Influence of Climate Change and Anthropogenic Activities on Groundwater Level in the Northern Huangqihai Basin, China

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**Influence of climate change and anthropogenic activities on groundwater
level in the northern Huangqihai basin, China**

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Abstract: The variation in the groundwater level, which is an indicative factor that can reflect changes in both groundwater level and groundwater quantity, was selected as the factor to be analyzed. Rainfall and groundwater exploitation were chosen as the representative factors of climate change and anthropogenic activities, respectively. By applying the elastic coefficient method and other mathematical statistical methods, the influence of climate change and anthropogenic activities on groundwater was analyzed qualitatively and quantitatively. The northern Huangqihai basin was chosen as the study area. The rainfall in the study area showed an increasing trend from 1996-2020, while most variations in groundwater level were negative. This result indicated that the positive influence of rainfall on the variation in the groundwater level in the study area was not enough to offset the negative influence of groundwater exploitation. The correlation between anthropogenic activities and variations in the groundwater level was lower in wet years than in normal years but the highest in dry years. Based on the comparative method of the slope changing ratio of cumulative quantity and the elastic coefficient method, it was determined that the contribution rate of climate change to the variation in groundwater level was 22.08% and that of human activities was 77.92%. Thus, the sustainable development of the groundwater environment can be realized by positively guiding anthropogenic activities and minimizing negative influences.

Keywords: Variation in groundwater level; Quantitative assessment; Climate change; Anthropogenic activities; Northern Huangqihai basin.

Introduction

Groundwater is an important resource for human survival and development, especially in the arid and semiarid areas of Northwest China, where water resources are scarce and the ecological environment is sensitive and fragile (Wang et al. 2020; Wu et al. 2019, 2020; Ren et al. 2021; Wei et al. 2021). In the past 100 years, the increase in temperature and rainfall variability, as well as changes in natural environment, has changed the quantity, quality and spatiotemporal distribution of groundwater resources (Li et al., 2019; Cui et al., 2020). Simultaneously, the interference of anthropogenic activities on groundwater has increased (Acharyya and Achiransu 2014; Yihdego et al., 2017b; Li et al., 2018b; He and Wu 2019a; He and Li 2020; Khan et al., 2020), which has changed the evolution of the groundwater environment from a single naturally driven model to a dual naturally-artificially driven mode (Wang et al., 2006). Quantitative research on the influence of climate change and anthropogenic activities on groundwater is a hot but challenging topic in the field of hydrology and water resources (Wang et al., 2011; Li 2014; Li et al., 2018b), and is of great significance for protecting groundwater resources and promoting the sustainable development of the groundwater environment.

Previous studies on the influence of climate change and anthropogenic activities on the groundwater level have mainly focused on qualitative analyses (Liao et al., 2014; Shi et al., 2014; Jin et al., 2020), while the quantitative analyses in this field have been based on mathematical statistics methods and simulation model (Su et al. 2020). Some researchers (Hotta et al., 2010; Kearns et al., 2015; Wilopo et al., 2021) have analyzed the influence of urbanization and groundwater exploitation on groundwater level by using mathematical statistical methods, such as correlation analysis and wavelet coherence analysis. Malaka et al. (2021) considered groundwater exploitation as the dominant factor in groundwater level change based on mathematical statistical methods. By applying multivariate linear regression analysis, Yihdego et al. (2017a) concluded that the rise in the groundwater level in coastal areas of New South Wales was caused by a long-term cumulative land-use change. Wei et al. (2016) used the bidirectional regression mutation analysis method to analyze the response relationship between a decrease in the groundwater level and the irrigation area in the Jiansanjiang region of Heilongjiang Province. The Mann-Kendall ($M-K$) test is commonly utilized to evaluate the influence of climate change and anthropogenic activities on changes in groundwater depth (Zhu et al., 2017; Cui et al., 2020). Gemitzi and Stefanopoulos (2011) applied the autoregressive integrated moving average

(ARIMA) model based on abundant basic data to analyze the influence of irrigation and rainfall on the groundwater level. He and Wu (2019b) and He et al. (2020) investigated the relationship between land use/land cover and groundwater quality, and concluded that the change in land use/land cover was an indicator representing integrated human activities and that its impact on groundwater can be quantified using the curved streamline searchlight shaped model. Fei et al. (2009) considered that groundwater exploitation played an important role in the decrease in groundwater level through correlation analysis.

From the perspective of hydrogeology, the variation in groundwater level is an intuitive indicator of not only the change in groundwater level but also the change in groundwater storage, as shown in Eq. (1) (China Geological Survey 2018).

$$\Delta Q = \mu \times F \times \frac{\bar{W}}{\Delta t} \quad (1)$$

where ΔQ is the variation in groundwater storage (m^3), μ is the specific yield of phreatic water, F is the area of the phreatic aquifer (m^2), $\bar{W}$ is the average variation in groundwater level (m), and Δt is time (a).

Therefore, the variation in groundwater level, which can directly reflect the changes in groundwater level and groundwater storage, was selected as the analysis factor of groundwater in this study. Rainfall, which is important to groundwater recharge, was selected as the factor of climate change that influences groundwater, and groundwater exploitation was chosen as the factor of anthropogenic activities that directly influences groundwater. First, the characteristics of annual rainfall, groundwater exploitation and the variation in groundwater level from 1996-2020 were qualitatively analyzed. Second, the influences of climate change and anthropogenic activities on groundwater were quantitatively analyzed by using the comparative method of the slope changing ratio and the elastic coefficient method. This study is very meaningful for the protection and management of groundwater.

Materials and Methods

Study area

The northern Huangqihai basin ($113^{\circ}2'-113^{\circ}28' \text{ E}$, $40^{\circ}43'-41^{\circ}3' \text{ N}$), in Right Chahaer County and the Jinning District of Wulanchabu city in Inner Mongolia, China, is located in the middle of the northern farming-pastoral ecotone and covers nearly 521 km^2 in area (Fig. 1). The study area is an important ecological barrier in the northern Beijing-Tianjin-Hebei region, where water resources are rare and the ecological environment is sensitive and fragile. The development of the regional social

economy is highly dependent on groundwater and mainly exploits a shallow aquifer, which is the Quaternary aquifer that consists of sand and gravel of varying sizes. The basin is surrounded by mountains on three sides, and the terrain around Huangqihai Lake is relatively low. Thus, groundwater generally flows from the surrounding area to Huangqihai Lake. There is a thick clay layer under the Quaternary aquifer, which results in a weak hydraulic relationship between the Quaternary aquifer and the deeper aquifer.

The recharge sources of groundwater are rainfall infiltration and groundwater lateral inflow, and rainfall infiltration accounts for approximately 60% of the total recharge. The discharge sources are exploitation, evaporation and discharge into the lake, and groundwater exploitation accounts for approximately 45% of the total discharge. The depth of groundwater in most areas is deeper than 5 m, exceeding the limit evaporation depth. According to Aver'yanov's evaporation equations, evaporation has a slight influence on the groundwater level. Therefore, rainfall and groundwater exploitation were selected as the factors of climate change and anthropogenic activities, respectively.

Data requirements and preparation

Groundwater level variation, groundwater exploitation and rainfall data were applied to research the influence of climate change and anthropogenic activities.

Groundwater monitoring in the study area started in the 1990s and has been gradually strengthened. The distribution of the monitoring wells was shown in Fig. 1. The groundwater level monitoring data (1996-2020) were collected from the Geological Environment Monitoring Institute of Inner Mongolia, and then these data were calculated. The annual variation (W) in groundwater level was the groundwater level in December minus the groundwater level in January, and the annual average of the groundwater level (H) was the average of the groundwater level for 12 months of the year.

Data on the quantity of groundwater exploitation (Q_{GE}) from 2011-2020 were derived from the Water Resources Bulletin of Right Chahar County. The data from 1998-2010 were calculated by the different proportions of total groundwater exploitation of Wulanchabu city in wet, normal and dry years. There were no available data from 1996-1997.

To ensure consistency with groundwater level data, the annual rainfall and monthly rainfall during the period from 1996-2020 were obtained from the China Meteorological Data Network

(<http://data.cma.cn>). Because the geographic position of the study area is near to Jining District, the meteorological station of Jining District was selected to reflect the climate change in the study area.

Methods

Based on an analysis of the characteristics of annual rainfall, Q_{GE} and W from 1996 to 2020, the influence of climate change and anthropogenic activities on groundwater level was qualitatively researched. The $M-K$ mutation test and cumulative anomaly method were used to determine the mutation years of annual rainfall and W , and the contribution rates of climate change and anthropogenic activities to groundwater level were calculated by using the comparative method of the slope changing ratio of cumulative quantity and the elastic coefficient method.

M-K trend test

The $M-K$ trend test is a rank nonparametric test method that is recommended by the World Meteorological Organization (Wang et al., 2019; Fang et al., 2019). This test was conducted to analyze the trend of annual rainfall in the study area from 1996 to 2020.

If the statistical value (Z) was greater than zero, it indicated that the trend of annual rainfall in the period was increasing, whereas if Z was less than zero, it indicated that the trend of annual rainfall was decreasing. Given the level of significance (α), if the absolute value of Z ($|Z|$) was greater than $Z_{1-\alpha/2}$, the trend was significant; if $|Z|$ was less than $Z_{1-\alpha/2}$, the trend was insignificant. When α was 0.05, the threshold corresponding to the level of significance was 1.96.

M-K mutation test

The $M-K$ mutation test is a simple and effective nonparametric statistical method to recognize mutations, it is widely utilized in meteorology, hydrology and other research fields (Zhu et al., 2017; Liu et al., 2019a).

By using the $M-K$ mutation test, UF and UB curves were obtained. When a given level of significance was exceeded, it indicated that the trend of the sequence was significant. When α was 0.05, the threshold corresponding to the level of significance was 1.96. If the intersection of the UF and UB curves was between the significant horizontal lines, the time corresponding to the intersection was considered as the time of the mutation (Cui et al., 2020).

Cumulative anomaly method

The cumulative anomaly method is a nonlinear statistical method that can directly reflect changes in the trends of discrete data. This method can directly reflect the changes in climate and hydrological

data in different periods and stages and then directly recognize the mutation year (Zhu et al., 2017; Liu et al., 2019b). The cumulative anomaly value (I_{LP}) of the analysis factor X at time t was calculated by using Eq. (2).

$$I_{LP} = \sum_{i=1}^n (x_i - \bar{x}) \quad (2)$$

where x_i is the value of the analysis factor X , i.e. rainfall and W , in the i th year ($i=1,2, \dots, n$) and $\bar{x}$ is the average of X .

Comparative method of the slope changing ratio of cumulative quantity

The comparative method of the slope changing ratio of cumulative quantity (Wang et al, 2012; Zhu et al., 2017; Zhao et al., 2019) was applied to calculate the contribution rates of climate change and anthropogenic activities to groundwater. The method was not influenced by subjective weight assignment, and the quantitative results were objective and reasonable.

Because the values of W were either positive or negative, normalization needed to be performed according to Eq. (3).

$$y_i = \frac{w_i - w_{min}}{w_{max} - w_{min}} \quad (3)$$

where w_i is the value of W in the i th year ($i=1,2, \dots, n$) and y_i is the normalized value of w_i .

Based on this finding, the linear slopes of the relationship between y_i and the years before and after the mutation were determined, i.e., S_{wb} and S_{wa} , respectively, and then the slope change rate of cumulative values of the groundwater level variation (R_{SW}) was obtained by using Eq. (4).

$$R_{SW} = \frac{(S_{wa} - S_{wb})}{S_{wb}} \times 100\% \quad (4)$$

Similarly, the slope change rate of cumulative values of the annual rainfall (R_{SR}) was obtained by using Eq. (5).

$$R_{SR} = \frac{(S_{Ra} - S_{Rb})}{S_{Rb}} \times 100\% \quad (5)$$

If R_{SW} and R_{SR} were positive, the slopes increased after the mutation; otherwise, the slope decreased after the mutation. The contribution rate (C_R) of the annual rainfall to W was defined as:

$$C_R = \frac{R_{SR}}{R_{SW}} \times 100\% \quad (6)$$

The contribution rate of groundwater exploitation (C_{GE}) to W was obtained according to Eq. (7).

$$C_{GE} = 1 - C_R \quad (7)$$

Elastic coefficient method

Based on previous research on the elastic coefficient of runoff to climate change (Guo 2016; Li 2016), the method was applied to quantitatively analyze the influence of climate change on groundwater level, and the median of the climate variable (Sankarasubramanian et al., 2001; Li et al., 2021) was adopted to estimate the elastic coefficient (ε_R) of W to annual rainfall.

$$\varepsilon_R = \frac{W_i - \bar{W}}{R_i - \bar{R}} \times \frac{\bar{R}}{\bar{W}} \quad (8)$$

where W_i is the annual variation in groundwater level in the i th year ($i=1,2, \dots, n$), R_i is the annual rainfall in the i th year, $\bar{W}$ is the average of W_i , and $\bar{R}$ is the average of R_i .

According to Eq. (9), the change in groundwater level variation after the mutation (ΔW_a) was calculated based on the elastic coefficient ε_R .

$$\Delta W_a = \frac{\bar{R}_a - \bar{R}_b}{\bar{R}_b} \times \varepsilon_R \times \bar{W}_b \quad (9)$$

where $\bar{R}_a$ is the average of the annual rainfall after the mutation, $\bar{R}_b$ is the average of the annual rainfall before the mutation, and $\bar{W}_b$ is the average of W before the mutation.

The contribution rates of annual rainfall and groundwater exploitation were calculated by using Eqs. (10) and (11).

$$C'_R = \frac{\Delta W_a}{W_a - \bar{W}_b} \times 100\% \quad (10)$$

$$C'_{GE} = 1 - C'_R \quad (11)$$

where $\bar{W}_a$ is the average of W after the mutation.

Results and Discussion

Variation characteristics of rainfall, Q_{GE} and groundwater level

The study area is in a semiarid continental climate zone and the average annual rainfall was 359.30 mm during the 1996-2020 period. The monthly rainfall distribution was uneven (Fig. 2) and mainly concentrated from June to August. The rainfall during these three months accounted for 60% of the annual rainfall. The wet and dry years appeared alternately; the maximum annual rainfall was 547.7 mm in 2012, while the minimum annual rainfall was 184.5 mm in 2009. The extreme ratio K , which was calculated by dividing the maximum by the minimum, was 2.97 and indicated a large difference in annual rainfall between the wettest year and the driest year. According to the $M-K$ trend test, there was an increasing trend of the annual rainfall from 1996-2020 (Fig. 3), but the Z value of the annual rainfall was 0.63, less than $Z_{1-\alpha/2}$, which indicated that the increasing trend of the annual rainfall from

1996-2020 was not obvious. The characteristic values of the annual rainfall were calculated by the P-III curve of hydrological frequency (Table 1), and the amount of rainfall substantially varied by years.

The Q_{GE} in the study area showed an upward trend from 1998 to 2016 (Fig. 3). The Q_{GE} values were relatively low in 2003, 2004 and 2012, which was mainly due to a abundant rainfall and the decrease in groundwater consumption by agricultural irrigation. The regional water administrative departments strengthened the rational management of the groundwater quantity from 2017 to 2020, and the values of Q_{GE} decreased year by year. The consumption of groundwater was different in different industries in the study area. The proportion rate of agricultural consumption in Q_{GE} exceeded 50%, domestic consumption had the second highest rate, and ecological demand for groundwater had the lowest rate.

The annual average of the groundwater level (H) was selected to reflect the change in groundwater level in the whole year. As shown in Fig. 3, H in the study area showed a decreasing trend overall due to unreasonable exploitation. H decreased rapidly from 2011 to 2018 and increased slightly in the period from 2019-2020. The values of W in the study area gradually changed from positive to negative for the period from 1996 to 2020 (Fig. 3), indicating a continuous decrease in the groundwater level. In 2011, the value of W was the maximum negative value, while the value of Q_{GE} in the same year was the highest. After 2014, the values of W generally increased, but the values of W remained negative.

Qualitative analysis of the influence of climate change and anthropogenic activities on groundwater

The changes in annual rainfall, Q_{GE} and W in different years were compared. In the wet year of 2012, the annual rainfall was 547.7 mm, which was the maximum rainfall in the period from 1996-2020; the Q_{GE} value was only 0.3156 billion m^3 in the same year, which was the minimum in this period. Under the comprehensive influence of rainfall and Q_{GE} , the value of W changed from negative to positive in 2012. Q_{GE} was relatively large in dry years, such as 2011, when the annual rainfall was only 214 mm, while the Q_{GE} value was 0.4808 billion m^3 . The decrease in groundwater level was exacerbated under the conditions of insufficient groundwater recharge and excessive discharge of groundwater.

Over the whole period of 1996-2020, the annual rainfall in the study area showed an increasing trend, but the values of W remained negative for many years, and H showed a decreasing trend. The more rainfall there is, the more groundwater recharges. The higher Q_{GE} there is, the more groundwater

discharges. The contrasting characteristics of the annual rainfall and W indicated that the positive influence of annual rainfall on groundwater level was weaker than the negative influence of groundwater exploitation. Due to excessive and unreasonable exploitation of groundwater in the study area for years, the groundwater level has continually decreased, and W has been negative for a long time. The negative values of W were reduced due to the decrease in Q_{GE} from 2017 to 2020.

In summary, the influence of climate change and anthropogenic activities on groundwater should not be disregarded. Hereafter, the influence of the two on groundwater was analyzed under different conditions.

Influence of annual rainfall on W under the same exploitation conditions

The Q_{GE} values in 1999 and 2000 were 0.4276 billion m^3 and 0.4214 billion m^3 , respectively, and the relative difference between them was less than 0.02%; thus, the Q_{GE} values in 1999 and 2000 were considered the same exploitation conditions. Similarly, the exploitation conditions in 2015 and 2016 were considered equivalent. The two identical exploitation conditions from 1999-2000 and 2015-2016, named conditions A and B , respectively, were chosen to perform the following research (Table 2 and Fig. 4).

As shown in Table 2 and Fig. 4, the decrease in W was reduced due to an increase in annual rainfall under the same exploitation conditions, and W changed from negative to positive during the wet year 2016. According to the Pearson correlation analysis, there was a positive correlation between the annual rainfall and W , and r was +0.9710 at the level of significance α of 0.05.

Influence of Q_{GE} on W under the same rainfall conditions

According to Table 1, the influence of Q_{GE} on W was discussed under the same rainfall conditions in wet years (A'), normal years (B') and dry years (C'). The comparison of Q_{GE} and W under the three conditions was shown in Table 3 and Fig. 5.

As shown in Table 3 and Fig. 5, the negative values of W decreased due to an increase in Q_{GE} under the same rainfall conditions.

Under condition A' , 1998, 2003 and 2016 were wet years; the annual rainfall in the three years was abundant; the Q_{GE} values were relatively low; and the W values were positive. The Q_{GE} value in

2016 was higher than the Q_{GE} values in 1998 and 2003, and the W value in 2016 was lower than the W values in the other two years.

Under condition B' , 1999, 2000 and 2014 were the normal years, and the rainfall was at the middle level. The negative values of W decreased due to an increase in Q_{GE} . The Q_{GE} values in the three normal years were larger than the Q_{GE} values in the wet years. The value of W was lower in the normal years due to an increase in Q_{GE} .

Under condition C' , 2001 and 2006 were dry years; rainfall was the lowest; and the Q_{GE} values in these two years were larger than the Q_{GE} values in wet years. The negative values of W decreased sharply due to an increase in Q_{GE} . Moreover, W was more sensitive to the change in Q_{GE} with the insufficient recharge of rainfall. Under the same rainfall conditions, the Q_{GE} value in 2006 was 1.11% larger than that in 2001, but the corresponding W was 489.43% larger in 2006 than that in 2001.

In summary, W decreased due to an increase in Q_{GE} under the same rainfall conditions. The Pearson correlation analysis showed that there was a negative correlation between Q_{GE} and W . Accompanied by the decrease in annual rainfall, the correlation coefficient r' between Q_{GE} and W changed from -0.4690 to -1.000 at the level of significance α of 0.01, which indicated that the influence of Q_{GE} on W increased with a decreasing in the rainfall recharge.

Influence of rainfall and groundwater exploitation on W in different months of the year

Due to the lack of monthly groundwater exploitation data, the analysis was focused on the changes in monthly rainfall and monthly variation in groundwater level (W_{mon}), and then the influence of groundwater exploitation on groundwater level was reflected peripherally.

According to the groundwater flow field (Fig. 6), the monitoring wells of the groundwater level upstream, midstream and downstream (M069, M030 and M017; M034 and M033) were chosen to analyze the changes in W_{mon} in different months of the year. The distributions of the monthly rainfall under different rainfall conditions varied; thus, the analysis was performed under the three rainfall conditions, i.e., wet years, normal years and dry years.

It can be seen from Fig. 7 that W_{mon} differed among the monitoring wells and varied by years. Overall, the W_{mon} values were low from January to April, and the W_{mon} value was mostly positive in April. These results were attributed to the lagging recharge from rainfall and the melting of ice and snow. Although the rainfall increased obviously in summer, the W_{mon} did not immediately change to

positive values but remained negative, and some negative values of W_{mon} decreased, such as the W_{mon} values at M017, M034, and M030 in July 2003. The consumption by agriculture and industry was high, summer was the peak period of groundwater exploitation, and the negative influence of anthropogenic discharge on the groundwater level was greater than the positive influence of rainfall recharge. Based on a comparison among the changes in the W_{mon} of the selected monitoring wells, the characteristics of the W_{mon} upstream, midstream and downstream were similar, indicating that for the whole area, the influence of groundwater exploitation was greater than that of rainfall.

Determination of the time of the mutation

The first step of a quantitative assessment of the influence of climate change and anthropogenic activities on groundwater level was to determine the time of the mutation. The $M-K$ mutation test and cumulative anomaly method were employed in this study.

According to Fig. 8, the UF and UB curves of the annual rainfall and W intersected in 2004 at a significance level of 0.05(Fig. 8). In addition, the inflection point based on the cumulative anomaly curves of the annual rainfall and W appeared in 2004 (Fig. 9). Therefore, the time of the mutation year was determined to be 2004; the period from 1996-2004 was defined as the period before the mutation; and the period from 2005-2020 was defined as the period after the mutation.

Quantitative assessment of the influence of climate change and anthropogenic activities on groundwater

The comparative method of the slope changing ratio of cumulative quantity and the elastic coefficient method were adopted to quantitatively evaluate the influence of climate change and anthropogenic activities on groundwater level. The results of the two methods are shown here.

As shown in Fig. 10 and Table 4, the slope of the cumulative annual rainfall after the mutation was elevated compared with that before the mutation, indicating that the rate of cumulative annual rainfall increase was faster after the mutation (2005-2020). In addition, the slope of the cumulative W (normalized) decreased compared to that before the mutation, meaning that the rate of cumulative W

(normalized) increase was slower after the mutation. Based on the comparative method of the slope changing ratio of cumulative quantity, the contribution rate of rainfall to W was 21.51%, and that of Q_{GE} to W was 78.49%. The contribution rate of anthropogenic activities was greater than that of climate change.

According to Table 5, the elastic coefficient (ε_R) of W to the annual rainfall was 1.50, indicating that there was a 15% change in W if the annual rainfall changed by 10%. The average annual rainfall after the mutation was reduced by 6.62% compared to that before the mutation; thus, the corresponding change in W based on ε_R after the mutation should have been -0.07 m. However, according to the statistics of the monitoring data, the actual change in W (ΔW) before and after the mutation was -0.33 m. By using the elastic coefficient method, the contribution rates of climate change and anthropogenic activities to W were calculated to be 22.64% and 77.36%, respectively.

According to the results of these two methods, the relative difference in the calculation results of the two methods was less than 5% (Table 6), and anthropogenic activities had a greater influence on the variation in groundwater level, while the influence of climate change was relatively small. The quantitative results were consistent with the qualitative analysis. Therefore, the averages of the calculated results based on the two methods were determined to be the quantitative results, that is, the contribution rate of climate change to W was 22.08%, and the contribution rate of anthropogenic activities was 77.92%.

Protection and management of groundwater

As shown in Fig. 3, the W values in the study area were always negative, and the groundwater level continued to decrease until recent years. The contribution rate of climate change to W was only 22.08%, which is much less than the contribution rate of anthropogenic activities to W (77.93%). The positive influence of increased rainfall on groundwater recharge was not enough to offset the negative influence of anthropogenic exploitation.

According to Table 3 and Fig. 5, when Q_{GE} was greater than 0.4 billion m^3 , the W values in the normal and dry years were always negative, and the groundwater level decreased. Under the current mining conditions, the recharge of groundwater in normal and dry years is insufficient, while the Q_{GE} is excessive, which is not conducive to the sustainable development of the groundwater environment.

Climate is uncontrollable and has a relatively slight influence on groundwater. According to this study, with the aid of the positive guidance of anthropogenic activities, groundwater exploitation can be appropriately reduced, unconventional water sources can be developed and utilized to relieve the pressure on groundwater, and additional measures can be taken to scientifically protect and manage groundwater.

Conclusions

In this paper, W was selected as the analysis factor of groundwater, and rainfall and Q_{GE} were selected as the factors of climate change and anthropogenic activities that influence groundwater, respectively. Based on the analysis of the changes in rainfall, Q_{GE} and W , the influence of climate change and anthropogenic activities on groundwater was qualitatively analyzed according to different years and conditions. The quantitative assessment was realized by the $M-K$ mutation test, comparative method of the slope changing ratio of cumulative quantity and elastic coefficient method. The main conclusions were as follows:

(1) The annual rainfall in the study area showed an upward trend, but W was always negative, and the groundwater level in the study area showed a downward trend. Through the comparative analysis of the W under different conditions, there was a positive correlation between the annual rainfall and W and a negative correlation between Q_{GE} and W , and the positive influence of rainfall on W was less than the negative influence of Q_{GE} .

(2) According to the $M-K$ mutation test and cumulative anomaly method, 2004 was determined as the mutation year. The period from 1996-2004 was defined as the period before the mutation, and the period 2005-2020 was defined as the period after the mutation.

(3) The quantitative assessment of the influence of climate change and anthropogenic activities was performed according to the comparative method of the slope changing ratio of cumulative quantity and the elastic coefficient method, and the relative differences in the results of the two methods were less than 5%. The contribution rate of climate change to the groundwater level was 22.08%, and the contribution rate of anthropogenic activities was 77.92%. The negative influence of anthropogenic activities on W was much greater than that of climate change, which was consistent with the qualitative analysis.

(4) Under the current mining conditions, W was negative in general, the recharge of groundwater in normal and dry years was insufficient, and Q_{GE} was excessive. According to this study, climate

change is uncontrollable and has a relatively slight influence on groundwater; however, anthropogenic activities can be guided positively to scientifically protect and manage groundwater, such as appropriately reducing groundwater exploitation and utilizing unconventional water sources.

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Fig. 1 Location of the study area and distribution of the monitoring wells

Fig. 2 Box chart of monthly rainfall (1996-2020)

Fig. 3 Changes in annual rainfall, Q_{GE} , W and H (1996-2020). For convenience, the order of magnitude of the annual rainfall was appropriately adjusted, and the Q_{GE} values were adjusted to negative values by multiplying by -1 due to the negative influence of groundwater exploitation on the groundwater level.

Fig. 4 Comparison of W and annual rainfall under exploitation conditions A (**a**) and B (**b**)

Fig. 5 Comparison of W and Q_{GE} under rainfall conditions A' (**a**), B' (**b**) and C' (**c**)

Fig. 6 Groundwater flow field and the distribution of the selected monitoring wells

Fig. 7 Changes in the monthly rainfall and W_{mon} during wet years (**a** and **b**), normal years (**c** and **d**) and dry years (**e** and **f**)

Fig. 8 UF and UB curves of the annual rainfall (**a**) and W (**b**) from 1996 to 2020 based on the $M-K$ mutation test

Fig. 9 Cumulative anomaly curves of the annual rainfall (**a**) and W (**b**) from 1996 to 2020 based on the cumulative anomaly method

Fig. 10 Cumulative curves of the annual rainfall (**a**) and W (**b**) and their trend lines. W (normalized): The W value has been normalized according to Eq. (3).

Figures

Figure 1

Location of the study area and distribution of the monitoring wells

Figure 2

Box chart of monthly rainfall (1996-2020)

Figure 3

Changes in annual rainfall, Q_{GE} , W and H (1996-2020). For convenience, the order of magnitude of the annual rainfall was appropriately adjusted, and the Q_{GE} values were adjusted to negative values by multiplying by -1 due to the negative influence of groundwater exploitation on the groundwater level.

Figure 4

Comparison of W and annual rainfall under exploitation conditions A (a) and B (b)

Figure 5

Comparison of W and Q_{GE} under rainfall conditions A' (a), B' (b) and C' (c)

Figure 6

Groundwater flow field and the distribution of the selected monitoring wells

Figure 7

Changes in the monthly rainfall and W_{mon} during wet years (a and b), normal years (c and d) and dry years (e and f)

Figure 8

UF and UB curves of the annual rainfall (a) and W (b) from 1996 to 2020 based on the M-K mutation test

Figure 9

Cumulative anomaly curves of the annual rainfall (a) and W (b) from 1996 to 2020 based on the cumulative anomaly method

Figure 10

Cumulative curves of the annual rainfall (a) and W (b) and their trend lines. W (normalized): The W value has been normalized according to Eq. (3).

Supplementary Files

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