Analysis of the dynamic characteristics of salinity intrusion in Shiziyang

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Abstract. This paper studies the law of the salt water intrusion of Shiziyang based on the salinity measurement data in the dry season of Shiziyang, and we can summarize the following characteristics: the salty fresh water in the upstream of Shiziyang is fully mixed, the downstream saltwater belongs to the partial mixed, saltwater is layered obviously during the neap tide, and the mixing effect is the best during the moderate tide. During the neap tide, downstream salt water is layered significantly, and hyperhaline invades rapidly from the bottom, fresh water discharges from the surface; during the moderate tide, salt fresh water mixes well, the salt boundary is the farthest from the estuary at the minimum flood moment; after the spring tide, salt water mixing gradually weakens, forming a salt water wedge.

1. Introduction
The Pearl River Estuary is an unique "net-bay" type of estuary, compositied by two different dynamics geomorphological units include network river and Lingdingyang Estuary Bay in vertical, and become interconnected and collaborative organic estuary systems by the eight inlet doors (Humen, Jiaomen, Hongqili, Hengmen, Modaomen, Jitimen, Hutiaomen and Yamen) linked to each other. Shiziyang is an important channel for the tide of Lingdingyang, salt tide activities range from the mouth of Humen to the north-east river junction, the collaborative organic estuary system makes the characteristics and dynamic mechanism of the salt tide activity of the Pearl River estuary quite complex, and the research of salt tide in the Pearl River estuary is relatively late. In view of the study of salt tide in the Pearl River Estuary, some prototype observations have been carried out, and some measured data have been accumulated, but in general, the synchronization of historical data is insufficient, the observation time sequence is too short, the number of vertical stratification is not enough to meet the current research requirements, but to carry out the Pearl River estuary range, long-term sequence of multi-point prototype measurement, need to spend a lot of manpower, material and financial resources. Before, many observations and studies have been carried out in Modaomen estuary which got the most prominent problem of salt tide in the Pearl River estuary. The study of Shiziyang salt tide started relatively late, and lacks of systematic measured data, for the reason, this paper based on the fixed-point prototype observation in the dry season of Shiziyang, studies the law of the salt water intrusion of Shiziyang.
2. Observations
Salt tide move from Humen to the north-east river junction in Shiziyang, according to the principles, in the length of about 40km of the river set up 4 measuring points along the route, the number is GY01 to GY04, the distance between each measuring points about 10km, along the route the point layout as shown in Figure 1 and Table 1. Observation in January 2016.

![Fig. 1. Measuring points in Shiziyang.](image)

| Num | Name                   |
|-----|------------------------|
| GY01| North-east river junction |
| GY02| Shawan river            |
| GY03| Dahu                   |
| GY04| Shanbanzhou            |

3. The spatial change of the salt water intrusion
Shiziyang is an important tidal channel at the Pearl River Estuary, and there is a depth of more than 10m of natural deep groove at the Lingdingyang Estuary Bay which is outside the Shiziyang, the bottom of the trough from the sea to land gradually raised, high-salt shelf water can be induced to invade the central hinterland of the estuary bay along the bottom of the deep trough, and then invaded to Shiziyang.

Figure 2–4 showed salinity vertical distribution at Maximum flood, Minimum flood, Maximum ebb, Minimum ebb moment. In general, the most significant characteristics of the salt water layering happened near the mouth of Shiziyang which named Humen, in the upstream the salt water is mixed well. The stratification state is the most obvious in the period of neap tide, and during the spring tide after the neap tide the mixing become more intensity. The terrain and the tide outside the mouth determine that the spatial change of the salt water intrusion in Shiziyang and Modaomen is different, there is almost no interval structure in Shiziyang, from the view of the salinity vertical contour, the salinity in the upper and bottom is layered distribution in the vertical direction, mixed evenness relatively during the moderate tide and spring tide and there is a significant horizontal gradient.
Reflects that, under the influence of the tide, vertical mixing between the bottom salt water and the upper freshwater is not sufficient.

Fig. 2. Salinity vertical distribution at Maximum flood, Minimum flood, Maximum ebb, Minimum ebb moment during neap tide.

Fig. 3. Salinity vertical distribution at Maximum flood, Minimum flood, Maximum ebb, Minimum ebb moment during moderate tide.
Fig. 4. Salinity vertical distribution at Maximum flood, Minimum flood, Maximum ebb, Minimum ebb moment during spring tide.

Analysis of the average stratified coefficient of the daily tide in each measuring point of Shiziyang, (because the salinity value of GY01 point is too small, basically fully mixed, so it is not analysed here), it can be seen from Figure 5 and Table 2, the stratification coefficients of each station is as follows: GY03>GY04>GY02, that is, salt fresh water is mixed most intensity in the upper reaches of the estuary, and layered most obviously in Humen where the mouth of the estuary. The stratified coefficient varies with the tide: it is the largest during the neap tide, and decreases gradually with the increase of tide range. the stratified coefficient in GY02 points sometimes be big sometimes be small because the salinity ups and downs during the neap tide turned to the spring tide, but it is small in most times.

Fig. 5. The average stratified coefficient of the daily tide at each measuring points of Shiziyang.

Tab. 2. The stratified coefficient in the different moment at each measuring points of Shiziyang.

| Tide          | Moment      | GY01 | GY02 | GY03 | GY04 |
|---------------|-------------|------|------|------|------|
| Neap tide     | Maximum ebb | 0    | 0.2  | 1.1  | 0.7  |
|               | Minimum ebb | 0    | 0.2  | 1.7  | 0.9  |
|               | Maximum flood | 0   | 0.2  | 0.9  | 0.4  |
|               | Minimum flood | 2.1 | 0.2  | 0.7  | 0.6  |
| Modrante tide | Maximum ebb | 0    | 0.3  | 0.3  | 0.4  |
|               | Minimum ebb | 0    | 0.2  | 1.0  | 0.5  |
|               | Maximum flood | 0.4 | 0.2  | 0.5  | 0.2  |
|               | Minimum flood | 0.3 | 0.0  | 0.4  | 0.3  |
| Spring tide   | Maximum ebb | 0.0  | 0.4  | 0.3  | 0.1  |
|               | Minimum ebb | 0.0  | 0.4  | 0.4  | 0.4  |
|               | Maximum flood | 0.1 | 0.1  | 0.2  | 0.2  |
|               | Minimum flood | 0.2 | 0.1  | 0.3  | 0.1  |
4. The velocity change of the salt water intrusion
In the process of reciprocating motion of salt tide in Shiziyang, four types of vertical structures formed during the salt water intrusion influenced by the upstream freshwater discharge, strong tidal and the density gradient force caused by the density difference, respectively, are structure of full-section ebb current, full-section flood current, flood current at the bottom and ebb current at the surface, and the maximum current in the middle.

As shown in Fig. 6, when the ebb(flood) tidal dynamic is large enough, the salty fresh water is mixing evenly, the tidal dynamics are the main factors affecting the distribution of velocity, at which time the vertical velocity as a whole to the downstream (or upstream), and from the surface to the bottom is exponentially decreasing, this mainly occurs when the tide is falling (or rising) fast enough; when the ebb tidal turning to the flood tidal, the velocity decreases overall, flow dynamics weakens, at this time the density gradient effect is relatively large, the underlying layer has a significant upstream density gradient force, when the density gradient force to the upstream is greater than the flow dynamic to the downstream, a special characteristic of the vertical flow structure of flood current at the bottom and ebb current at the surface is formed, and when the flood tidal dynamic is gradually enhanced and the effect of the density gradient force is still exists, on the one hand the velocity caused by the tidal dynamic is small at the bottom but large at the surface, and on the other hand, the velocity caused by the density gradient force is large at the bottom but small at the surface. Thus, the two forces are superimposed to form a vertical structure which the maximum current in the middle.

Fig. 6. The vertical velocity structure of Shiziyang.

5. Conclusion
Analysis based on the above salinity measurement data, we can summarize the following characteristics:

The salty fresh water in the upstream of Shiziyang is fully mixed, the downstream saltwater belongs to the partial mixed, saltwater is layered obviously during the neap tide, it is mixed gradually strengthens and the stratified coefficient is the smallest during the moderate tide, the mixing effect is best.

The law of salinity intrusion in Shiziyang can be summarized as follow: During the neap tide, downstream salt water layered significantly, the vertical structure which flood current at the bottom and ebb current at the surface is obvious, hyperhaline intrusion rapidly from the bottom, fresh water discharge from the surface; Tidal range increased gradually to the moderate tide, at this time the velocity Increase overall, salt water mixing gradually enhances, the salt from the bottom gradually mixes with the surface, salt fresh water mixing well, salt moves in and out with the tides rising and falling, the salt boundary is farthest from the estuary at the minimum flood moment; With the
discharge of upstream fresh water, gradually take away more salt mixed on the surface, salt boundary gradually lower, the surface salinity difference gradually increased; the tide range gradually decreased after the transition to the spring tide, salt water mixing gradually weakens, forming a salt water wedge, the bottom salt water quickly invades the upper reaches of the river, this happened again and again and formed the salinity intrusion of Shiziyang.

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