Ocean & Coastal Management 95 (2014) 81–92

Contents lists available at ScienceDirect

Ocean & Coastal Management

journal homepage: www.elsevier.com/locate/ocecoaman

Wavelet analysis of the dynamic characteristics of saltwater intrusion – A case study in the Pearl River Estuary of China

Bingjun Liu [a], Shulan Yan [a], Xiaohong Chen [b], Yanqing Lian [c,*], Yanbo Xin [d]

[a] Department of Water Resources and Environment, Sun Yat-sen University, Guangzhou 510275, People's Republic of China
[b] Key Laboratory of Water Cycle and Water Security in Southern China of Guangdong High Education Institute, Sun Yat-sen University, Guangzhou 510275, People's Republic of China
[c] The Prairie Research Institute, University of Illinois at Urbana-Champaign, 2204 Griffith Drive, Champaign, IL 61820, USA
[d] Hydrology Bureau of Pearl River Water Resources Commission Pearl River, Guangzhou 510611, People's Republic of China

ARTICLE INFO

Article history:
Available online 28 April 2014

ABSTRACT

The Modaomen Waterway (MW), a major outlet of the Pearl River Estuary, is a crucial source of water supply for Macao and Zhuhai City in Southern China. This waterway is frequently affected by saltwater intrusion from the South Sea, which has caused serious water shortage in recent years. For the planning and management of water supply at this waterway it is necessary to understand the characteristics of saltwater intrusion particularly in the low flow period of the year. However, as a result of multiple impacts from tide, river discharge, wind, topography, channel bathometry, and some other factors, the saltwater intrusion into this waterway is highly non-linear. In order to account for the non-linear characteristics, the wavelet method was used to analyze the period characteristics of tidal range, river discharge, and salinity and the impact of tidal range and river discharge on the salinity. Results show that the tidal range at Sanzao station and the salinity at Pinggang station both exhibit a stable 14.8-day period and the salinity in the MW is largely impacted by the tidal range during low stream flow periods. River flows from upstream of the waterway don't show any stable period characteristic, it, however, is critical in mitigating the salinity for water supply during saltwater intrusion. A minimum total flow of 2 500 m^3/s from upstream at Sanshui and Makou stations has been practiced as a threshold for safe water supply. This study has found that the percent time when salinity is below the maximum permissible salinity of 250 ml/g for water supply increases as the river discharge from upstream increases and up to 50–70% of the time the salinity at water supply pumping station is below 250 mg/l when the upstream flow is greater than 2 500 m^3/s. Planning and management of water supply operation at the MW is politically, economically and mostly importantly technically challenging, findings from this study can provide some guidance for operation and further research. For example, the phase lag of average salinity to tidal range was quantified to be 3.4–3.8 days. This phase lag time would suggest that the pumping operation to store freshwater in the backup storages needs to be at least 4–5 days ahead of the spring tide so as to avoid serious impact from saltwater intrusion. Safer water supply strategies can be developed by scheduling reservoir operations to maintain the threshold stream flow and the pumping.

1. Introduction

Saltwater intrusion is a major problem in estuaries because it disturbs and threatens the domestic water supply systems and exacerbates the mortality of species out of predation and disease along the estuaries (Zhang et al., 2010a). Salinity is often used as an indicator of water quality for water consumption or the dilution capacity of a river system (Lewis and Uncles, 2003; Reinert and Peterson, 2008; Nguyen et al., 2012). Understanding the variation of salinity is important for the maintenance of ecological health, and the management of economy and society development in the coastal region (Steven et al., 2012).

Numerous studies have shown that the distribution of salinity in estuaries is affected primarily by the volume of river discharge and the magnitude of tidal current (Leonard, 1976; Mao et al., 2004; May et al., 2010). The river discharge can exert a positive pressure on the salinity stratification and dilute the estuary salinity (Uncles and Stephens, 1996; Brockway et al., 2006), while the tide can drive

* Corresponding author. Tel.: +1 217 333 1495; fax: +1 217 333 2304.
E-mail address: ylian@illinois.edu (Y. Lian).

http://dx.doi.org/10.1016/j.ocecoaman.2014.03.027
0964-5691/

saltwater along the estuary and increase the salinity of freshwater (Turrell et al., 1996; Dame et al., 2000). The effect of tide or discharge on saltwater intrusion differs largely in different tidal mixing estuaries. In general, the saltwater intrusion is more sensitive to the tide in a well-mixed estuary but more to the river discharge in a partially mixed estuary (Bowen and Geyer, 2003; Hetland and Geyer, 2004; Ralston et al., 2008). Geyer and Farmer (1989) found that in an estuary with tidal range less than 2 m, saltwater usually penetrates underneath the freshwater and intense density stratification can be maintained by the river discharge when the wind and tide-induced turbulence only partially mix water column. A study by Vieira and Bordalo (2000) on the saltwater intrusion of Portuguese Douro revealed that saltwater intrusion was more sensitive to river discharge than to tidal action. Even during the spring tides, the tidal range was not powerful enough to destroy the vertical stratification. Luettich et al. (2002) observed that water level variation and circulation pattern of the Neuse River Estuary are primarily determined by the river discharge at a long-time scale because the astronomical tide in this estuary can be negligible. Lerczak et al. (2009) studied the relationship between different mixing type of estuaries and tides in Hudson River estuary. They detected that saltwater intrusion is longer during spring tide in those completely mixed estuaries.

The Pearl River Estuary (PRE), located in southern Guangdong Province, is characterized by a complex river network as shown in Fig. 1. The Modaomen Waterway (MW) is a major outlet of the PRE, and saltwater intrusion in this waterway has seriously affected the habitat of aquatic species and the quality of domestic water consumed in several metropolitan cities like Macao, Zhuhai, Zhongshan, and Foshan. The high salinity in the MW mainly comes from the Pacific oceanic tidal propagation, and the river discharge and tide both play important roles in regulating saltwater intrusion in this waterway (Bao and Liu, 2008; Gong and Shen, 2011). Mao et al. (2004) found that the semidiurnal and diurnal tides had different effects on saltwater intrusion. The study of Wang et al. (2012) showed that saltwater intrusion in the PRE is influenced by tide, topography and wind stresses, and the high salinity usually occurs during neap tide. In addition to tide, the river discharge has an obvious dilution on the salinity in the MW as well (Twigt et al., 2009; Zhang et al., 2010a). In general, a high river discharge leads to a decreasing salinity and vice versa. Lv and Du (2006) regarded that the increase of saltwater intrusion in recent years was mainly attributed to the decrease of river discharge from upstream and the increase of tidal amplitudes. They found that the peak of salinity usually appears ahead of the peak of tidal range but did not quantify the phase lag. Gong and Shen (2011) found that saltwater transport in the MW is enhanced during the neap to spring tide and the river discharge in dry season has obvious impacts on saltwater intrusion.

All above-mentioned studies have proven that saltwater intrusion in the MW exhibits high correlations with the tide and river discharge. However, the change characteristic of salinity, and the effects of tide and river discharge on the salinity remain unclear. In order to explain the non-linear characteristics of saltwater intrusion in the MW and quantify the relationships among the salinity, the tide, and the river discharge, this study selected to use the cross-wavelet transform (XWT) and wavelet coherence (WTC) methods to analyze the period characteristics of tidal range, river discharge, and salinity, and the effects of tidal range and river discharge on the salinity. Hopefully, findings from this study will help to guide the management and operation of water supply to provide safe water to Macao and Zhuhai.

2. Study area and methodology

2.1. Study area

Shown in Fig. 1 are the Modaomen waterway (MW) in the Pearl River Estuary (PRE) and some gage stations from which time series data have been used for this study. The MW is located in the downstream portion of the West River, extending from Beiqintou to the mouth of the river for about 63 km with water depths ranging

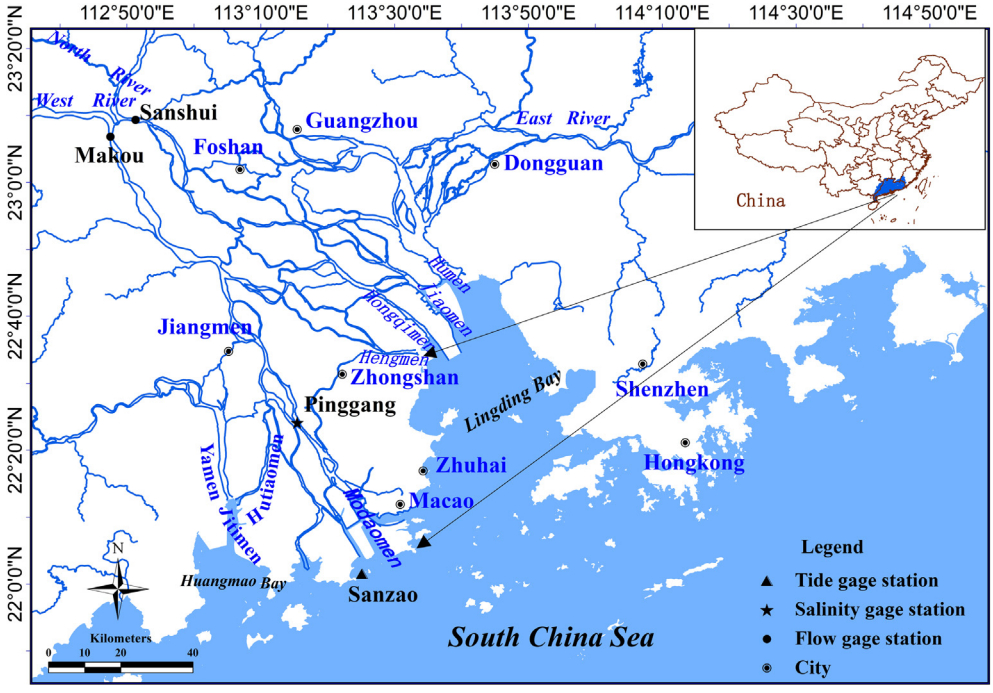

Fig. 1. Location map of the Modaomen waterway and gage stations.