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Modeling increased riverine nitrogen export: Source tracking and integrated watershed-coast management

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ABSTRACT

The global NEWS model was calibrated and then used to quantify the long term trend of dissolved inorganic nitrogen (DIN) export from two tributaries of Jiulong River (SE China). Anthropogenic N inputs contributed 61–92% of river DIN yield which increased from 337 in 1980s to 1662 kg N km^{-2} yr^{-1} in 2000s for the North River, and from 653 to 3097 kg N km^{-2} yr^{-1} for the West River. North River and West River contributed 55% and 45% respectively of DIN loading to the estuary. Rapid development and poor management driven by national policies were responsible for increasing riverine N export. Scenario analysis and source tracking suggest that reductions of anthropogenic N inputs of at least 30% in the North River (emphasis on fertilizer and manure) and 50% in the West River (emphasis on fertilizer) could significantly improve water quality and mitigate eutrophication in both river and coastal waters.

1. Introduction

Over the past few decades, estuaries and coastal marine ecosystems have been heavily loaded with riverine nutrients (e.g. N and P) as a result of anthropogenic activities (Howarth, 2008; Peñuelas et al., 2013; Turner and Rabalais, 1994). Increasing watershed nutrient export has caused eutrophication, harmful algal blooms and other negative environmental effects in coastal waters around the world (Anderson et al., 2008; Billen and Garnier, 2007; Davidson et al., 2014; Paerl et al., 2011; Smith et al., 1999). Riverine export of dissolved nutrients (especially N) from Asian watersheds has been predicted to continue to increase through 2030 (Seitzinger et al., 2010). Anthropogenic N inputs from agricultural production, livestock and poultry farming and sewage discharge affect the magnitude and trajectory of riverine dissolved inorganic N (DIN). Nutrient over-enrichment has become a critical issue in Chinese estuaries and coastal waters due to rapid socio-economic growth and poor nutrient management (Chen and Hong, 2012; Huang and Hong, 2010; Li et al., 2014; Yin and Harrison, 2008). Modeling of long-term trends of DIN export provides scientific understanding of the watershed–coast relationship (Sattar et al., 2014), and tracking key sources assists in identifying critical factors to reduce N pollution loading and in mitigating eutrophication in riverine and coastal aquatic ecosystems.

A number of models have been developed to estimate riverine N export from watersheds. For example, INCA (the Integrated Catchment Model of Nitrogen) simulates N transport through terrestrial systems into rivers based on detailed hydrological and biochemical process equations (Whitehead et al., 1998); SWAT (the Soil and Water Assessment Tool) simulates nutrients yield in surface runoff and identifies critical source area (CSA) (Arnold et al., 1998); and SPARROW (SPAtially Referenced Regressions On Watershed attributes) is a hybrid process-based statistical model which quantifies pollutant source and transport by linking watershed characteristics and in-stream water quality (Smith et al., 1997). Implementing these models requires detailed, high quality input data which is often not available for large watersheds. Global NEWS-2 (Nutrient Export from WaterSheds) is a spatially explicit watershed scale model (Mayorga et al., 2010) which has been applied at the global (Dumont et al., 2005; Mayorga et al., 2010; Seitzinger et al., 2010) and regional scales (Bowes et al., 2005; Qu and Kroeze, 2010; Suwarno et al., 2013). Global NEWS-2 is an ideal tool for management purposes in data-poor regions such as China's coastal watersheds because it requires mainly social–economic input data and simple model parameters. The model has been applied to large Chinese rivers including the Pearl River (Strokal et al., 2015) and the Yangtze River (Yan et al., 2010). However, how the model assists in controlling nutrient pollution is still under studied. Nutrient management should address the river–estuary–bay continuum within an integrated framework (Chen and Hong, 2012). Typically, coastal and estuary waters receive N loading from various tributaries. To mitigate eutrophication in an efficient way, modeling the long-term trend of N export by source

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at the sub-watershed scale is essential to help decision makers to prioritize pollution management strategies.

In this study, we applied the Global NEWS–DIN model to the Jiulong River watershed, a meso-scale (14741 km^2) agricultural watershed in southeast China. Two major tributaries (North River and West River) discharging fresh water into the estuary and then Xiamen Bay. The North River contributes two-thirds of water discharge and is profoundly influenced by livestock breeding, while the West River has a smaller catchment area with widespread cultivation of cash crops. Riverine inputs dominate N loading in the Jiulong River estuary and Xiamen Bay, which have suffered undesirable algal blooms since the mid-1990s when nutrient enrichment began (Chen et al., 2013). Due to their distinct watershed characteristics and economic development patterns, these two tributaries provide an ideal opportunity for comparison by modeling of the increased N export. Based on an extensive database (1980–2010) and previous research on N biogeochemistry in the Jiulong River watershed, model parameters were calibrated and modified by tributary and then used to estimate N inputs and river DIN yield. This study aims to quantify the long term (1980–2010) trend of DIN export from watershed to coast and to determine the relative contribution of the two tributaries, and the contributions of various N sources within each tributary. Scenario analysis was conducted to provide a future management strategy (how much and where to reduce N input) to meet national water quality criteria as well as mitigate eutrophication in coastal waters.

2. Materials and methods

2.1. Study area

The Jiulong River flows through an agricultural river watershed in southeast China, with a subtropical climate and annual precipitation ranging from 1400 to 1800 mm. Two main tributaries (North River and West River) converge at the head of the estuary and discharge water to Xiamen Bay (Fig. 1). The North River is the largest tributary (annual discharge 127–437 m^3 s^{-1}), contributing two-thirds of the total water discharge. The North River is 272 km long and has a catchment area of 9562 km^2, encompassing four major cities/counties (Longyan, Zhangping, Changtai, and Hua'an) and part of Anxi County and Zhangzhou City. Over 60% of this watershed is covered by forest and upland orchard. In its upper area (Longyan City), there is a large population of 0.5 million as well as a large number of livestock (mainly pigs), resulting in excessive nutrient discharge from human and animal wastes (Chen et al., 2013). For the purposes of hydropower generation and irrigation, more than 60 dams (including six large dams along the main stem) have been constructed since the late 1990s. Jiangdong Reservoir in the lower river is impounded by a dike adjacent to the estuary, and provides over 80% of drinking water to Xiamen City. The West River has a shorter length of 172 km, a drainage area of 3938 km^2, and annual water discharge of 68–209 m^3 s^{-1}, and the drainage area encompasses four major cities/counties (Pinghe, Nanjing, the majority of Zhangzhou

Fig. 1. Map of study area showing two tributaries in the Jiulong River watershed, Southeast China.