The analysis of sea(salt) water intrusion in Weibei-plane of Shandong

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Abstract. Based on the environmental geological survey, sample test and hydrogeological survey, this paper makes a systematic analysis on the source, formation, weather, topography and hydrogeology of sea water (salt) intrusion, and analyzes the plane sea water (salt) intrusion in the north of Wei River.

1. Development process of sea (salt) water intrusion
The first sea (salt) water intrusion in Weibei-plane was discovered in 1976[1]. In the long-term monitoring wells in Shouguang and Hanting District, salt water quality and Cl− concentration were firstly observed, which were only isolated point-like intrusions[2-8]. With the continuous and rapid development of national economy and the increase of groundwater exploitation, the intrusion of sea (salt) water is expanding rapidly to the south. From 1985 to 1990, the intrusion speed of sea (salt) water was faster, the average rate of intrusion was 53 km² per year; from 1990 to 2000, the intrusion speed became slower, the average rate of intrusion was 12.32 km² per year; from 2000 to 2005, the intrusion speed continued to slow down, the average annual rate of invasion was 14.77 km². During 2005~2009, the rate of invasion accelerated suddenly, the average annual rate of invasion was 126.69 km². During 2009~2015, the rate of invasion was faster, the average annual rate of invasion was 200.75 km². By the end of 2015, the area of shallow salt water in the working area was 1645.08 km². Compared with 2009, the Sea Water Invasion Front in 2017 pushed southward from Nanhan village to the north of Gaoli town, south Zhongzhai village to the north of Gudi town, South Xingfu, Taobu to the north of Weizi.

2. Sources of sea (salt) water intrusion
According to the source of intrusion, the Weibei-plain can be divided into two types: Saltwater intrusion and saltwater-seawater intrusion. Seawater intrusion is the phenomenon that the salt-fresh water interface advances to the land when the fresh water head is lower than that of the wedge-shaped body of seawater. Salt-water intrusion is a phenomenon that the salt-water interface pushed inland due to the overexploitation of the adjacent freshwater resources in the quaternary salt-water bodies buried in marine sediments. Saltwater intrusion includes the dispersion of Cl− at the saltwater-freshwater interface and the movement of Cl− with the groundwater under pressure difference.
2.1 Saltwater-seawater intrusion zone
The mixed intrusion of Saltwater and seawater in the Weibei-plain takes the form of upper saltwater intrusion and lower saltwater intrusion, which are mainly distributed in the northern Weihe of Changyi. The distribution width of the underground brine in the Binhai Zone is 10-20 km, the Weihe River valley is wider, the backwater from the estuary affects more than 20 km in the lower reaches (up to Xin’Anzhuang Tidal Gate). There are two ancient rivers in Weihe, which are located in the area of Changyi-Longchi and Liutuan-Qingxiang in Long Tri. Most of the remains are buried in shallow layers. According to the data of geophysical exploration near Liutuan and hydrologic drilling in Liutuan middle school, the depth of the brines is 12-14m, the brackish water layer is up and down, the upper layer is sandy soil, and the water permeability is strong. It is obvious that the source of the upper intrusion in the Weihe River valley is from the seawater of Weihe. The Cl-content in the samples of the well is 695.13 mg / L and 937.00 mg / L, respectively. From the section from the entrance to the West Bank of the Liutuan River (Fig.1.), it can be seen that there are two vertical layers of clayey soil with relative water-resisting layers in the area. The buried depth of the roof is about 10m and 13m respectively, and the thickness of the water-resisting layers are 2-3m. Therefore, the intrusion source of the Lower Aquifer is brine. There are wide underground salt water and brines in the coastal area, so the tide can not directly invade the inland fresh water, so the main source of the intrusion in the south of Liutuan is salt (brine) water.

2.2 Saltwater intrusion zone
The area is located in the coastal plain areas along the Bailang river in northern Weifang, extending from the Fengchanhe River in the east to the western end of the working area in the West. The distribution of underground brines in the Binhai Zone is 20-30 km in width and the depth of brines ranges from the surface to 80 m. The width of salt water zone is 8-10km and the thickness of salt water layer is 100m. There is a seasonal flow of the Mi River into the sea. The Mi River has almost no run-off throughout the year. The Laohekou River is located at the Bund of Yangkou saltworks in the northwest corner of the working area. The Xinhekou River and the Bailang River merge into one. The Limin River and the Fengchan River join the Yu River into the sea. The estuaries is relatively small, the influence area of seawater back flow is small. The underground salt water extends from the north salt water area to the south salt water area in the east-west direction in the form of brackish-fresh water mixed zone and wedges into the fresh water aquifer. The brackish-freshwater mixed zone is more than 30 km from the modern coast, and it is difficult to push the seawater across the underground brackish water zone to the inland freshwater zone by the superstorm surge.

3. Invasion mode and characteristics of sea (salt) water
There are three main types of sea (salt) water intrusion in the region: areal invasion, banded invasion and cross-flow invasion.

3.1 Areal invasion
Areal invasion is the most common type of invasion in the area. The area is mainly coastal plain and Lower Valley Plain. The aquifers are mostly alluvial, alluvial and alluvial sand or gravel layers. The continuity and permeability of the aquifers are good, generally, the same aquifer with salt and fresh
water co-exist. The Sea (salt) water can penetrate inland along the Aquifer. The intrusion is in plane shape and wedge shape in profile (Fig. 2.). In addition, the dispersion of Artesian Brine at the interface of salt and fresh water and the flow with the pressure difference of groundwater also result in the area intrusion of salt water.

![Fig. 2. Schematic diagram of Yangjiawa to Coastline](image)

The obvious characteristic of the areal sea (salt) water invasion is that the invasion area and the groundwater drop area (Liulv funnel, Weihan funnel, Changyi Funnel) are interrelated in distribution, the invasion velocity is affected by the amount of groundwater extraction, mining method and precipitation (Fig. 3.). However, due to the exploitation not only of fresh water, but also of Brine, salt water and deep pore water for irrigation and cultivation of marine products, it not only forms a landing funnel in the freshwater area, but also forms a landing funnel in the brackish water area, at the same time, as a result

![Fig. 3. Change chart of sea (salt) water intrusion front](image)
of the increase of the exploitation of the deep pore water, the Artesian head drops more than ten meters than that of the salt water, resulting in the leakage of the salt water, which is equivalent to the further exploitation of the salt water. For example, an underground watershed is formed between the freshwater funnel and the brine funnel, which limits the movement of sea (salt) water across the watershed to the freshwater funnel center.

3.1.1 East of the Bailang River
The mining of underground brine and salt water in this area is mainly used to extract bromine and sun-cured Salt. Driven by Yangkou salt field, the mining quantity is large and relatively stable. The salt water intrusion was mainly influenced by the Liulv funnel and irrigation water. During 2000-2005, with the area of the Liulv funnel reduced by half, the salt water bodies dispersed in the same aquifer with the effect of groundwater exploitation for agricultural irrigation in the south, advancing southward by an average of 1.4 km per year.

During 2005-2008, the area of Liulv funnel was reduced to 1/8, and the saltwater intrusion front was affected by the decrease, which was 1.5 km per year on average. During 2008-2009, with the increase of groundwater exploitation, the area of the funnel expanded to 2.7 times of that in 2008, and the saltwater intrusion front line showed a trend of advancing toward the center of the funnel. During 2009-2015, with the increase of the area of the infundibulum and the dispersion of the salt water in the front of the infundibulum in the east-west direction in 2009, the salt water intrusion front in this area pushed southward as a whole.

3.1.2 Section from Bailang River to Yu River
The exploitation of underground brines, brackish water and brackish water is mainly used to extract bromine, sun-dried salt and breed marine products, it is also affected by the exploitation of underground brine, brackish water and brackish water. During 2000-2005, the area of Weihan funnel decreased by one third, but the area of fruit and vegetable planting in Gudi town increased year by year, and the irrigation water consumption increased accordingly, the saltwater intrusion front moved southward at an average rate of 1.1 km per year. During 2005-2008, the area of Weihan funnel was further reduced to half of the 2005 area in 2008, while the agricultural irrigation water consumption in Gudi town remained at the 2005 level. As a result, the saltwater intrusion front retreated slightly at an average speed of 0.9 km per year. During 2008-2009, the funnel area increased, but with the rapid development of aquaculture, the exploitation of deep brackish water in the north also increased (shallow brackish water recharge increased). During 2009-2015, the area of the Weihan funnel was further expanded to double its original size, and a new deep funnel area was formed between Bozi and Yangzi in the north due to excessive exploitation of the deep salt water and slightly salt water, therefore, the saltwater intrusion front tends to recede in the deep funnel area.

3.1.3 East section of Weibei Farm
In the northern part of this section, within 37 km from the modern coastline, the underground brine and salt water mining is mainly used for drying salt in the salt fields of Weibei farm and Zaohu farm. The deep brackish water from the Dongliyu to the front line area is mainly used for farmland irrigation and seafood breeding. Due to the unified management of the Weibei farm and the Zaohu saltworks, the scale of the saltworks has not changed much except for the extension of the Zaohu saltworks in 2007, the land area and cultivated crops are relatively stable. The development of the aquaculture industry in the lower reaches of Weihe had begun to take shape before 2000 and has changed relatively little so far. Therefore, the amount of underground brine, salt water and brackish water extracted has not changed much, the change of saltwater intrusion front in this area is mainly influenced by the funnel of Changyi on the southeast side. During 2000-2005, the funnel area in Changyi was reduced by half, but with the increase of the demand for groundwater by textile enterprises in Liutuan industrial park and the increase of the planting area of ginger fields in the south, the sea (salt) water intrusion front was pushed inland at the rate of 1.0 km per year. During 2005-
2008, with the further decrease of funnel area in Changyi and the expansion of salt pans in Zaohu saltworks, the exploitation of underground brine increased, and the intrusion front of sea (Salt) water retreated at the rate of 1.9 km per year. During 2008-2009, the funnel area in Changyi began to increase, and the sea (salt) water intrusion front further invaded south. By 2015, the funnel area in Changyi doubled that in 2008, and the sea (salt) water intrusion front also advanced to Wang Fanzhuang village.

Because of the seawater intrusion on both sides of the Weihe River, the construction of the Xin Anzhuang Tidal Gate made it impossible for the seawater to flow back into the river except for the extreme storm surge. The annual runoff of the Weihe River was larger, and the seawater intrusion was blocked by the support of the river water, it's not moving as fast as the two sides of the valley. In addition to seawater intrusion, shallow brackish water is also the main source of intrusion, and the concentration of brackish water is inversely proportional to the distance from the river channel, which is the main reason that the intrusion speed of both sides of Weihe River is faster than that of the river valley.

3.2 Banded invasion
The Weihe River, Changyi-Longchi, and Liutuan-Qingxiang are mainly sandy soils with strong permeability, which are rich places of groundwater. Due to the groundwater exploitation in the area, the water level of the Aquifer is lower than the sea level, and the seawater intrudes inland along the paleochannel in the form of a belt, and the intrusion speed is relatively fast.

3.3 Cross-flow intrusion
The transgressive intrusion mainly occurs in the deep fresh water and brackish water mining area in the north of the working area. There is a large area of brackish (brines) water distributed in the area, under which is confined fresh water. As a result of the rapid development of the mariculture industry, especially the increase of mud carp farms and the increase of the amount of brackish water extracted from the deep underground, there is no order in the working area, the water level is dropping fast. Taking the 300m deep well of Chuijia Yangzi fish farm in Yangzi town as an example, the water level of the well was 32.10m on January 15, 2012, and 46.82m on April 18, 2012. The pumping of deep fresh water and brackish water causes the head of confined fresh water to drop several meters to more than ten meters than that of brackish water, which causes the intrusion of Brackish water downward. The deep pore water aquifer in this area is relatively continuous and permeable, and the fresh water polluted by vertical cross-flow quickly disperses in the aquifer plane, which makes the area of deep pore water invaded by salt water larger and the quantity of deep fresh water decreased year by year.

4. Conclusion
(1) The intrusion of sea (salt) water was first discovered in 1976, and the rate of the intrusion was fast from 1985 to 1990 and 2005. By the end of 2011, the area of shallow salt water in the area was 1645.08 km².

(2) According to the source of the intrusion, the area can be divided into two types: Saltwater intrusion and saltwater-seawater intrusion, of which saltwater intrusion is the main one. Saltwater intrusion is mainly distributed in the coastal plain areas along the Bailang River in northern Weifang, from east to Fengchan River and West to the western end of the working area.

(3) There are three main types of sea (salt) water intrusion: areal invasion, banded invasion and cross-flow invasion. The areal invasion is the most common type of invasion in the region. The banded invasion is manifested in the distribution of the Weihe River, Changyi-Longchi and Liutuan-Qingxiang. The cross-flow invasion mainly occurs in the deep fresh water and brackish water mining area in the north of the working area.
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