Groundwater Chemical Characteristics and Mining Potential Evaluation of the Quaternary in the Boxing Section of Shandong Province in the Lower Yellow River

Qin Peng¹, Yao Yingqiang¹, Liu Hongliang¹, Liang Zhihao²

¹Shandong Geological Environmental Monitoring, 17 Jingshan Road, Jinan, China
²School of Statistics, Shandong University of Finance and Economics, 7366 Erhuan Dong Road, Jinan, China
365375850@qq.com

Abstract: Boxing is located in the lower reaches of the Yellow River, all of which are covered by loose rock layers. Quaternary loose rock pore water mainly exists in aqueous media such as medium sand, medium coarse sand and fine sand, forming multiple layers of loose rock pore water. Water-containing structure is interlayer confined water development. From the southeast to the northwest, the aquifer formation gradually becomes thinner with the Quaternary overburden, the thickness of the single-layer sand layer gradually becomes thinner, and the water richness gradually weakened. The chemical types of groundwater are mainly HCO₃⁻ and HCO₃⁻·Cl. The pore water of loose rocks in the middle and deep layers is decreasing from south to north, and the content of Cl⁻ is increasing. From west to east, the percentage of HCO₃⁻ mg equivalent decreases gradually, and the percentage of Cl⁻ mg equivalent increases gradually. The area enclosed by the groundwater level buried depth 40m is the controlled mining area.

1. Introduction
Boxing is located in the lower reaches of the Yellow River. The area is covered by loose rock layers. Quaternary loose rock pore water mainly exists in aquifers such as medium sand, medium coarse sand and fine sand. Viscous soil acts as a relatively impervious layer. Multi-layer water-containing structure of loose rock-like pore water, and confined water between layers is developed. From the southeast to the northwest, the aquifer formation gradually became thinner with the Quaternary overburden, the thickness of the single-layer sand layer gradually became thinner, and the water richness gradually weakened. The chemical types of groundwater were mainly HCO₃⁻ and HCO₃⁻·Cl.

2. Meteorology and hydrology
The average precipitation of Boxing for many years (from 1981) is 562.7 mm, and the average evaporation of many years (from 1981) is 1752 mm, and the evaporation-down ratio is 3.11. Based on the statistics of precipitation in the past 33 years, 25% of the guaranteed rate is the year of high water, 50% is the year of flat water, and 75% is the year of dry water. It can be calculated by frequency analysis method. The critical values of precipitation are 653.3 mm, 539.3 mm, and 502.5 mm. The Yellow River flows northeast through the north, and the Xiaoqing River flows through Boxing near east-west.
3. The distribution of groundwater in the middle and deep layers
The available freshwater and brackish water in the quaternary middle-deep loose rock pores are mainly distributed in the area south of Chenguang (Figure 1). The buried depth of the freshwater top interface gradually increased to less than 300m from south to north. The aquifer is multi-layered and affected by the thickness and particle size of the sand layer.

3.1 Middle-deep freshwater
The burial depth of the quaternary mid-deep freshwater top interface in the area gradually increased from south to north to more than 280m. The deep sand layer in this area is relatively continuous. The salt water intrudes from north to south in a wedge shape. The buried depth of the freshwater roof slowly declines between 100m and 150m, and decreases gradually between 150m and 300m (Figure 2).
3. In the area of Boxing, the water content is medium and the aquifer is a multi-layer structure, mainly medium sand and medium coarse sand. The number of sand layers gradually increases from 3 to 5-6 layers from south to north. The particles become finer and single layers. The thickness of the sand layer gradually decreases. The Quaternary thickness in this area is between 200-300m, and the depth of Jimin wells is mostly less than 300m. Due to the different depths, the thickness of freshwater aquifers varies from 10m to 23m, and the thickness of a single layer of sand is between 2m and 14m. The buried depth of the top interface gradually increases to 200m to the north.

3.2 Medium and deep brackish water
The quaternary mid-deep brackish water in the area is distributed in a strip in the northern part of the middle-deep freshwater. The narrow strip of the Pangjia-Yanfang line gradually increases from south to north at the interface of the brackish water top to more than 300m. Due to the difference in the depth of the brackish water top interface, the plane of the brackish water distribution zone shows a trend of wide west and narrow east. The lithology of the aquifer is mainly composed of fine sand and medium-fine sand, with a multilayer structure. The thickness of the Quaternary system decreases from west to east. The sand layer decreases, the particles become finer. The water richness weakens. The groundwater quality is poor. TDS is between 1g / L and 3g / L, and mostly is sodium bicarbonate water.

3.3 Medium and deep salt water
Medium-deep saline water is wedge-shaped into the freshwater area from north to south. The salty water has a low degree of Baume and cannot be exploited as a brine source, and the total dissolved solids are greater than 3g / L, so it cannot be used as domestic water and farmland irrigation water. Our work does not do research on medium and deep saline water.

4. Medium and deep salt water

4.1 Supply conditions
The groundwater in the middle and deep layers of the area is mainly infiltrated by atmospheric precipitation in the mountainous area of Luzhong. The alluvial sedimentary layer is replenished along the bedrock fissures and flows into the area from south to north and southwest to northeast. A small amount of shallow groundwater recharged. According to the Schoeller(Figure 3), it can be seen that the pore water in the middle and deep layers of the Quaternary System and the shallow pore water in the Quaternary system have approximately the same trend, which indicates that the pore water in the
middle and deep layers of the Quaternary system accepts the upper part at the same time and shallow salt water and brackish water are replenished.

4.2 Runoff conditions
The middle-deep aquifer is the main water supply target layer for industrial production and residential drinking water in the area. From the 1978 middle-deep groundwater level map (Figure 4), it can be seen that in the natural state, groundwater flows from the south to the north, the groundwater is not discharged smoothly, and the runoff is sluggish. Artificial mining has changed its natural flow field. With the rapid development of the industry in the region, by 2005, a deep groundwater overdraft funnel centered on Boxing had been formed, and the funnel center was located in the west of the county seat. At present, after the implementation of a series of water control measures in Boxing and the marginalization of industrial and mining enterprises, the funnel center has moved to the north of Pangjia.
4.3 Excretion conditions
Groundwater in the middle and deep layers is mainly discharged by artificial mining. Part of the middle and deep groundwater is used for farmland irrigation, and part of it is used for domestic drinking. Most of the groundwater is concentrated in the denser areas of the villages in the south of Boxing. Deep groundwater focuses on industrial mining, followed by domestic water, concentrated in the northern part of Boxing. From the analysis of the changes in the amount of mining for many years, the changes in agricultural and raw water consumption are relatively small, and the increase in industrial water is relatively large. The groundwater supply area in the middle and deep layers is far away, the movement is slow, and the supply conditions are poor. Therefore, after a large amount of mining, the water head was significantly reduced. In the 1980s, the artesian region in the north had all disappeared.

5. The chemical types and characteristics in the middle and deep groundwater
From north to south in the area, the pore water in the middle and deep layers of the Quaternary System gradually passed from fresh water to brackish water, and gradually passed to the Quaternary System, which was all salt water. The freshwater and brackish water groundwater chemical types are mainly HCO$_3$ and HCO$_3$·Cl water (Figure 5).
The change of pore water in the middle-deep layer of loose rock pore water from south to north is shown in the piper diagram (Figure 6): The content of Ca\textsuperscript{2+} is continuously decreasing, but except for the southern GRS13-1 water quality monitoring point, the milligram percentages in other regions are roughly the same, all at 15 -20%. The content of Mg\textsuperscript{2+} is highest in the middle, the Mg\textsuperscript{2+} mg equivalence percentage of GRS13-4 water quality monitoring points is about 60%, and the northern mg equivalence percentage is the lowest, less than 20%. Na\textsuperscript{+} mg equivalence percentage continues to increase, increasing from 20%. The content of Cl\textsuperscript{-} is increasing continuously, and the percentage change of mg-equivalent percentage is large, mostly below 20%. Except for GRS525 water quality monitoring point, the depth of the well is 140m, the water intake level is shallow, and the value of Cl-content is higher than other monitoring points. The percentage of SO\textsubscript{4}\textsuperscript{2-} mg equivalent is relatively stable in most areas below 20%. The percentage of HCO\textsubscript{3} mg equivalent is stable above 55%, which decreases slightly from south to north.

The change in the chemical type of pore water in the middle and deep layers of loose rocks from west to east is shown in piper (Figure 6). The percentages of milligram equivalents of each ion in groundwater in the central and eastern regions are similar, such as GRS2-6, GRS5-6, GRS8-6, and GRS11-6 water quality monitoring points, which are closely located in the piper. The eastern water quality situation is different. It can be seen from the lower right triangle that due to the similar latitude of the water point in the figure, the percentage of SO\textsubscript{4}\textsuperscript{2-} mg equivalent is relatively close to 20%. The percentage of HCO\textsubscript{3} mg equivalent decreases gradually from west to east, and the percentage of Cl\textsuperscript{-}
mg equivalent is negative related. It can be seen from the lower left triangle that the percentage of mg equivalent of Mg$^{2+}$ has been increasing, while the percentage of mg equivalent of Na$^+$ and Ca$^{2+}$ ions has been relatively stable with little change.

5.1 $\text{HCO}_3^-$ type groundwater

Quaternary mid-deep $\text{HCO}_3^-$ groundwater is distributed in a large area in the Pangjia-Yanfang area in the middle and south of the map.

Groundwater in the middle and deep layers is mainly run off by the pore water in the southern front of the mountainous area after receiving atmospheric precipitation infiltration and recharges laterally. Affected by the southern Ordovician strata, especially the Shouguang uplift, groundwater anions are mainly bicarbonate. Because the recharge area is far away, the occurrence of aquifers is low, and groundwater runoff is slow. Affected by the replenishment of paleo-salt water in the middle layer, the main cations are sodium and magnesium ions. Calcium ions are involved in the south of Xingfu in the south. The effect of water invasion increases the percentage of sodium ions, and groundwater forms $\text{HCO}_3^-$-Ca-Na-Mg, $\text{HCO}_3^-$-Na-Mg, and $\text{HCO}_3^-$-Na water from south to north. TDS gradually increases, and the water quality gradually deteriorates.

5.2 $\text{HCO}_3^-$-Cl groundwater

It mainly distributed in the northern Chunhua-Qiaozhuang area. From south to north, the thickness of medium and deep salty water is increasing. With the increasing depth and exploitation of fresh and brackish water in the middle and deep layers, in the horizontal direction, the northern salt water is gradually replenished to the south, and the hydraulic connection between water and deep fresh water is constantly increasing vertically. Affected by salty water in the middle and deep layers, the chloride and sodium ions in the groundwater are constantly increasing. The anions are dominated by bicarbonate and chloride ions, and the cations are dominated by sodium ions. Generally greater than 3g/L, the water quality is poor.

6. Development and utilization of groundwater resources in the middle and deep layers

The deep groundwater in the area has always been an important part of industrial production in the area because of its good water quality and large amount of water. According to the dynamic data, the deep groundwater level in this area has a continuous downward trend under the influence of artificial mining. A deep groundwater dropping funnel centered on Pangjia has been formed and the buried depth of the funnel center water level exceeds 100m (the water level elevation is -107.23m). The water
level decline rate is about 4m/a, and the decline rate in peripheral areas is relatively slow, which is 2-3m/a. There is no pick-up during the year, and it has no mining potential.

Although the rate of decline of the deep groundwater level outside the funnel and its surrounding areas did not reach the value of the funnel area, it also showed a continuous downward trend under the influence of artificial mining. Some sections were already in an over-mining state. The buried depth of the water level was mostly 40-50m, and the water level dropped, and the rate is 1-2m/a. The recovery rate is not large during the year, and this state is still continuing. Although there is a certain mining potential, the potential is not great.

7. Prospects for the development and utilization in the middle and deep groundwater

At present, the development and utilization of groundwater in the middle and deep layers and deep layers in the area are relatively high, and over-exploitation funnels have been formed. According to the hydro-geological characteristics, the distribution of aquifers, the current status of groundwater exploitation and utilization in the middle and deep layers, it is divided into controlled mining areas and reasonable mining areas (Figure 7).

7.1 Control mining area

In the area enclosed by the water level buried depth 40m, the wells in the area are vertically divided into 3 water intake groups according to the water intake group section and well spacing. The first group of sections is 200-300m with well spacing greater than 1570m. The second group of sections is 300-450m with well spacing greater than 1460m. In order to control the production volume in each mining area, it is necessary to control the planned number of wells and the permitted production volume in each aquifer group and each mining area.

7.2 Reasonable mining area

In the area where the water depth is less than 40m, the area is closed according to the existing mining and utilization conditions and groundwater utilization planning, and the deep wells with unreasonable well spacing are shut down. The well spacing and number of mining wells are reasonably planned to avoid over-exploitation.
8. Conclusion

The groundwater in the middle and deep layers of the Quaternary system in the Boxing Section of the lower Yellow River in Shandong Province gradually thinned from the southeast to the northwest as the Quaternary cladding layer gradually became thinner, and the thickness of the single-layer sand layer gradually decreased, and the water richness gradually decreased. The chemical types of groundwater are mainly HCO$_3^-$ and HCO$_3^-$·Cl. The deep sand layer in this area is relatively continuous. The salt water intrudes from north to south in a wedge shape. The buried depth of the freshwater roof slowly declines between 100 and 150m, and decreases gradually between 150 and 300m. The pore water in the middle and deep layers of the Quaternary System received replenishment from the upper shallow salt water and brackish water. The pore water of loose rocks in the middle and deep layers is decreasing from south to north, and the content of Cl$^-$ is increasing. And from west to east, the percentage of HCO$_3^-$ mg equivalent decreased gradually, and the percentage of Cl$^-$ mg equivalent increased gradually. In the area enclosed by the groundwater level at a depth of 40m, the wells in the area are vertically divided into 3 water intake groups according to the water intake group section and well spacing. The first group of sections is 200-300m with well spacing greater than 1570m. The second group of sections is 300-450m with well spacing greater than 1460m. In order to control the
production volume in each mining area, it is necessary to control the planned number of wells and the permitted production volume in each aquifer group and each mining area.

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