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Investigation and analysis of spatial distribution of brine concentration in the underground brine mining area of the northern coastal area of Weifang City

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Abstract: *The underground brine resources in the northern coastal area of Weifang City are widely distributed, and brine is rich in important minerals such as bromine and iodine. With the increasing scale of brine mining in recent years, it has a negative impact on the groundwater environment and leads to a shortage of brine resources. Therefore, clarifying the current occurrence status of brine resources can provide an indicator for mining. This article conducted a survey on the distribution of brine resources in the coastal brine mining area in the northern part of Weifang City in 2022. The survey covers the areas of Wopu (2.0 km northeast) - Yangzhuang (1.5 km north) - Daokou - Chahe (1.0 km northeast) - along the route of Provincial Highway 320 - Qingxiang - Xiaying (1.5 km south) - north of the Jiaolai River Bridge. The survey results of brine show that the concentration of brine (TDS) is distributed vertically, ranging from 10° Be' to 16.5° Be'. Due to the influence of atmospheric precipitation and top support, the TDS exhibits a low high low distribution pattern from shallow to deep; In the horizontal direction, the concentration range of brine is between 5° Be ' and 19.4° Be'. Due to the combined action of seawater and inland freshwater, the salinity of brine from coastal areas to inland areas shows a trend of low high low. There are 3-6 layers of confined brine layers in the entire region, with the first, second, and third confined brine layers being the main brine layers in the region. The TDS of the main brine resources is greater than or equal to 70 g/L. By investigating the distribution of brine concentration in the northern coastal areas of Weifang City, important reference basis can be provided for the utilization of water resources and environmental protection in the region.*

Keywords: *Brine concentration; Spatial distribution; Underground brine; Northern Weifang; Coastal areas*

1. Introduction

On a global scale, coastal areas are influenced by climate, structure, and sedimentary environment, and contain a large amount of ancient seawater, saline water, and brine formed by Quaternary marine invasion [1-3]. The underground brine resources in arid and semi-arid regions are widely distributed, rich in important minerals such as bromine and iodine, which mainly come from coastal underground brine[4-7]. The underground brine resources in China's coastal areas are mainly concentrated in the eastern coastal areas, among which the northern coastal areas of Weifang City have abundant brine resources, mainly distributed in the shallow aquifers of the Quaternary along the coast. The region is known as one of the four major salt regions in China due to its abundant brine resources. The local government has utilized this unique advantage to vigorously develop related chemical industries, and in recent years, the scale of brine extraction has increased[8]. However, in the context of mining, the specific distribution area and concentration of underground brine in the northern coastal areas of Weifang City have not yet been accurately determined.

The utilization of groundwater in the northern coastal areas of Weifang City is mainly achieved through two methods: natural groundwater flow and artificial pumping. The natural flow of groundwater is mainly caused by surface rainfall. For deep confined groundwater, its recharge source mainly comes from the lateral and transverse flow of groundwater, while artificial pumping is currently the only drainage method[9]. In the past 20 years, the high profits generated by the extraction of bromine from brine have greatly stimulated the exploitation of brine, resulting in a decreasing concentration of brine year by year[10], a continuous decrease in groundwater level[11], and the formation of a precipitation funnel with an increasing number[12]. Due to the excessive exploitation of underground fresh water, the area of the saline water area caused by the southward invasion of seawater continues to expand. Today, the saline

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brine area in the northern part of Weifang City has reached more than 1800 square kilometers.

The formation of brine is related to historical Shanghai invasion and regression. Since the late Pleistocene, there have been three large-scale marine invasions and regressions, corresponding to the formation of three layers of marine strata[13]. The residual seawater in the sediment undergoes concentration, evaporation, infiltration, and metamorphism[11], and its salinity continues to rise, ultimately forming brine. However, there is currently insufficient research on the distribution and concentration of the main brine layers.

In order to explore the current spatial occurrence status of brine concentration in coastal brine mining areas under the background of brine extraction, this article extracts mixed brine well samples from monitoring points within the brine mining area, and determines brine concentration (TDS). The aim is to clarify the spatial distribution characteristics and formation reasons of brine concentration, quantify the planar distribution area and concentration range of different brine layers.

2. Overview of the survey area

The survey area is located in the northern coastal area of Weifang City. The geographical coordinates are 118 ° 38 ' 00 " to 119 ° 37 ' 00 " east longitude and 36 ° 57 ' 00 " to 37 ° 18 ' 30 " north latitude. It starts from the Xiaoqing River in the west and ends at the Jiaolai River in the east, and is respectively under the jurisdiction of Shouguang City, Hanting District, Binhai Economic and Technological Development Zone, and Changyi City. It is 83 km long from east to west and 6 to 20 km wide from north to south. The total area of the survey area is 1940 km^2, and the survey points are shown in Figure 1. The terrain in the area ranges from high to low from south to north, with a flat and vast terrain. Most of it is a coastal plain landform, with a slope of one thousandth and an elevation of 2-7 meters. It belongs to the coastal accumulation plain landform. Due to the large amount of sediment carried in by small and medium-sized rivers such as the Weihe River, Jiaolai River, Bailang River, Mi River, and Yu River, the seabed accumulates rapidly, the shallow shoals become wider, the seawater becomes shallower, and the distance between the bay mouths continues to shorten.

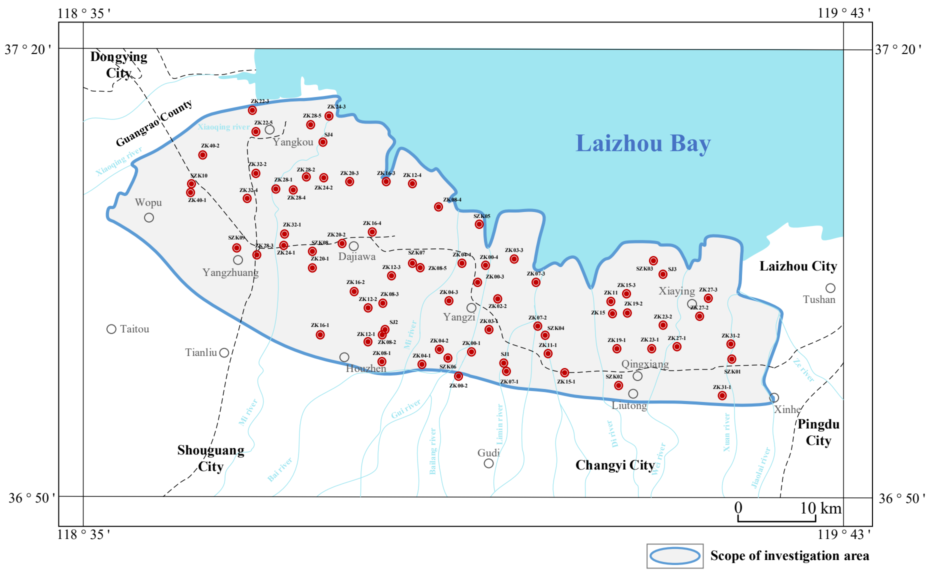

Figure 1: Survey Area and Monitoring Point Map

The area is a typical muddy coast with severe soil salinization on the surface. The sediment in the nearshore zone is mainly composed of sediment brought by historical river and wave erosion. According to previous research, there is an early formed saline sedimentary layer in the area[13], which can store and conduct groundwater. The sedimentary layers mainly include river lake facies, marine land interaction, and loess accumulation facies, composed of thick clay, coarse sand, and fine sand layers (Figure 2). Usually, during low sea level periods, the grain size of river sediments is coarser, while during seawater intrusion, the grain size of marine sediments is finer, mainly composed of organic rich clay, silt, and fine sand[2].

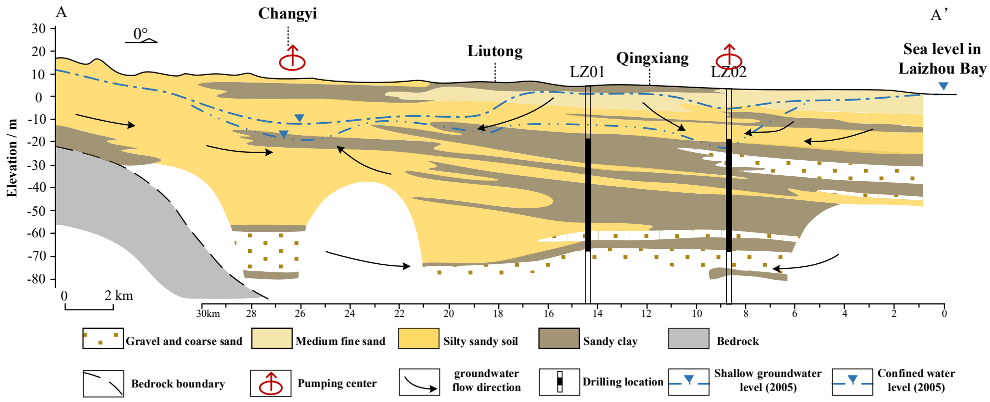

Figure 2: Stratigraphic Profile of Changyi-Qingxiang[14]

The survey area is located in the northern temperate monsoon zone, with a land facing sea and a warm temperate monsoon semi-arid continental climate. According to the data from Weifang Meteorological Bureau (Figure 3), the average annual temperature in the survey area is 12.1℃, gradually decreasing from the south to the north. The highest temperature occurs from July to August, with an average temperature of 28-32℃; The lowest temperature occurs from January to February, and the average temperature is between -6℃ and 1℃. The annual average precipitation is 600-700 mm, concentrated from July to September, with a precipitation of about 60-65%. The annual average evaporation can reach 1900-2400 mm, which is more than twice the annual average precipitation[15]. Atmospheric precipitation has become the main source of replenishment for rivers and groundwater in the region, and river flux and groundwater level are both affected by the total amount of rainfall.

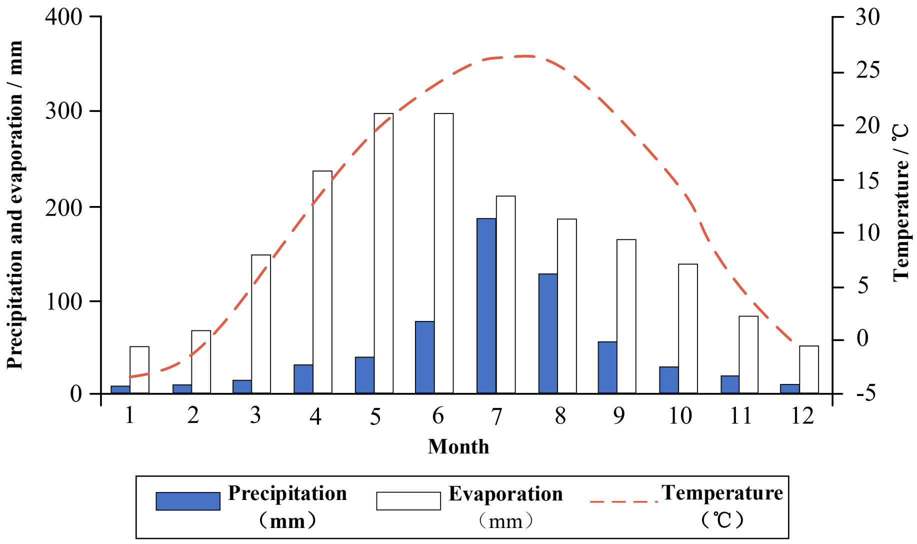

Figure 3: Changes in average monthly precipitation, evaporation, and temperature in the northern coastal areas of Weifang over the years

3. Survey results and analysis

3.1 Investigation and analysis of vertical distribution of brine concentration

3.1.1 Investigation of vertical distribution of brine concentration

The brine layer vertically presents a lens like shape, and can be divided into 2-7 layers. The lithology of the brine layer is mainly composed of silt, fine sand, medium fine sand, coarse sand, etc. The bottom plate is buried at a depth of 48.74-148.69 meters. In the southern part of Yangkou Town, the western and northern coastal areas of Xiaying Town, the burial depth of the bottom plate is the highest, all exceeding 100 meters.

According to the 2022 brine survey, the brine concentration (TDS) shows significant zoning in the vertical direction. Due to the influence of atmospheric precipitation on the upper part and the top replenishment of shallow saline and brackish water in the deep part, two low concentration layers are formed vertically, with a vertical distribution of high concentration layers in the middle. In the depth range of 28 m to 55 m, the concentration of brine reaches its highest, ranging from 10° Be′ to 16.5° Be′ (as shown in Figure 4). From this high concentration layer up and down, the concentration of brine gradually decreases and transitions to saltwater.

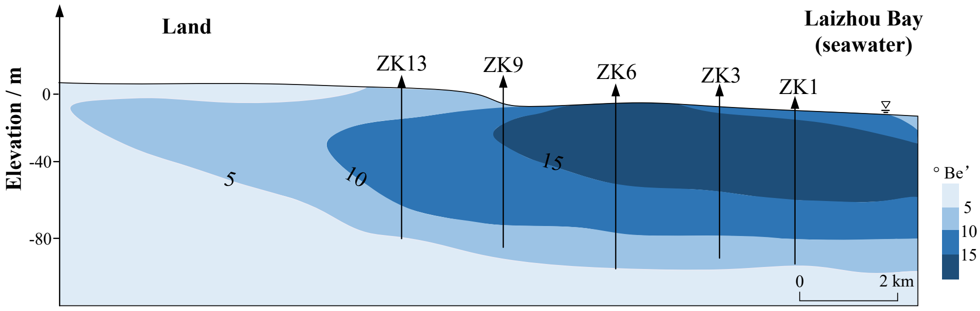

Figure 4: Vertical distribution profile of brine concentration in the northern part of Weifang

3.1.2 Analysis of the vertical distribution of brine concentration

The reason for the above distribution characteristics is that there is a close hydraulic connection between the brine in the upper groundwater layer, surface water, and seawater, and their water level and concentration changes are significantly influenced by atmospheric precipitation and surface water. During the summer flood season, due to the increase in precipitation, the groundwater level will significantly rise, and the concentration of brine will also show a downward trend. On the contrary, during the dry season, the groundwater level will decrease and the concentration of brine will correspondingly increase. In contrast, the storage conditions of the middle and lower confined brine layers are superior and less affected by tides and atmospheric precipitation. Therefore, the brine concentration in this layer is high and relatively stable. There is no fixed boundary between brine and saltwater, and saltwater and brine often coexist in the same aquifer. Moreover, the interface position between saltwater and brine is not fixed and will move with the change of hydraulic pressure difference on both sides of the interface, further increasing the complexity of the relationship between brine and saltwater.

3.2 Investigation and analysis of brine concentration plane

3.2.1 Investigation and analysis of the planar distribution of brine concentration

The scope of the brine survey conducted in 2022 extends from the south bank of Xiaoqing River to the west bank of Jiaolai River. Based on the long-term monitoring data of Weifang Geological Environment Monitoring Station since the 1980s and the detailed survey results of brine resources, the southern boundary of underground brine can be depicted. The boundary roughly starts from the sleeper area (2.0 km northeast), passes through Yangzhuang (1.5 km north), Daokou, and Chahe (1.0 km northeast), then extends along Provincial Highway 320 to Qingxiang and Xiaying (1.5 km south), and finally reaches a vast area north of the Jiaolai River Bridge on Provincial Highway 320. In this area, the TDS (total dissolved solids) value of brine ranges from 50 to 165 g/L, as shown in Figure 5.

Through the summary and analysis of drilling data on the south bank of Laizhou Bay, it was found that the underground brine ore body is divided into 2 to 5 layers, and the thickness of each layer varies significantly, ranging from 17.80 to 58.70 meters. In terms of brine concentration, the range is between 5° Be′ and 19.4° Be′, showing certain zoning characteristics, with a total distribution area of approximately 1300.54 km^2. Among them, the distribution area of 50≤TDS<70 g/L is about 550.58 km^2, accounting for 42.34% of the total area; 70 g/L≤TDS<100 g/L, with a distribution area of approximately 426.24 km^2, accounting for 32.78% of the total area; The distribution area of TDS≥ 100 g/L is about 323.61 km^2, accounting for 24.88% of the total area (Figure 5).

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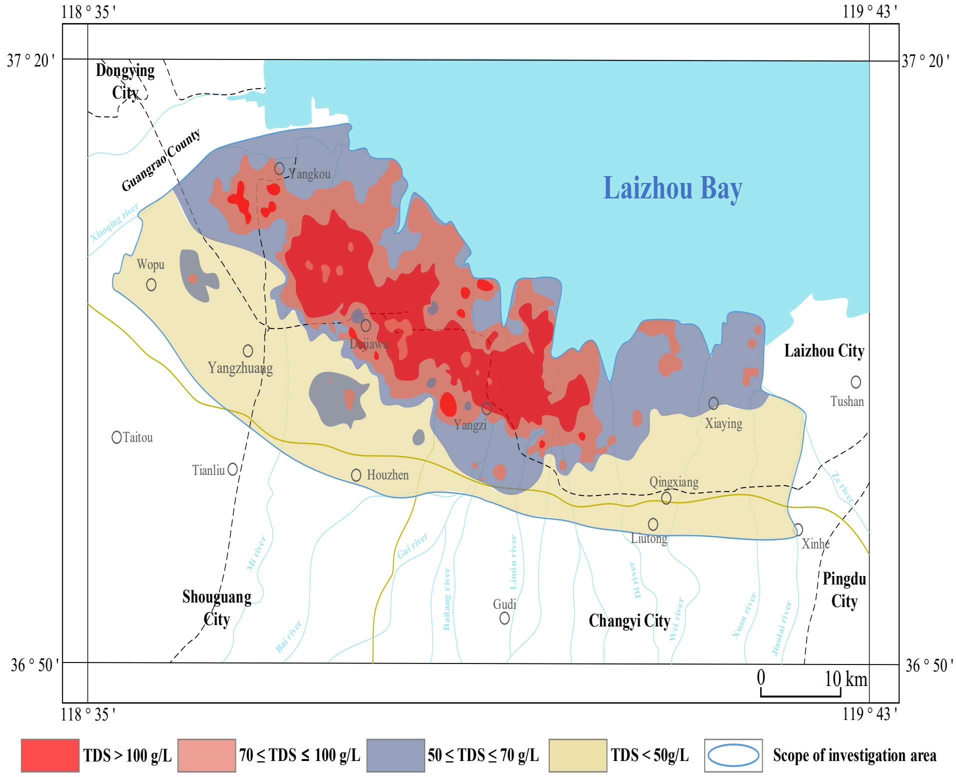

Figure 5: Planar distribution of brine concentration in 2022

The brine layer has a zoning characteristic in the horizontal direction, and its shape presents a regular lens shape. Due to the influence of seawater and inland freshwater in the horizontal direction, the concentration of brine from coastal to inland areas generally varies from low to high to low, forming a distribution pattern of low concentration zones near and far shore, and high concentration zones in the middle (Figure 5).

The low concentration zone in the nearshore area is a zone with frequent tidal action in modern seawater, with a width of approximately 5-10 km. The TDS content of brine is usually maintained in the range of 50 to 100 g/L. The middle is a high concentration zone, mainly distributed in the southern and southeastern parts of Yangkou Town, the northern part of Dajiawa Street, the northern and northeastern parts of Yangzi Street, with a width of 2-12 km. Except for being affected by annual and monthly major tides, it is generally not affected by tides. Therefore, the brine concentration in this area is relatively high and stable, and its TDS content is usually between 100-150 g/L, with a maximum of 194 g/L. The low concentration zone on the far shore is relatively far from the coast, with a width of 5-10 km. Due to its distance from the ocean, it is less affected by seawater and is more affected by terrestrial freshwater and atmospheric precipitation. The TDS content of brine is generally between 50 and 100 g/L, but gradually changes towards the inland direction and eventually turns into saline water with a TDS below 50 g/L.

3.2.2 Plane investigation of concentration of pressurized brine layer

The pressurized brine layer is widely distributed throughout the region, consisting of 3-6 relatively stable brine layers (Figure 6), with a hydrochemical type of Na Cl type. Among them, the first, second, and third confined brine layers are the main brine layers in the region. The TDS of the main brine resources is greater than or equal to 70 g/L, and the brine resources with TDS ranging from 50 g/L to 70 g/L are distributed in the northern seaside and the west of Yangzi Street, with TDS less than or equal to 50 g/L. The brine resources are distributed in the northern seaside, southwest of Yangkou Town, and north of Xiaying Town.

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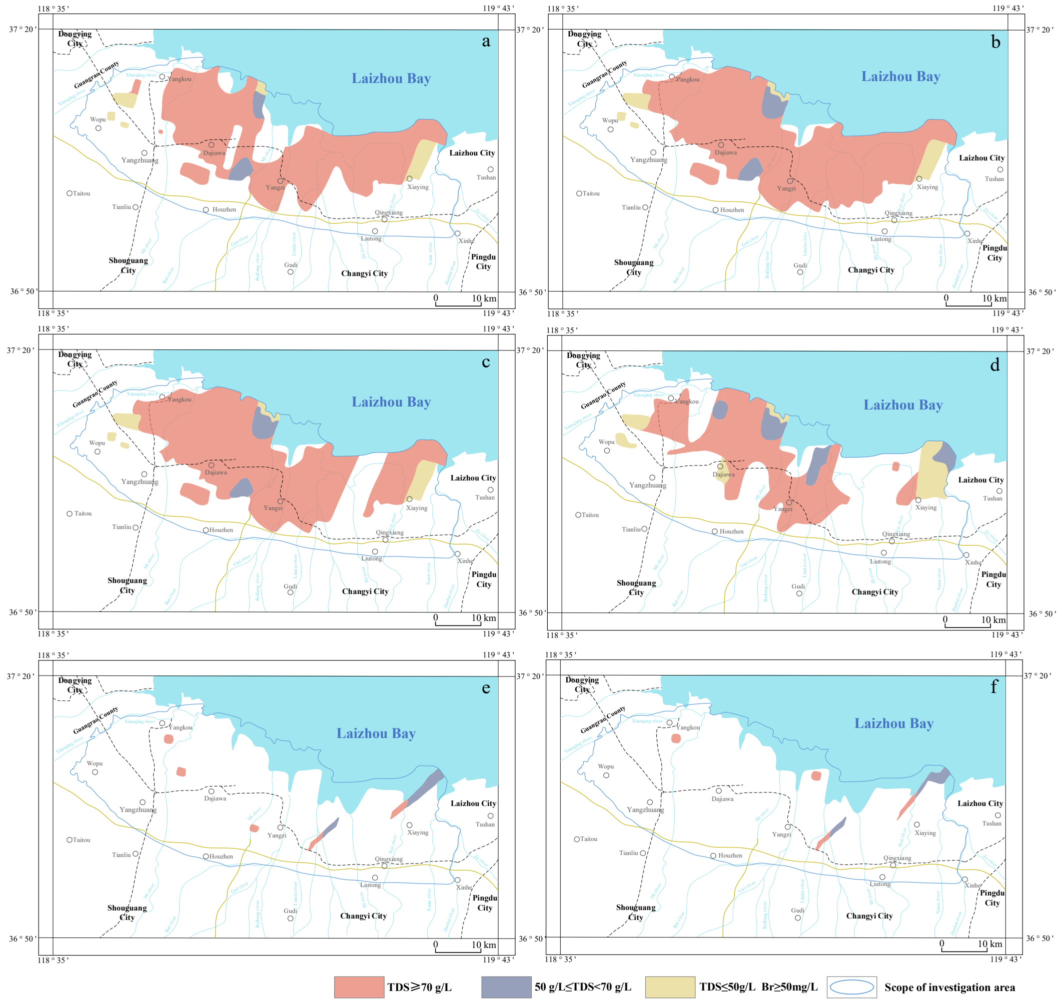

Figure 6: Distribution Plan of Concentration in Pressurized Brine Layer

The first pressurized brine layer is widely distributed in this area and is the main brine layer in this area (Figure 6a). The distribution area of this layer is 898.59 km^2, with the top plate buried at a depth of 9.01-28.50 m and the bottom plate buried at a depth of 17.01-34.00 m. The lithology of the brine layer is mainly composed of silt, followed by fine sand, with few medium to coarse sand. There are a small amount of shell fragments, and it is the second marine layer with a thickness of 0.80-17.48 m. TDS ranges from 33.4 to 130.8 g/L, mainly consisting of brine resources with TDS≥70 g/L. Brine resources with TDS≤50 g/L are distributed in the northern coastal areas and the west of Yangzi Street. Brine resources with TDS≤50 g/L are distributed in the northern coastal areas, southwest of Yangkou Town, and north of Xiaying Town. Due to the continuous exploitation of underground brine, this layer has been drained from the center and periphery of the water level depression funnel with a burial depth greater than 20m in the Caiyangzi Salt Field and the northeast area of Dajiawa Street.

The second pressurized brine layer is distributed in this area and is the main brine layer in this area (Figure 6b). The distribution area of this layer is 1002.44 km^2, with the top plate buried at a depth of 20.60-43.79 m and the bottom plate buried at a depth of 32.91-56.61 m. The lithology of the brine layer is composed of silt, fine sand, occasionally medium coarse sand, and a small amount of shell fragments. It is the second marine layer, with a thickness of 1.20-20.68 m and a TDS of 33.4-182.2 g/L. The main brine resources are TDS≥70 g/L, with 50 g/L≤TDS<70 g/L brine resources distributed in the northern coastal area and the west of Yangzi Street. TDS≤50 g/L brine resources are distributed in the northern coastal area, southwest of Yangkou Town, and north of Xiaying Town.

The third confined brine layer is the main brine layer in this area, which is distributed in other areas except for the insufficient concentration in the northern part of Liutuan Town (Figure 6c). The distribution area of this layer is 940.45 km^2, with the top plate buried at a depth of 37.50-68.26 m and the bottom plate buried at a depth of 47.80-73.60 m. The lithology of the brine layer is composed of silt, fine sand, occasionally medium coarse sand, and a small amount of shell fragments. It is the first marine layer with a thickness of 1.19-25.69 m. It is the thickest in the area from Caiyangzi Salt Farm to Qingshuibao Farm in Yangkou Town, with a TDS of 34.3-163.7 g/L, mainly composed of brine resources with a TDS of ≥70 g/L. The brine resources with a TDS of 50 g/L≤TDS<70 g/L are distributed along the northern coast and west of Yangzi Street, with a TDS of ≤50 g/L brine resources. Distributed in the northern seaside, southwest of Yangkou Town, and north of Xiaying Town.

The fourth confined brine layer is distributed in the area of Yangkou Town Dajiawa Street Yangzi Street and the northern part of Xiaying Town (Figure 6d). The distribution area of this layer is 700.73 km^2, with the top plate buried at a depth of 54.89-84.95 m and the bottom plate buried at a depth of 68.81-10.378 m. The lithology of the brine layer is mainly composed of silt, followed by fine sand and a small amount of medium coarse sand, which is the first marine layer with a thickness of 1.06-15.36 m and a TDS of 42.9-115.6 g/L. The main brine resources are TDS≥70 g/L, with TDS≤70 g/L. The brine resources are distributed in the northern coastal area and the east of Yangkou Town, while TDS≤50 g/L brine resources are distributed in the northern coastal area, southwest of Yangkou Town, Dadawa Street, and north of Xiaying Town.

The fifth and sixth pressurized brine layers are only distributed on a small scale in the south of Yangkou Town, the west of Yangzi Street, the southeast of Xili Fishing Village, and the northwest of Xiaying Town, and are not found in other areas (Figure 6e, 6f). The distribution area is about 40 km^2, with the top plate buried at a depth of 78.80-124.49 m and the bottom plate buried at a depth of 94.70-148.68 m. The lithology of the brine layer is mainly coarse sand, medium fine sand, and silt, with a small amount of gravel, fine sand, and silt mixed in. The thickness is 0.69-31.47 m, and the TDS is 56.7-118.7 g/L. The brine resources with a TDS ≥ 70 g/L are distributed in the south of Yangkou Town, the north and east of Yangzi Street, and the north of Xiaying Town. The brine resources with a TDS≤50 g/L and a TDS< 70 g/L are distributed in the east of Yangzi Street and the north of Yangkou Town.

4. Conclusion

The vertical distribution of brine concentration (TDS) is lens shaped, and there is a close hydraulic connection between brine, surface water, and seawater. The water level and concentration changes are significantly influenced by atmospheric precipitation and surface water, forming a low high low distribution feature from shallow to deep; In the horizontal direction, due to the joint action of seawater and inland freshwater, the concentration of brine varies from coastal to inland, forming a distribution pattern of low concentration zones near and far shore, and high concentration zones in the middle. There are 3-6 layers of confined brine layers in the entire region, with the first, second, and third confined brine layers being the main brine layers in the region, and the TDS of the main brine resources is greater than or equal to 70 g/L.

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