

THE CHARACTERISTIC AND CAUSE OF SEA WATER INTRUSION AND POLLUTION IN SOUTH LIAODONG PENINSULA

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ABSTRACT: Based on various patterns of groundwater and their abundance characters in south Liaodong Peninsula, the distribution, stage, pattern and characters of sea water intrusion in the serious sea water intrusion areas are analysed. The reasons to cause sea water intrusion are uneven precipitation, limited recharge of surface water, artificial overpumping, lithology and geological structure. It can provide scientific basis for reasonable utilization of limited water resource in line with the local conditions.

KEY WORDS: south Liaodong Peninsula, sea water intrusion

South Liaodong Peninsula includes Dalian, Wafangdian, Zhuanghe, Xinjin, etc., where water resource is poor, with average annual quantity of 3.48 billion m^3 , 1.23 billion m^3 of groundwater and 0.64 billion m^3 of exploitable water resource. The quantity of water per person is 760 m^3 , which only reaches 81.6 % of that of Liaoning Province and 28.7% of that of the whole country. Especially in the district in the south of Jinzhou, where industry, city and population are concentrated, the quantity of water resource per person is less than 200 m^3 , only reaching 7.4% of that of the whole country. The groundwater resource is one of the important factors which prohibit the economic development in south Liaodong Peninsula. Therefore it is very important for us to recognize the characters of the spatial and temporal distribution and the formation reasons of groundwater invaded and polluted by sea water so as to provide a scientific basis for reasonable utilization and reservation of the limited groundwater resource in line with local conditions.

I. THE TYPES OF GROUNDWATER

1. Fissure Water in Pore of Block Stone

It is mainly distributed in Xinjin, Zhuanghe and the east of Jinzhou (Fig.1)^[1]. The rock kinds are mainly metamorphic rock and igneous rock formed in various periods. The groundwater is mainly reserved in netlike weathering fissures of bedrock, which is characterized by thin burying, poor wateriness and uniform distribution. In certain areas where the condition of water accumulation is favorable and the weathering shell is thick, the quantity of water that a well pours is from 10 to 100 t/ d.

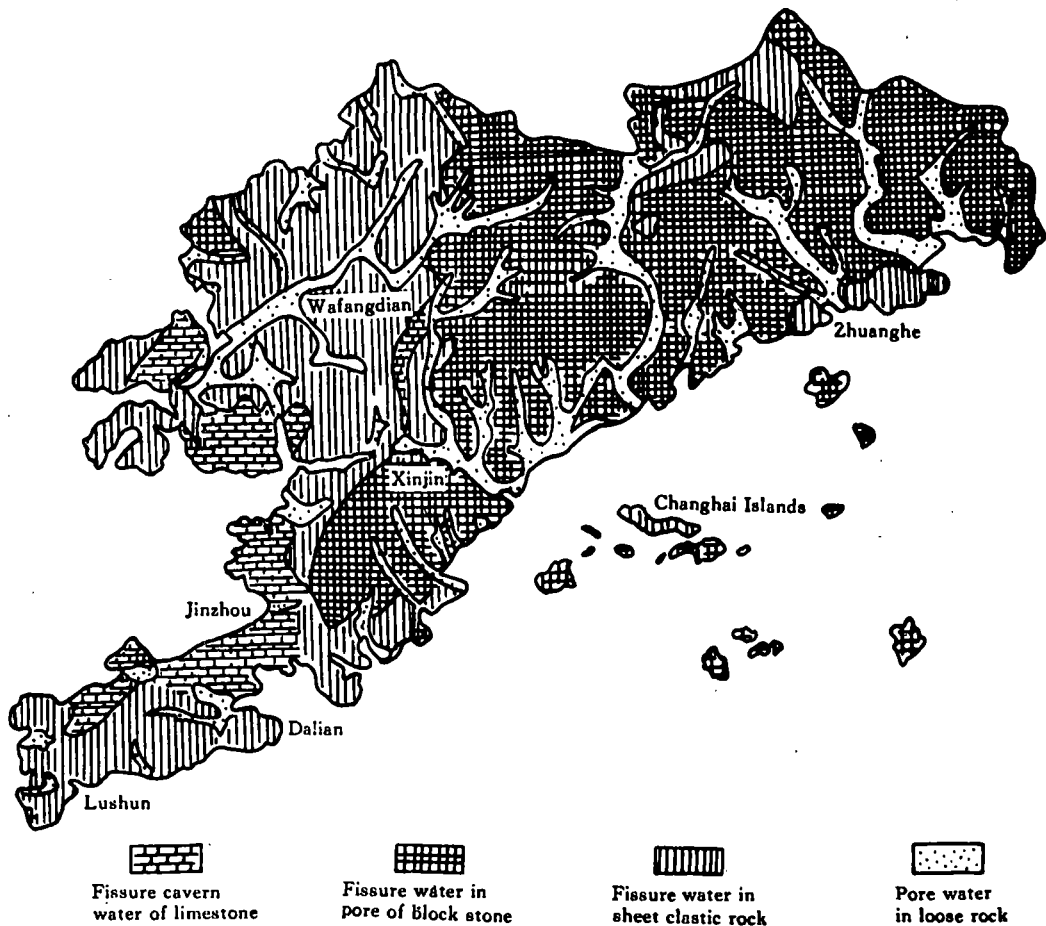


Fig.1 Groundwater types in south Liaodong Peninsula

2. Fissure Water in Sheet Clastic Rock

It is mainly distributed in Wafangdian, the north of Zhuanghe, the south of Dalian

and Changshan Islands, etc.. The kinds of rocks are sandstone, conglomerate, quartzite, slate, etc.. The groundwater is mainly reserved in tectonic fissure of brittleness rock. It shows poor watery and non-uniform distribution. Constantly the quantity of water that a well pours is about 100 t/ d and quantity of water is large in the areas where the relief, rock and structure are favorable.^[2]

3. Fissure Cavern Water of Limestone

Its main distribution areas are in the southwest and middle of Wafangdian, the southwest of Jinzhou, the northeast of Dalian, the north and middle of Lushun. The kinds of rocks are mainly limestone, etc.. The groundwater is mainly reserved in the areas where caves are growing, with rich water resources and extremely non-uniform distribution^[3]. The quantity of water that a well pours is about 1,000 t/ d in water-enrichment areas and less than 100 t/ d in water-short areas. Since 1960, the water-enrichment areas have been successfully supply the urban areas with water.

4. The Pore Water in Loose Rock

It is mainly distributed in valley terrace and valley flat, piedmont and littoral plain, the deltas where rivers flow into the sea, etc..The kind of rock is mainly alluvium, in which the water is richer,shallowly distributed and can be extracted easily. The groundwater depend on the thickness of aquifer. The quantity of water that a well pours is from 100 to 1,000 t/ d.

5. Structural Fissure Water of Bedrock

It is one of the main water reserving types in south Liaodong Peninsula. The groundwater is mainly reserved in fault shatter where water is congested. It is characterized by vein-like distribution with certain direction, deeper burying, good water quality, abundant water quantity and extremely uneven water enrichment. The quantity of water that a well pours is from 500 to 1,000 t/ d^[4].

II. THE INTRUDING CHARACTERS OF SEA WATER

The characters of the tendency of water distribution in space and time in the district intruded and polluted seriously by sea water in south Liaodong Peninsula are shown as follows:

1. Zonality of Sea Water Intrusion

The distribution of the districts invaded and polluted by sea water are restricted in certain districts. They are mainly distributed in the following districts.

1.1 The coastal district in sea gulfs

In the coastal areas of Fuzhou Gulf, Pulandian Gulf, Jinzhou Gulf and Yingchengzi Gulf of the Bohai Sea, Dalian Gulf, Dayao Gulf of the Yellow Sea, etc., the groundwater is intruded and polluted evidently and the areas polluted are the largest (Fig.2).

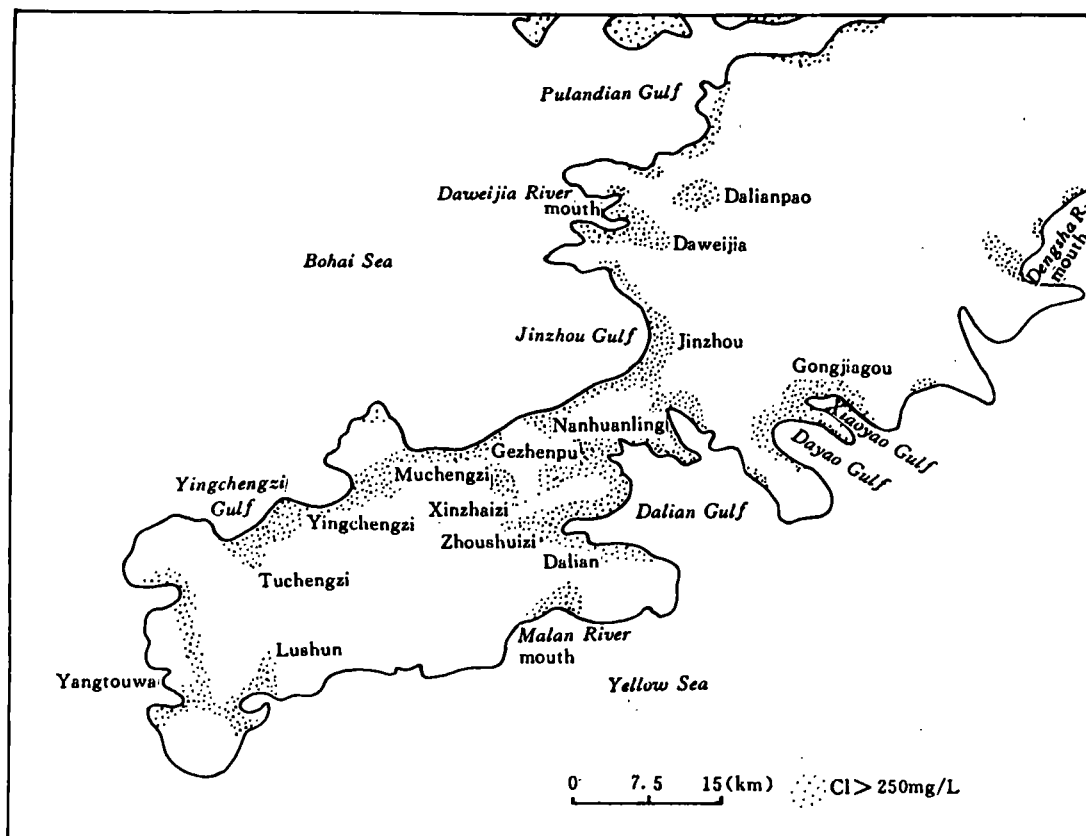


Fig.2 The distribution of groundwater seriously invaded and polluted by sea water in south Liaodong Peninsula

1.2 Lower and plain district

It include Fuzhou River mouth, Malan River mouth; costal plains of Tuchengzi and Muchengzi; basins of Daweijia, Dalianpao, Gezhenpu, Nanguanling ,etc.

1.3 The districts where rock rich in water

They include districts of loose strata where the water-reserving ability is strong such as Yingchengzi; limestone districts where the water-reserving ability is good, such as Dalianpao, etc., and the districts where fractures are growing, such as Nanguanling, etc..

1.4 Districts where the quantity of water extraction is large

These districts are industrial and mining areas, such as Zhoushuizi, Dongjiagou, etc.; farming product bases, such as Muchengzi, etc.; sources of water supply, such as Daweijia, Gezhenpu, etc..

2. The Stage of Water Intrusion

The general tendency of the sea water in south Liaodong Peninsula can be divided into four periods according to the rate of sea water intrusion and the area extension since 1964 (Fig.3).

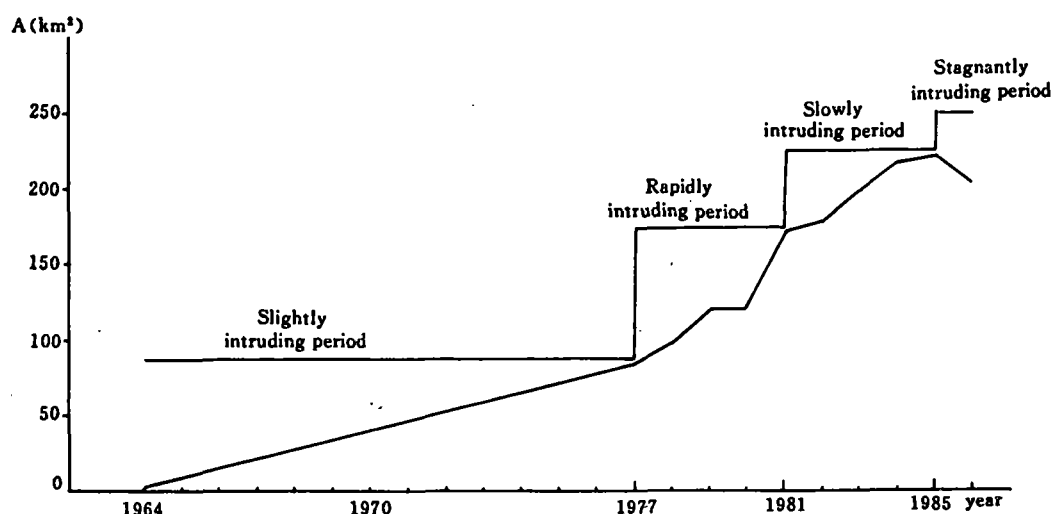


Fig.3 The increasing and changing curves of the areas intruded and polluted by sea water in south Liaodong Peninsula from 1964 to 1986

2.1 Slightly intruding period

From 1964 to 1977, the area invaded and polluted by sea water reached 83.95 km², with a general increasing rate of about 6.2 km². For example, the intrusion of sea water began in 1964 in Nanguanling district and the area invaded reached 14.5 km² in 1977, with an average increasing rate of 1.1 km².

2.2 Rapidly intruding period

From 1977 to 1981, the sea water intruded rapidly, and the area invaded and polluted by sea water has reached 173.5 km^2 , with a total increase of 107% and an average annual increasing rate of $22.39 \text{ km}^2/\text{a}$. For example, the increasing rate was the highest in Jinzhou district, the area invaded and polluted by sea water increased as much as 20.72 times.

2.3 Slowly intruding period

From 1981 to 1985, because the exploited quantity of groundwater was controlled, although the area intruded and polluted was increasing, the increase speed was slower than that of last period and the area reached $222.8 \text{ km}^2/\text{a}$, with an increase of 28% and an average increasing rate of $12.3 \text{ km}^2/\text{a}$. In this period the areas intruded in different districts increased or decreased slightly.

2.4 Stagnantly intruding period

Since 1985, because the exploited quantity of groundwater was controlled strictly, the area intruded has declined to 208.8 km^2 , being 14 km^2 less than that in 1985.

III. THE TYPES OF SEA WATER INTRUSION

The types of sea water intrusion in south Liaodong Peninsula are confined by different mediums. They are different due to the different factors including the types of rocks, structures and their combination (Fig.4), and the main types are as follows.

1. Intrusion in Plane Form

This is mainly confined by the uniform medium in aquifer of Quaternary loose accumulation. Sea water stretches to inland in plane form, and the invasion is extensive and regular. The isopleths of Cl^- are parallel with the coast line, the content of Cl^- declines gradually and slowly from coastal areas to inland, and the average increasing rate of Cl^- is smaller.

For example, the aquifer is composed of sands and gravels with a thickness of 4 to 7 m of pore water in the stratum in Muchengzi. The isopleths of Cl^- are paralleled with the coast line and the content of Cl^- from the coast to inland. The profile of Cl^- from the coast to inland was measured practically in May of 1987. The contents of Cl^- are 1044,

529,371 and 221 mg/ L in Houhai, Houmu, Qianmu and the Muchengzi River respectively (Fig.5).

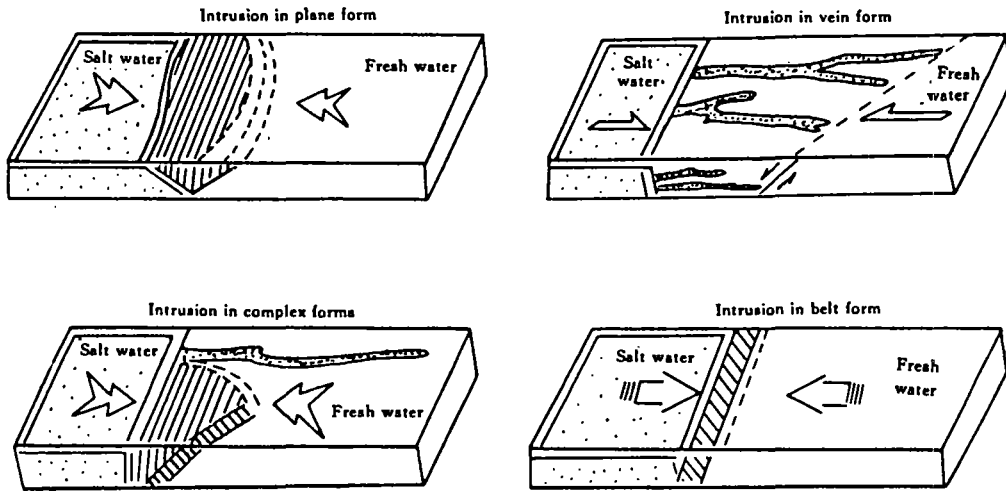


Fig.4 The models of sea water intrusion of groundwater in south Liaodong Peninsula

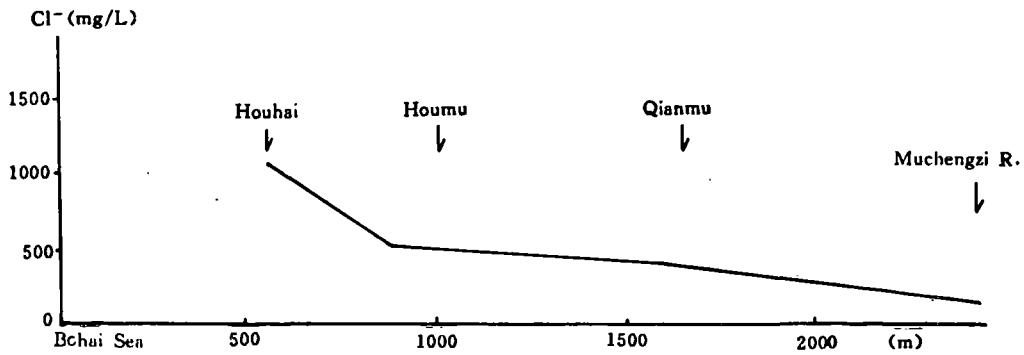


Fig.5 The distribution of Cl^- in Muchengzi district

In the section of 529 to 1,044 mg/ L, the average increasing rate of the content of Cl^- is 1.5 mg/ (L · m), and in the section of 371 to 529 mg/ L, it is only 0.14 mg/ (L · m).

2. Intrusion in Vein Form

It is mainly confined by non-uniform medium of karst of carbonate rock. The sea water wedges into inland along the passage way of karst in vein form. The isopleths of Cl^- changes suddenly and unregularly from coast area to inland and the average increasing rate is much higher than that in plane form.

For example, in Nanguanling area, under the control of the fractures in north-west di-

rection or in the nearly east–west direction, the sea water intrudes in vein form from Sandaogou and Quanshuiyan to Nanguanling northwest ward (Fig.6) and then diversifies to south–west with 9 km intrusion into inland. The isopleth of Cl^- of 1,000 mg/ L is almost vertical with coastal line. The content of Cl^- is distributed non–uniformly from coastal areas to inland and in some areas in inland the content of Cl^- is much higher than that in coastal areas, and the average increasing rate reaches 75 to 150 mg / (L • m).

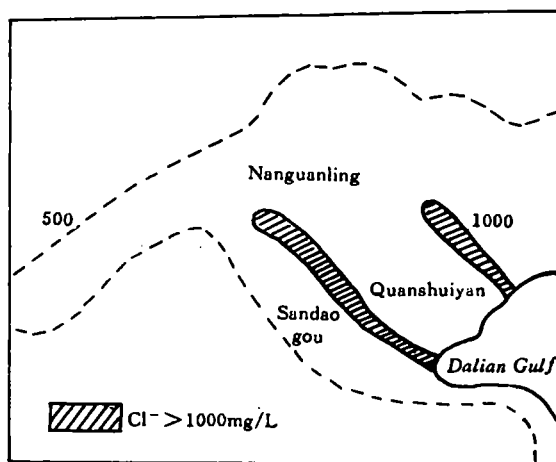


Fig.6 The isopleths of Cl^- in Nanguanling area

3. Intrusion in Belt Form

This is mainly confined by non–uniform medium of structural fissure of quartzite and slate. It shows the character that the sea water intrudes in certain direction and mostly in belt form. The isopleth of Cl^- is most parallel with the coast line and the rang stretching into inland is narrow. The content of Cl^- decrease from coastal areas to inland, and the average increasing rate is higher than that of the intrusion in plane form and lower than that of the intrusion in vein form.

For example, in the south coastal areas of Dalian Gulf, quartzite and slate trends in east–west direction, and the tendency is in south direction with an inclining angle of about 45° , and the sea water intrudes in belt form. The isopleth Cl^- of 1,000 mg/ L is basically parallel to the coast line in a range of 0.5 to 1 km near the coast(Fig.7).

4. Intrusion in Complex Form

Because of the complexity of rock combination and of the structure in the areas intruded by sea water, the sea water intrudes in complex way with the character of different

types of sea water intrusion.

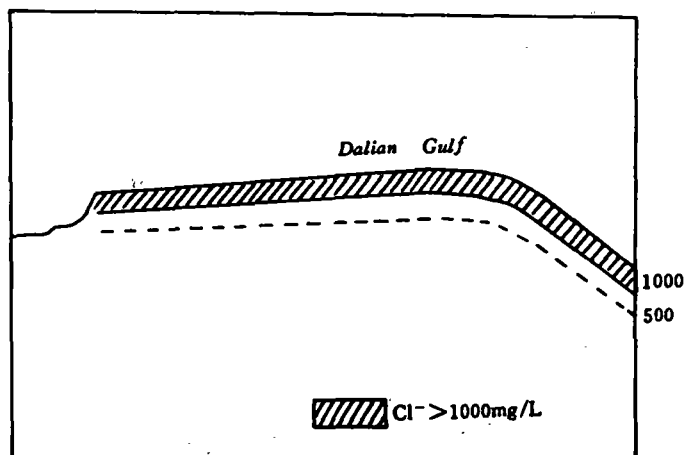


Fig.7 Isoplethes of Cl^- on the southern bank of Dalian Gulf

For example, in Muchengzi the pore water of loose stratum is in the upper layer and the fissure water of karst is hidden in the lower layer. From the coastal area to railway section, the intrusion is in uniform plane form ; from railway to limestone foot of hills, the intrusion is in vein-form. The content of Cl^- is higher in the district of the hill foot than that in the coastal district, the Cl^- of 1,000 mg/ L is parallel to the foot of the hill in east-west direction in vein form.

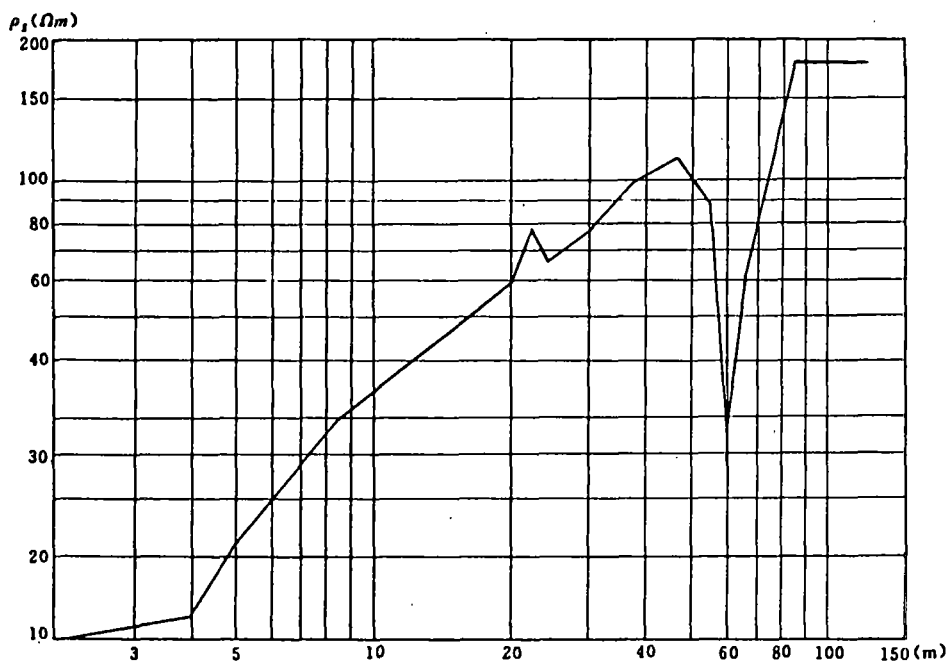


Fig.8 The groundwater curves by electrical sounding in Xiaoheshi area

The district of Xiaoheishi area is another example. Through the analysis of hydrological exploration results^[5], it is discovered that the sea water invades in plane form in the upper layer and in vein form in the lower layer, and this is the most obvious in the depth of 60 m.

Among the four intruding types of sea water mentioned above, the non-uniform medium intruding in vein form polluted the groundwater most seriously.

IV. THE CAUSES OF SEA WATER INTRUSION

Whether the sea water intrudes or not depends on the relationship between the hydrostatic pressures of groundwater and sea water in the medium. When the groundwater level is higher than sea level, the groundwater drains into the sea and the sea water intrusion does not happen; when the groundwater level is equal to sea level, the limited intrusion appears; when the groundwater level is lower than sea level, the sea water intrudes inland. Some special factors provide favorable conditions for the sea water intrusion in south Liaodong Peninsula.

1. The Great Difference of Rainfall and Limited Replenishment

The groundwater is mainly replenished with rainfall of interior areas in south Liaodong Peninsula, but rainfall is less, concentrates in summer season and changes greatly in different years. For example, in the district intruded by sea water seriously in the south of Jinzhou, the rainfall is about 650 mm each year and 75% of which concentrates in June–September, and the ratio of the maximum rainfall to the minimum rainfall is 3.0 to 3.7. The replenishment quantity of groundwater by rainfall is unstable.

This district is located in the south end of the peninsula and is surrounded by sea in three directions, and the area is narrow and small, the low mountains and hills rise and fall with exposed bedrocks and bad permeating capacity, the rainfall quickly turns into surface runoff and in short distance streams into the sea. So the permeating conditions are bad and the quantity of groundwater replenishment is limited.

Rivers in this area are short and small, and most are mountainous and seasonal ones. In rainy seasons the rivers flow and the runoff in June–September takes up more than 80 % of the total volume in a year; in low-water seasons the rivers are dried-up. So the regulating and storing ability of the rivers is lower.

2. Continuous and Concentrated Exploitation Causing Imbalance of Water

2.1 Concentrated wells and excessive exploitation

After 1964, especially from 1970 to 1984, the water used in industry and agriculture increased rapidly. As water supply was insufficient, most of the factories, mines, enterprises and institutions exploited groundwater from their own wells, and the agricultural irrigation water basically came from groundwater. So the amount of wells increased very rapidly in every district, and the well density increased. Commonly the density was more than 3 to 5 wells per km^2 . In the district of pore water of loose stratum in Houmu, the density of big-size wells reached to about 10 wells per km^2 . The density of motor-pumped wells reached to 18 wells per km^2 in the districts, there were even 3—4 wells within the distance of about 100 m. In the district where water was abundant, the wells were concentrated and excessive exploiting occurred. The quantity of excessive exploitation was as much as 3 to 7.5 times, the consequence was the imbalance of water.

2.2 The imbalance of water increasing in dry years

During the period from 1978 to 1986, the rainfall was small, in 6 years out of the 9 years the rainfalls were below the average annual rainfall. It continued for four years during the period from 1980 to 1983 that the rainfall was 30% below the average annual rainfall.

As a result of the insufficient rainfall and serious shortage of replenishment, the difference between exploitation and replenishment of groundwater became greater than before. Especially in dry year the rainfall was lacking and the water became greater than water needed for crop growing was great, the amount of water used for irrigation increased. Consequently excessive exploitation multiplied, and the imbalance of water exploitation and replenishment became worse.

2.3 The water level dropping

In the district where exploitation was constant, excessive and fierce, the groundwater level dropped quickly and the groundwater hoppers were formed. In the case that more and more water was used and exploited continuously and fiercely, the depth in groundwater hoppers grew and the area expanded continuously, then many regional groundwater hoppers were formed. For instance, until the time of intruding rapidly in south Jinzhou, more than ten hoppers had been formed. The water level in the centre of the groundwater hoppers was below the standard height of zero meter. Between 1980 and 1983 the center water levels of about 60% of the water hoppers were below -20 m, such as -25.3 m in Gezhenpu^[7] and 3—3.75 m in Qipanmo.

2.4 The water seriously polluted

Due to the high intensity of excessive exploitation, the water levels have been dropping rapidly and the fresh water tends to dryness. In order to reach a new balance under the condition of intense exploitation, the pressure of the water head forced the salt water wedge to intrude inland, expand and move into the districts of the groundwater hoppers, the consequence is that the groundwater is salinized and polluted.

In some coastal districts in the early 1960s, the highest value of Cl^- in groundwater was 876 mg/L, and the area excessively exploited was just several km^2 ; In 1978 the highest value of the content of Cl^- was 5 times as much as before; By 1981 it was 7.8 times as much as that in the 1960s and reached 680 mg/L, and the area exploited excessively reached 173.5 km^2 .

Generally speaking, the degree of the intrusion and pollution of sea water increases with the increase of the depth of groundwater levels (Fig.9). In the period from 1981 to 1983 the groundwater level dropped to the lowest point and the content of Cl^- reached to the highest point of 230 km^2 in the region seriously intruded in south Liaodong Peninsula. The reduced quantity of groundwater resource reached 1,416 million m^3 , which is as much as about 9% of the groundwater resource in the districts intruded and polluted seriously.

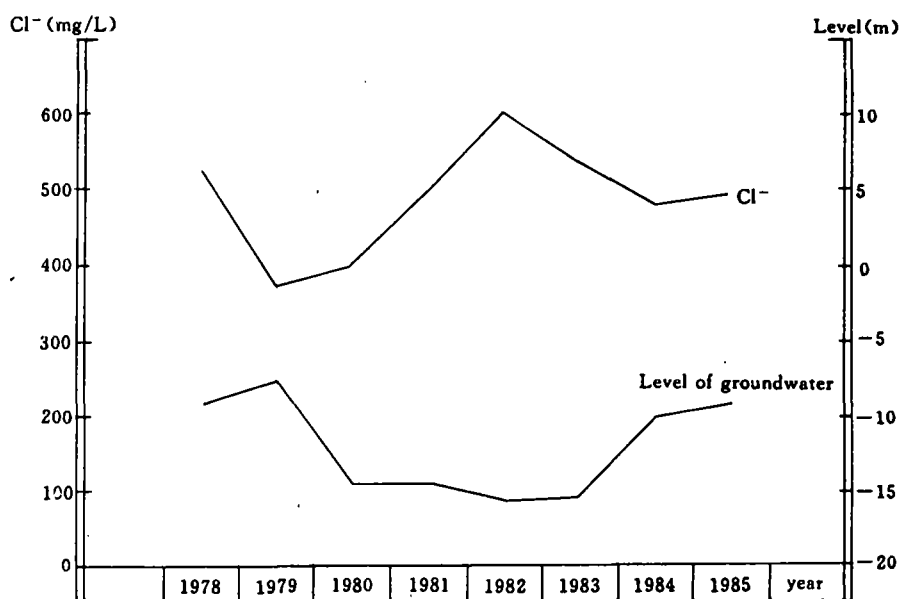


Fig.9 The contrast between the annual variation of Cl^- and the groundwater level

3. The Intrusion Influenced by Water-Controlling Structures

3.1 Transmitting structures helping the sea water intrusion

For example in Xiajiahezi and Yingchengzi, the transmitting structure in NE direction linked with the sea, and made the sea water intrude the hilly land of Muchengzi from north-east to south-west. Another example, in Daweija, the contour of water table of 0 m in groundwater hoppers did not expand to the coast and the upper layer of groundwater was not polluted, but through the transmitting structure, the wedge of salt water intruded inland directly and polluted the groundwater.

3.2 The intrusion of sea water blocked by the water-blocking structures

For example, in Yangtun of Jinzhou there were six wells near the coast and the influence of sea water intrusion was small, this owed to the water-blocking structures in the beach, which was parallel to the coast in EW direction^[8].

V. CONCLUSION

To sum up, there are many types of groundwater in south Liaodong Peninsula and the character of water reservation are different from each other. In the lower coastal regions where groundwater is exploited excessively and seriously, the groundwater is intruded and polluted seriously by sea water in the districts where karst are growing and the districts where the structures are cut through. The process of sea water intrusion can be divided into four periods: slightly intruding period, rapidly intruding period, slowly intruding period and stagnantly intruding period. The ways of sea water intrusion are related to the water-bearing medium and show the four types of intrusion in vien form, plane form, belt form and complex form. The causes of sea water intrusion are mainly attributed to the man-made exploitation which are concentrated, excessive and constant, they cause the natural dynamic balance of water to be damaged. In order to protect the precious resource of groundwater, the groundwater should be exploited reasonably and prevented from sea water intrusion. The following measures should be adopted according to the natural law.

1. Scientifically Selecting Well Positions

According to the reservation rules of various types of groundwater, the wells ought to be distributed reasonably, the formation of the groundwater hoppers should be prevented.

2. Strengthening Scientific Management

We should perfect the well-observing network in every district and establish the systematic technological archives of water wells, strengthen middle and short term forecasting of water situation and keeping abreast of the changes of water situation at any time so that the critical face of intrusion and the dropping of regional water levels can be controlled. According to the local conditions, the rotate exploitation, confined exploitation or no exploitation should be carried out so that the natural dynamic balance of water can be kept.

3. Increasing the Replenishment

The regional replenishment of fresh water should be increased through blocking flood, cutting off undercurrent and man-made recharge, the water quality should be improved and the level of groundwater should be raised, so that the intruding degree can be alleviated and the area of sea water intrusion can be reduced^[9].

4. Building Water-Blocking Barriers

The real passage of each intruding type through which the sea water intrudes into every district should be checked clearly, water-blocking barriers in key positions should be built, so that the sea water intrusion can be prevented.

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