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Seasonal variability of estuarine dynamics due to freshwater discharge and its influence on biological productivity in Yeongsan River Estuary, Korea

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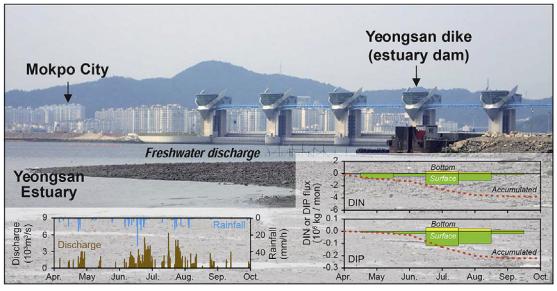
HIGHLIGHTS

- Seasonal dynamics of water quality characterized in closed estuarine system.
- Simulation supported the strong seasonal trends of nutrients with dominated outfluxes.
- Vertical fluxes of nutrients and OM primarily controlled by the freshwater discharge.
- Numerical dye experiment revealed fast nutrient flushing followed by lesser productivity.

GRAPHICAL ABSTRACT



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ABSTRACT

In order to evaluate water quality and biological productivity, observation data sets were collected and analyzed in Yeongsan River Estuary, Korea. We also set up a numerical model to resolve hydrodynamics and fate of water quality variables in the system. Results show that most of nutrients loading are trapped in the lake and higher concentrations of nutrients and organic matters (OM) are present only inside of the artificial sea dike. There exist episodial discharges at the dam, which coincide mostly with rainfall events during summer monsoon periods. During this discharge event, lower salinity and higher suspended solids, nutrients, and OM are observed in surface layer of the estuarine section. Hydrodynamic model results show that circulation in the estuarine section is governed by freshwater discharge from the lake, resulting in an enhanced two-layer estuarine circulation being dominated, during and after the freshwater is discharged. Such two-layer estuarine circulation combined with higher concentration of nutrients in the surface layer results in that outfluxes of nutrients in the surface layer dominate over the influxes in the bottom layer during summer high precipitation periods. Meanwhile, numerical dye experiment results show that the discharged water with elevated nutrients levels have a short residence time (~5–10 days) in the estuarine section. Due to this fast flushing rate, excessive nutrient loadings are not used to produce biological matters in the estuarine section. This limited biological productivity,

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characterized by seaward side of the artificial sea dike, makes Yeongsan estuarine system excluded from acting as an active carbon sink.

1. Introduction

Estuary is a linkage between terrestrial and ocean systems and involves major biogeochemical pathways for freshwater as well as materials including nutrients, organic matters, and sediments. By its definition in Cameron and Pritchard (1963), a typical estuary is characterized by a semienclosed body of water wherein ocean water is diluted by freshwater derived from the land. This mechanism generates a horizontal geochemical gradient with salinity decreasing from the ocean toward the land. The horizontal salinity gradient is one of the most important driving forces in the lotic estuarine system, which establishes and maintain vertically stratified structures being mixed by wind, wave and tidal forcings (Valle-Levinson, 2010 and references therein). Thus, the horizontal salinity gradient, depending on freshwater inflow to an estuarine system, plays a key role in determining the fluxes of salt and other materials in an estuary (Geyer, 2010).

The Yeongsan River drains freshwater from the area of about 3371 km^2 in southwestern part of Korea to Yellow Sea. The river mouth used to have a well-developed estuary and extensive tidal flats (ca. 280 km^2) due to macrotidal characteristics of the tidal range up to 6 m in the eastern Yellow Sea. In 1982, in order to provide consistent freshwater for agricultural and industrial uses, the sea dike was constructed in the middle part of the estuary, about 8 km from the estuary mouth. Since then it is composed of an artificial lake inside the dam and the estuarine section, now defined as the region between sea dike and river mouth, which is strongly influenced by the freshwater discharge control at the sea dike. Although the freshwater discharge via the dike gate is controlled artificially, large discharge events are still related to the natural cycle of summer monsoon, i.e., high precipitation concentration during summer. More than 80% of rainfall is concentrated during July to September, so is freshwater discharge through the sea dikes (Rhew and Lee, 2011; Kim et al., 2013). Cho et al. (2004) and Kim et al. (2013) reported the seasonal variability of hydrographic and hydrodynamic structures depending on the freshwater discharge in the Yeongsan River Estuary. They found that two-layer estuarine circulation pattern is intensified during and right after freshwater discharge events, whereas well-mixed or multi-layer structures are present during low discharge periods.

Different mixing and circulation regimes induced by intermittent freshwater discharge would have a critical impact on the biogeochemical settings in an estuary (Goñi et al., 2009; Lucas, 2010). High sediment and nutrient loadings from terrestrial and anthropogenic sources along with freshwater input and subsequent excessive biological production of organic matters have been reported in wide spectrum of estuaries (Lohrenz et al., 2008, 2013; Cai et al., 2011). Goñi et al. (2009) showed the cycling of biogeochemical materials, particulate organic matter in particular, is strongly influenced by discharge and thus circulation and flux patterns in an estuary. Bang et al. (2013) and Cho et al. (2015) reported, in the Yeongsan River Estuary, the variability in sediment transport and hypoxia formation is fundamentally controlled by freshwater discharge events. Cai et al. (2011) and Lohrenz et al. (2013) demonstrated that the riverine/estuarine coastal environments receive the massive fluxes of carbon, nutrients, and sediments from freshwater, but also it can act as strong sinks for atmospheric carbon dioxide due to high productivity. Having a large, stagnant freshwater lake just inside reach of the sea dike, the Yeongsan lake and estuary system might also act as an efficient place for atmospheric CO_2 sink. Thus, it would be critical to evaluate the fate of those organic matters in the system including artificial lake and estuary like Yeongsan.

In this study, we analyzed year-round field-observed data to depict the variability in biogeochemical characteristics in the Yeongsan River Estuary, especially with respect to different discharge conditions. To better understand the variability of the fate of such biogeochmical components, we also developed a numerical model to simulate the estuarine flushing and mass fluxes of major water quality variables, including nutrients and organic matters. We estimated the material flux for those variables to show the seasonal flushing pattern of the Yeongsan lake-estuarine system. Finally, we compared our study results with long-term data sets from one of Korean national ocean observatory networks, named the Marine Environmental Monitoring System, to understand long-term flux of nutrients and organic matters in the Yeongsan River Estuary.

2. Study area

The Yeongsan River Estuary is located in the southwestern tip of Korean peninsula. The southwestern part of Korea has extensive agricultural areas, especially wide rice fields that use massive freshwater. The Yeongsan River flows through the rice fields and provides majority of water for them. In order to maintain consistent freshwater source for agricultural and industrial uses, a sea dike was constructed in 1982, approximately 8 km from the mouth of the Yeongsan River Estuary (Fig. 1).

The Yeongsan River has a drainage area of about 3371 km^2, with an annual mean discharge of about 1.5×10^8 m^3 (Cho et al., 2004). More than 80% of the rainfall occurs during summer months (July, August, and September) due to the summer monsoon season (Rhew and Lee, 2011). When the water level of the freshwater lake inside of the sea dike during those months, the dike gates are open to discharge fresh water mostly during low tide. Accordingly, the majority of freshwater discharge occurs during the summer.

The estuarine section, up to 8 km from the sea dike, shows relatively straight east-west direction with about 2 km widths. The water depths ranges 10–20 m in the middle of estuary. The tides in the estuary are principally semidiurnal, with mean spring range of up to 6 m (i.e., macrotidal; Cho et al., 2004). It has been reported that the tidal amplitudes have increased and tidal currents have decreased since the construction of sea dike (Choi, 1984; Kang, 1999). Of note, the wide open estuaries and tidal flats of ca. 280 km^2 developed in this area have been disappeared by the series of embankment since early 1980s (Fig. S1).

3. Materials and methods

3.1. Study design and sampling

Study design in the present study was presented in Table 1, and data sets can be divided into three categories according to the specific objectives. Four liters of water samples were collected from