Affecting Factors of Salinity Intrusion in Pearl River Estuary and Sustainable Utilization of Water Resources in Pearl River Delta

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Abstract The rivers in the Pearl River Delta were seriously affected by the strong salinity intrusion and the drinking water of residents in this area was continuously threatened in recent years. To solve the salinity intrusion problem, the Pearl River Water Resources Commission (PRWRC) has organized fresh water transfers from upstream several times since 2005. Noticing the fact that the salinity intrusion in recent years is getting more active, the duration is getting longer, the affected scope is getting larger, the intensity is getting stronger, and etc, this paper analyzes the factors that affect the salinity intrusion in the Pearl River Estuary from the following aspects: the variation of upstream runoff, the change of river topography, the variation of sea level, wind and its direction, and etc. Based on the analysis, this paper proposes some measures for preventing the salinity intrusion to ensure the safety of water supply and the sustainable development of water resources.

Key words: Pearl River, salinity intrusion, sustainable water resources

Introduction

The Pearl River Delta has a large population, developed industry and high-level urbanization. With the growth of population, the quick industrialization and urbanization, the water supply demand is continuously expanding. However, due to the weak adjusting ability of local water resources, the salinity intrusion has had a serious effect on the water supply in the Pearl River Delta area in recent years. In addition, since the global warming causes the rise of sea level, the water demand in the middle and upper stream of the river basin increases, the river-bed sand dredging for construction material and the navigable channels dredging in the estuary rivers, the salinity intrusion in recent years is getting more active, the duration is getting

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longer, the affected scope is getting larger, the intensity is getting stronger. Since the autumn of 2003, the strong salinity intrusion seriously threatens the safety of the water supply in the Pearl River Delta, especially Macau and Zhuhai cities. The salinity intrusion results in serious economic loss and negative social effect to the Pearl River Delta. In order to solve the salinity intrusion problem, and protect the safety of drinking water, PRWRC organized and executed the emergent fresh water transfer project in the Pearl River Basin by transferring the upstream fresh water to the Delta to repel salt water intrusion in early 2005 and early 2006. And PRWRC implemented fresh water transfer from the upstream major reservoirs in the river basin during the dry periods of the years 2006–2007 and 2007–2008.

With the rise of global temperature and sea level, the salinity intrusion has a more serious effect on the water supply in the Pearl River Delta. So, studying the factors affecting the salinity intrusion in Pearl River Estuary and exploring the effective measures for utilizing the water resources of the whole river basin have a very important significance to ensure the sustainable development of water resources and the social stability in the Pearl River Delta.

Analysis of Factors Affecting Salinity Intrusion

In the Pearl River estuary, there are many waterways forming a rivers network. The behavior of the salt tide is mainly controlled by the upstream runoff and the downstream tidal current. When the high saline tidal water mass in the continental shelf flows into the estuary during the flood tidal period, the salt water diffuses and mixes with the fresh water coming from upstream, which makes the water in upstream rivers salty. This causes a salinity intrusion (or called salinity invasion) (Chen and Zong, 1999). When the chlorine content in the water exceeds 250 mg/l, the water quality will not meet the drinking water standard. The factors influencing the salinity intrusion in the Pearl River estuary are as follows: the river mouth shape, the rivers topography, the sea level variation, the wind and its direction, etc., in which the effect of the astronomic tide is relatively stable and periodic. The tidal current in the Pearl River estuary is irregular and semidiurnal, with two flood tides and low tides a day. Usually, on the first day and the fifteenth day of each lunar month, the water level during the flood tide period reaches maximum, and the effect of the salinity intrusion is also relatively large.

The Decrease of the Runoff from Upstream in Dry Period

The upstream runoff is an important factor influencing the salinity intrusion. The larger the fresh water amount coming from upstream is, the shorter the distance of the salinity intrusion will be and the less the effect of the salinity intrusion will be. The salinity intrusion often occurs in dry seasons. The observed data show that
when the upstream runoff decreases, the salinity observed in the rivers increases, and vice versa. In recent years, the upstream runoff (the data obtained at Makou Station + Sanshui Station represents the upstream runoff of the West River and the North River, corresponding to Wuzhou Station + Shijiao Station in the upper stream, respectively) is less than 2000 m$^3$/s during the salinity intrusion period. Especially, the most serious salinity intrusion all happened in the spring, particularly in 1993, 1999 and 2004. The corresponding discharge was between 1500–1600 m$^3$/s. But in the dry period of 2002–2003, the salinity intrusion was relatively weak, the corresponding monthly upstream water amount at the Wuzhou Station and Shijiao Station were ample or partially ample.

The Topography Change of Estuary and Rivers

Since 1990s, there are more and more such human activities as dredging sand from rivers, navigation channel dredging, and so on, which leads to the riverbed level getting down in the Pearl River Estuary area and hence, makes the major tidal channels deep. According to statistics (Chen, 2005), the annual average sand amount from upstream is about 50,000,000 m$^3$, but in recent 15 years, the annual dredged sand amount is about 120,000,000 m$^3$, which means that the annual over-dredged sand amount is about 70,000,000 m$^3$. Due to the over-dredging year after year, the sand amount from the upstream of the Pearl River cannot supplement the dredged sand amount, which causes the riverbed to recede seriously and leads to the salinity intrusion.

The Rise of Sea Level Resulting from Global Warming

Global warming leads to the melting of polar ice, consequently, the rise of sea level. According to a study finished cooperatively by 13 organizations in Chinese Academy of Sciences in July 2003, the coastal sea level of Pearl River Delta may rise by 30 cm to 2030. If there are no prevention measures, Pearl River Delta will be intruded by more serious flood, storm tide, water logging disaster and salinity intrusion (Jiamakou Yellow River Diversion Administration Bureau, 2005). The rise of sea level accelerates the salinity intrusion to the Pearl River Estuary. By calculating the change of the distance of salinity intrusion in the estuaries of Lingdingyang Bay, Modaomen Mouth, Jitimen Mouth and Huangmao Sea under the condition that seal level rises by 0.4–1.0 m, Li Suqiong et al. reached the conclusion that when the high tide occurs in a dry period, the intrusion distance in Humen Waterway increases by 1–3 km, and the maximum is about 4 km; the maximum intrusion distance in Modaomen Waterway increases by about 3 km; the maximum intrusion distance in Huangmao Sea increases by about 5 km (Li and Da-guang, 2000).
The Effect of Wind Direction on Salinity Intrusion (Pan, 2007)

From topography, most rivers in Guangdong Province are high in northwest and low in southeast. The annual leading wind direction is eastward wind in the coastal area. Hence, the wind has a great effect on salinity intrusion. Different kinds of winds and their directions have different effects on the intrusion speed and distance for the salinity intrusion. If the wind direction is in accordance with the tide direction, the speed of salinity intrusion will be quicker and the intrusion distance is longer. But the effect of wind and its direction varies from place to place. For example, the eastward wind and northeastward wind can make the salinity intrusion disasters heavier in Tanzhou and Shenwan of Zhongshan City, and Hongwan of Zhuhai City, meanwhile, making the salinity intrusion disaster lighter in the northeast of Sanzhao of Zhuhai. The different wind directions in the different seasons can have different effects on salinity intrusion. However, the northwestward wind in winter can limit the salinity intrusion. But northeastward wind is unfavorable, which can make the salinity intrusion heavy as it may resist the tide going to the sea. This is because the flow directions of Modaomen and Hengmen waterways are both southeastward in Zhongshan City. The southeastward wind in spring can accelerate the salinity intrusion. The salinity intrusion is the most serious in March and April of each year, mainly due to the southeastward wind in the Pearl River Delta in spring.

Sustainable Utilization of Water Resources in Pearl River Delta

The salinity intrusion results from natural and human factors. The intensity of salinity intrusion is mainly controlled by the tide activity and upstream runoff. The tide activity is a natural phenomenon, which can be adjusted by human beings in a very limited degree. The reduction of the upstream runoff in recent years was caused by the global draught and upstream large water amount consumption which belongs to both human and natural factors. However, the upstream runoff can be adjusted by human beings to a certain extent. In fact, the water-holding capacity of the existing reservoirs in the upstream of the Pearl River cannot ensure the water supply of the Pearl River Delta. Some experts analyze that the water-holding amount in the upstream in winter and spring shall be 9,000,000,000 m³, while the current water-holding amount is just 4,000,000,000 m³. Even though regardless of the hydropower plants operations and the benefit of these enterprises, the problem of water supply cannot be solved either (Su and Luo, 2005). Prevention of the salinity intrusion and solution of the problem of water resources in the Pearl River Delta must be based on the unified dispatching and reasonable arrangement of water resources in the whole river basin.

First, according to above analysis of factors affecting the salinity intrusion, the decrease of upstream runoff in dry period has a great influence on the fresh water supply, but the runoff can be adjusted by the upstream key reservoirs to a certain extent. For the topography change of estuary and rivers, some measures can be taken,
such as prohibiting from dredging river sand, limiting dredging channels, and so on, in order to prevent riverbed recession. The influencing factors, such as the rise of sea level resulted from global warming and the effect of wind and its wind direction on salinity intrusion, can be adjusted by human beings to a very limited extent, but the influence of the tide activity can be controlled by the engineering construction.

Second, a fundamental method is to construct a water-saving anti-polluting society. In recent 20 years, the demand of urban and rural water supply has increased quickly in the Pearl River Basin, especially Pearl River Delta, due to the rapid economic and social development and the quick urbanization. For example, the amount of water consumption in the Pearl River Delta increased from 950,000,000 m\(^3\) in 1980 to 10,250,000,000 m\(^3\) in 2000. The increase of the waste and polluted water amount and the amount of water consumption worsens the water environment of the major waterways and river networks in the Pearl River Delta further and reduces the usability of local water resources. In order to resist salinity intrusion effectively and protect the water supply in the Pearl River Delta, some effective measures must be taken to control the increase of water consumption and water pollution. In the long term, the Pearl River Basin shall construct a water-saving anti-polluting society center, establish a management system of water resources adaptable to the water rights index control by executing a reform of the water utilization system, establish an economic structural system adaptable to the carrying ability of regional water resources by adjusting the economic structure and industrial structure, and establish a hydraulic engineering system adaptable to the optimizing arrangement of water resources by constructing water resources arrangement and water-saving projects. Only by these can the efficiency and benefit of water resources utilization be increased and the sustainable development be realized.

Third, the hydraulic engineering construction shall be speeded up. The hydraulic engineering is the basis of water resources arrangement and water quantity dispatching. To solve the problem of water supply in Pearl River Basin, the hydraulic engineering construction in the basin shall be strengthened, which can adjust the upstream runoff in different seasons. At present, the developing ratio of water resources in the Pearl River is less than 18%; the total reservoir capacity just accounts for 11% of the annual runoff amount, much lower than the national level. There are no large projects which have regulating and controlling capability in the Pearl River basin, and there exists serious shortage of water. So we shall speed up the pace of the comprehensive planning of water resources in the basin and the water supply planning of cities in the Pearl River Delta, consider the safety of water supply in the basin, the Pearl River Delta, Hongkong and Macau as a whole, and adjust the geographical distribution of urban water supply. To clear the way for the construction of key hydro-projects, previous works such as the Dateng Gorge Hydro-project shall be speeded up. Meanwhile, all the cities in the Pearl River Delta shall build more water gates, pumping stations, reservoirs, water treatment plants, etc., enlarge the emergent water supply capacity, carry out the dredging, enlarging, maintaining and enforcing of the existing works, enhance the capacity of transferring and storing fresh water, and increase the guarantee of water supply.
Fourth, the function of the management organizations in the basin shall be given full attention and the unified management of water resources in the basin shall be strengthened, to realize the unified dispatching of the key reservoirs in the basin. The unified management of water resources means not only the combination of water basin management and administration regional management, but also the unified management of water resources in development, utilization, arrangement, prevention, treatment, etc. The unified management of water resources accords with the characteristics of water and adapts to the national condition. At present, we should base our planning on the existing engineering system in the Pearl River, emphasize the unified management of water resources in the whole basin, and reduce the effect of drought, saltiness and pollution by the scientific dispatching to ensure the water supply of the Pearl River Delta and hence increase the utilization rate of water resources.

Fifth, the fundamental research for the basin water resources management shall be carried out. The unified administrative law of water resources in accordance with the present situation of the Pearl River Basin shall be established as soon as possible. On the basis of the upstream runoff situation, the specific approaches of managing and dispatching water resources of the Pearl River shall be studied. The establishment of the dispatching and management procedure of the key reservoirs in the Pearl River Basin shall be speeded up to standardize the dispatching principle of the reservoirs for the flood and drought prevention. The mechanism of salinity intrusion in the Pearl River Delta shall be studied further and the pre-warning system of salinity intrusion shall be established, to provide the scientific support for preventing salinity intrusion and ensuring a reliable water supply.

**Concluding Remarks**

In recent years, due to successive dry seasons, the change of river topography, the rise of sea level, the effect of wind its direction, and etc. in the Pearl River estuary, the salinity intrusion becomes more serious in the Pearl River Delta. The drinking water is endangered in this area (esp. Macau, Zhuhai and Zhongshan), which has unfavorable or negative effects on the social and economic development.

It is predicted that in the future tens of years the economy of the Pearl River Delta will be increasing continually and stably. The population, the industry and urbanization will also increase. The demand of water resources will increase in both quantity and quality. Thus, the stress created from the economic development on the regional resources and environment will be even larger. Therefore, on the one hand, the measures for preventing the salinity intrusion should be put forward; and on the other hand, the sustainable utilization of water resources should be ensured to support the sustainable development of the economy and society.
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