Analysis of the Influence of Atmospheric Precipitation on the Spring Level in Jinan

Xiaoxun Lan¹, Liting Xing*, Yanan Dong¹, Chunmei Yao², Qianqian Cao¹

¹ School of Water Conservancy and Environment, University of Jinan, Jinan, China
² Shandong Provincial Geological Environment Monitoring Station

Abstract: In order to realize the rational use of groundwater in Jinan and guarantee the continuous gushing of spring water, a hydrogeological survey was conducted in the study area to collect precipitation and spring water level data over the years, and to analyze the correlation between precipitation and spring water level at different time scales and spaces. Research shows that the correlation coefficient between precipitation and spring water level is the largest in the 1960s, and human activities have less influence on spring water, with the increase of groundwater demand from social development and the implementation of related spring protection measures such as groundwater limitation and replenishment, the correlation coefficient between precipitation and spring water level decreased first and then increased, mining volume remains the main factor affecting groundwater levels; precipitation lag time of Xing long Station, Donghong miao Station and Yanzi shan Station is short. The areas where these rainfall stations are located may be suitable for recharge and replenishment. The research results provide technical basis for spring water protection.

1. Introduction
Jinan is famous for spring water. The spring water and karst water from the southern supply area play an important role in Jinan's economic development and the stability of people's lives. The spring water is the source of water for the residents' life and industrial production in Jinan[1]. Precipitation is the main source of karst water supply in springs. The precipitation of Jinan City has the characteristics of uneven distribution within the year, interannual and space[2], which is an important influencing factor of the dynamic change of spring water. Atmospheric precipitation in the 1950s and 1960s was the main influencing factor of spring water dynamics. With the increase of groundwater mining, in the 1980s and 1990s the main influencing factor of spring water changed from atmospheric precipitation to artificial mining[3]. In recent decades, the amount of karst water extracted in urban areas has increased from about 100,000 m³/50s in the 1950s and 1960s, increased to 700,000 m³/d at the beginning of the 21st century[4, 5].

2. Geological profile of the study area
Jinan spring area is located in the inland mid-latitude zone and belongs to the northern temperate continental monsoon climate. The average annual rainfall is 669.91mm. Most of the precipitation is from June to September, accounting for 70 to 80% of the annual precipitation. Atmospheric precipitation is the main source of spring water supply. The terrain is high in the south and low in the north, with a relative height difference of 100-250m. The Jinan spring area is based on the Taigu Yutai Group formations, and is covered by Cambrian and Ordovician formations. Precipitation and surface runoff infiltration have formed rich fractured karst water.
3. Research methods
The precipitation data of 15 observation stations including Shao er, Donghong miao, Xing long, and Yanzi shan in the spring from 1916 to 2017 were selected. The spring water level data source was the actual monitoring data of Baotu spring water level. The Excel software was used to draw the inter-annual variation of atmospheric precipitation, the trend of change at different time scales, and the trend line of spring water level. The effects of inter-annual and monthly scales on spring water level and the influence of rainfall stations on spring water level at different time scales were compared and analyzed. The SPSS software was used to analyze and evaluate the correlation between the current years precipitation, the previous year's precipitation, and the first two years precipitation on spring water levels.

4. Results and discussion

4.1 Interannual relationship between spring water level and precipitation
Atmospheric precipitation, as the main source of replenishment in the Baotu Spring spring area, not only has an important influence on the dynamics of groundwater level, but also an important factor affecting the entire groundwater dynamic field. Comprehensive analysis shows that the precipitation of Jinan City has the characteristics of uneven distribution within and between the years (Figure 2).

![Figure 2 Inter-annual precipitation curve](image)

From 1960 to 1969, Establish a multivariate regression model of the average water level in the outcrop area of the spring group and the current year's rainfall, the previous year's rainfall, and the previous two years' precipitation Multiple regression model: \( Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \varepsilon \). Which \( Y \) represents the average annual groundwater level, \( X_1, X_2, X_3 \) represent the current year's precipitation, the previous year's precipitation, the previous two years' precipitation, \( \varepsilon \) is a random variable, \( \beta_0, \beta_1, \beta_2, \beta_3 \) are regression parameters. By calculation, the regression equation is: \( Y = 25.393 + 0.002X_1 + 0.003X_2 + 0.001X_3 \). Test the independent parameter. Calculated under the condition of significance level \( \alpha = 0.05 \), It reflects that the precipitation is the main cause of the
influence of groundwater level at this stage, and the impact of human activities on spring water is small, and the dynamics of groundwater are natural.

From 1970 to 1989, The calculated regression equation is: \( Y = 23.797 + 0.003X_1 + 0.003X_2 \). The overall linear relationship of the equation is not significant, indicating that the main factors affecting the groundwater level and their intensity have changed. In the 1970s and 1980s, artificial mining was the main factor affecting the groundwater level. During this period, precipitation was no longer the main factor affecting the groundwater level.

Establishing a multiple regression model during 1990-2002: \( Y=25.393+0.002X_1+0.003X_2+0.001X_3 \). The effect of precipitation on groundwater levels in the previous year has increased significantly. It shows that the implementation of related spring protection measures such as groundwater limitation and replenishment, the impact of precipitation on groundwater level has increased, and the impact of groundwater extraction has decreased.

4.2 Relationship between precipitation and spring water level at different time scales

4.2.1 Relationship between annual scale precipitation and spring water level

The annual change of water level and annual precipitation from 1959 to 2012 were selected for research. The annual change of water level was \( y \), and the annual precipitation was \( x \). A scatter plot was drawn (Figure 3), and the relevant equation is: \( y = 0.0027x-1.8328 \).

![Figure 3 Relationship between annual changes in water level and annual precipitation from 1959 to 2012](image)

The correlation coefficient \( R^2 \) is only 0.2695, and the correlation between annual groundwater level fluctuations and annual precipitation is poor. The correlation between precipitation and spring water level is not obvious during the period of large mining volume. In order to study the correlation between precipitation and groundwater level, the influence of mining volume must be excluded. Therefore, the relationship between precipitation and spring water level was selected to study the stable and relatively small amount of mining time. According to the urban mining volume statistics from 1959 to 1967 (Table 1), the average mining volume was only 89,500 m³. The annual change of spring water level during this period is positively correlated with the annual precipitation (Figure 4), the correlation coefficient \( R^2=0.961 \), and the function equation is: \( y = 0.0033x-2.4357 \).

![Figure 4 Relationship between annual changes in water level and annual precipitation from 1959 to 2012](image)

| Year | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 |
|------|------|------|------|------|------|------|------|------|------|
| Mining volume in urban area (10,000 m³ / d) | 7.27 | 9.65 | 10.79 | 9.08 | 8.3  | 8    | 9.61 | 10.77 | 12.6 |

The regression analysis of annual precipitation and spring water level reveals that meteorological factors are the main influencing factors of spring water under natural conditions, but with the intensification of human action, the influencing factors of spring water dynamics have become more complicated.
4.2.2 Relationship between monthly scale precipitation and spring water level

The 2008-2012 data without impact of mining in the urban area was used to analyze the relationship between monthly precipitation and spring water level. The monthly precipitation \(x\) was used as the abscissa, and the monthly change in water level \(y\) was used as the ordinate. The combined trendline equation is: \(y = 0.0038x - 0.1411\)

The correlation coefficient \(R^2\) is 0.6865, which shows that they have a good linear relationship. When the precipitation is too small in practice, it is invalid precipitation, so there must be a "threshold value" for the amount of precipitation that causes the groundwater level to rise. It can be concluded that under the current mining conditions, the "threshold value" of monthly precipitation that maintains the dynamic and stable Jinan spring water during the dry season is 37mm, otherwise artificial recharge is needed to curb the downward trend of water level.

![Figure 5 Relationship between monthly changes in water level and monthly precipitation from 2008 to 2012](image)

4.3 Spatial distribution of precipitation and spring water level

In order to study the relationship between the spatial distribution of precipitation and the spring water level, the data of 15 rainfall stations were selected in the spring area for direct and indirect recharge (Figure 6) were studied using observational data of precipitation and spring water levels at different time scales from 2009 to 2015.

![Figure 6 Rainfall Station Distribution in Baotu Spring](image)

4.3.1 Analysis of the impact of the ten-scale descending water amount of each rainfall station on the spring water level

Because the response of the spring water level to atmospheric precipitation is lagging, the designed water level lag time is 0 to 6 days, and the spring water level change amplitude uses the water level difference corresponding to the lag time. Correlation coefficient. Based on the long-term precipitation data of 15 rainfall stations from 2009 to 2015, a graph of the correlation coefficient and the lag time is drawn.

By comparing the correlation coefficients of various rainfall stations, in ten-year scale, the rain stations with a lag time of 2 days include Xing long, Yanzi shan, Huangtai qiao, Qiu jia zhuang, Zao...
lin, and Xi ying; the lag time is 3 days. The rainfall stations are Donghong miao and Nangao Er; the rain stations with a lag time of 4 days include Liujiazhuang, Shao er, and Lao shan. Combining with the analysis of the lithology of the spring area and the groundwater flow field, the precipitation lag time of Xing long Station, Donghong miao Station, and Yanzi shan Station is short in the ten-scale spring water level. The areas controlled by these stations may be recharge sites.

4.3.2 Analysis of the impact of the five-day descending water volume of each rainfall station on the spring water level

Using the same method as ten-year scale, the lag time of the spring water level is designed to be 0 ~ 6 days, and the correlation coefficients of the seven spring water level fluctuations and the five-day scale precipitation are calculated. Based on the long-term precipitation data of 5 rainfall stations from 2009 to 2015, draw the relationship curve between the correlation coefficient and the lag time.

By comparing the correlation coefficients of various rainfall stations, in the five-day scale, the rainfall stations with a spring lag time of 2 days are Liujiazhuang, Shao Er, Dong hong Temple, Xing long, Yanzi shan, Huantai qiao, Wangjia zhuang, Zao lin, Wo pu; Dong wu and Wohu shan are the rain stations with a lag time of 3 days; Xi ying and Qiujia zhuang are the lag time of 4 days. Based on the analysis of the lithology, groundwater flow field, and distance from the spring group, the precipitation lag time of Xing long Station, Donghong miao Station, and Yanzi shan Station on the five-day scale is short. The areas controlled by these stations may be suitable for implementation. Recharge the source project.

5. Conclusion

(1) With the increase of groundwater extraction, the degree of influence of precipitation on groundwater levels in the 1960s to 1980s gradually decreased. From the 1990s to the beginning of the 21st century, the implementation of related spring protection measures such as groundwater limitation and replenishment, the impact of precipitation on groundwater levels increased.

(2) Under the current mining conditions, the "threshold value" of the monthly precipitation that maintains the dynamic and stable Jinan spring water during the dry season is 37mm, otherwise artificial recharge is needed to stop the downward trend of water level.

(3) Under the ten-day scale and the five-day scale, the precipitation lag time of Xinglong Station, Donghongmiao Station, and Yanzishan Station is short. The areas controlled by these stations may be favorable sites for recharge.

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