to moderate pollution) | | $1\leqslant P_j<2$ (Moderate pollution) | | $2\leqslant P_j<3$ (Moderate to heavy pollution) | |
| | | | Number | Percentage % | Number | Percentage % | Number | Percentage % | Number | Percentage % | Number | Percentage % |
| | | 22 | 0 | 0 | 0 | 0 | 19 | 86.36 | 3 | 13.64 | 0 | 0 |

The pollution status of heavy metals in the park is evaluated by using Geoaccumulation index method. We consider the sedimentary rock natural geological process and human activities, such as the influence of various factors on the soil environment. As an important parameter to measure the degree of the impact of human activities, the cumulative index can comprehensively reflect the natural characteristics of the soil heavy metals and the impact of human activities on the soil environment[25-26]. The calculation results are shown in Table 9. Geoaccumulation index calculation results show that soil Cu accumulation index is 0.01 − 0.41, which belongs to the light pollution; soil Cd accumulation index is −1.91 −0.49, which belongs to non-pollution to light pollution; soil Hg accumulation index is −0.79 − 0.12, which belongs to non-pollution to light pollution; soil Ni accumulation index is −0.14 −0.69, which belongs to non-pollution to the light pollution; soil Pb, Cr, as, Hg, Zn accumulation index is less than 0, belonging to non-pollution. Thus, there is light pollution or no pollution in the soil of Penglai Fairyland Park, and the pollution index of eight kinds of soil heavy metal is in the order of Ni > Cu > Cd > Hg > As > Zn > Cr > Pb.

**3.4 Potential ecological risk assessment of heavy metals in soils** One of the commonly used methods in the study of soil heavy metals is the quantitative classification of the possible ecological damage degree of heavy metal elements[27]. Using potential ecological risk index method, we use the toxicity analysis of heavy metal elements in soil and sediment migration transformation rule analysis in order to make the evaluation, excluding the effects of regional differences, which can indicate that the heavy metals have potential harm to ecological environment[28]. It can be seen from Table 10 that the value of Pb, Cd, Cr, Cu, Zn, Hg, As, Ni and $Er^i$ is less than 40, and the ecological risk is slight. From the composite ecological risk hazard index evaluation, the hazard index is less than 150, and the degree of ecological harm is relatively slight. The potential ecological harm degree is in the order of

Hg > Cd > Ni > As > Cu > Cr > Pb > Zn. Based on potential ecological harm evaluation results, using cumulative index method, it is found that the heavy metals in agricultural soil from Penglai Fairyland Park are in the state of non-pollution to light pollution, and the accumulation pollution index size is in the order of Ni > Cu > Hg > Cd > As > Zn > Cr > Pb. Potential ecological hazard index evaluation shows that the park soil is at the level of slight ecological damage, and the potential ecological harm degree is in the order of Hg > Cd > Ni > As > Cu > Cr > Pb > Zn. The cumulative index method and the potential ecological risk index method show that the soil is mainly affected by Cd, Cu, Ni, Hg, and the factor analysis method is also used in the 22 sampling points. Potential ecological risk index method not only considers the types of heavy metal elements in terms of the synergistic effect, heavy metal toxicity, pollution concentration, but also considers the ecological environment's sensitivity to heavy metals, to make up for the defects of accumulation index method. Therefore, the concentration of heavy metals in the soil should be combined with its potential ecological risk index, in order to better evaluate the extent of heavy metal pollution in the soil[29].

**Table 10 Indexes of single factor potential ecological risk ($Er^i$) and compound ecological risk of heavy metals($R_j$) in soil**

| Detection itemorder | Evaluation index range | Number of test points | Single element potential ecological risk factor $E_r^i$: $E_r^i<40$ (Slight ecological harm) | | $40 \leqslant E_r^i < 80$ (Moderate ecological risk) | | $80 \leqslant E_r^i < 160$ (Strong ecological hazard) | | $160 \leqslant E_r^i < 320$ (Stronger ecological hazard) | | $E_r^i > 320$ (Extremely strong ecological hazard) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Number | Percentage % | Number | Percentage % | Number | Percentage % | Number | Percentage % | Number | Percentage % |
| Pb | 0.20 – 0.60 | 22 | 22 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cd | 6.00 – 31.50 | | 22 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cr | 0.48 – 0.97 | | 22 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Hg | 20.80 – 39.20 | | 22 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| As | 4.21 – 6.53 | | 22 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cu | 3.80 – 5.00 | | 22 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Zn | 0.14 – 0.39 | | 22 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Ni | 5.45 – 9.70 | | 22 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| *RI* (Potential ecological risk index) | Number of test points | *RI* < 150 (Slight ecological harm) | | 150 ≤ *RI* < 300 (Moderate ecological risk) | | 300 ≤ *RI* < 600 (Strong ecological hazard) | | *RI* ≥ 600 (Strong ecological hazard) | |
|---|---|---|---|---|---|---|---|---|---|
| | | Number | Percentage % | Number | Percentage % | Number | Percentage % | Number | Percentage % |
| | 22 | 22 | 100 | 0 | 0 | 0 | 0 | 0 | 0 |

## 4 Conclusions

(i) The heavy metals, Cu, Hg, Ni in soil from Penglai Fairyland Park have greater value than Guizhou's soil background value in varying degrees, and the pollution level is in the order of Cu > Cr > Ni > Zn > Pb > As > Hg > Cd. (ii) Factor analysis results show that Cd, Cu, Ni, Zn, Cr pollution mainly comes from human activities and traffic pollution, Hg pollution comes mainly from soil parent material and human activities, and As, Zn, Ni are from a natural source, less affected by human. (iii) The cumulative pollution index shows that the heavy metals in agricultural soil from Penglai Fairyland Park are in the state of non-pollution to light pollution, and the accumulation pollution index size is in the order of Ni > Cu > Hg > Cd > As > Zn > Cr > Pb. (iv) The assessment of potential ecological risk index shows that the soil in the park is at the level of slight ecological harm, and the potential ecological harm degree is in the order of Hg > Cd > Ni > As > Cu > Cr > Pb > Zn.

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respectively, that is, the water consumption due to soil evaporation and crop transpiration accounted for 46.4% and 24.1% of total irrigation water and precipitation, respectively, and leakage accounted for 30.3% and 60.6%, respectively. The annual irrigation water loss in GT – TR1 and GT – TR2 of Guanting irrigation area in 2013 was also simulated. Results show that the annual actual evapotranspiration in GT – TR1 and GT – TR2 of Guanting irrigation area was 632.6 mm and 646.9 mm, respectively, and leakage was only 14.9 mm and 6.7 mm, respectively, that is, leakage accounted for 2.6% and 1.2% of total irrigation water and precipitation, respectively, indicating that the leakage was very weak. RMSE of the simulation results of the groundwater depth in Daxia irrigation area during the two periods was 92.3 mm and 27.7 mm, respectively. And RMSE of the simulation results of the moisture content of soil profile in the two monitoring sites of Guanting irrigation area was 2.04% and 5.81%, respectively, indicating that the simulation results were reliable.

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