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Reducing future river export of nutrients to coastal waters of China in optimistic scenarios

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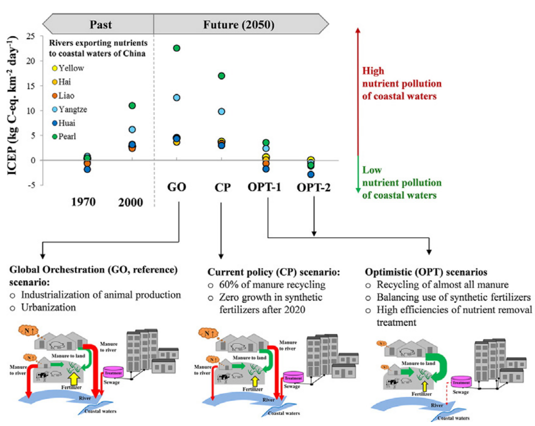
HIGHLIGHTS

- In optimistic scenarios the risk for coastal eutrophication in China is low.
- In 2050 river export of most N and P can be back to levels of around 1970.
- Recycling manure on land is essential in scenarios with low N and P inputs to rivers.
- Sewage control is needed to reduce future P in rivers from urbanized areas.
- Current policy plans may not be enough to reduce future coastal water pollution.

GRAPHICAL ABSTRACT



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ABSTRACT

Coastal waters of China are rich in nitrogen (N) and phosphorus (P) and thus often eutrophied. This is because rivers export increasing amounts of nutrients to coastal seas. Animal production and urbanization are important sources of nutrients in Chinese rivers. In this study we explored the future from an optimistic perspective. We present two optimistic scenarios for 2050 (OPT-1 and OPT-2) for China. Maximized recycling of manure on land in OPT-1 and OPT-2, and strict sewage control in OPT-2 (e.g., all sewage is collected and treated efficiently) are essential nutrient strategies in these scenarios. We also analyzed the effect of the current policy plans aiming at “Zero Growth in Synthetic Fertilizers after 2020” (the CP scenario). We used the *MARINA* (a *M*odel to *A*ssess *R*iver *I*nputs of *N*utrients to se*A*s) model to quantify dissolved N and P export by Chinese rivers to the Bohai Gulf, Yellow Sea and South China Sea and the associated coastal eutrophication potential (ICEP). The Global Orchestration (GO) scenario of the Millennium Ecosystem Assessment was used as a basis. GO projects increases in river export of dissolved N and P (up to 90%) between 2000 and 2050 and thus a high potential for coastal eutrophication (ICEP > 0). In contrast, the potential for coastal eutrophication is low in optimistic scenarios (ICEP < 0). This is because in 2050 loads of most dissolved N and P in Chinese seas are around their levels of 1970. Maximizing manure recycling can reduce nutrient pollution of Chinese seas considerably. Sewage control is effective in

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reducing P export by rivers from urbanized areas. The CP scenario, on the other hand, shows that current policy plans may not be sufficient to avoid coastal eutrophication in the future. Our study may help policy makers in formulating strategies to ensure clean coastal waters in China in the future.

1. Introduction

Rivers supply increasing amounts of nitrogen (N) and phosphorus (P) nutrients to coastal waters of China (Huang et al., 2003; Li et al., 2014; Strokal et al., 2015; Sumei et al., 2008). This causes eutrophication and blooms of harmful algae (Liu and Diamond, 2005; Qu and Kroeze, 2012; Wang, 2006; Xiao et al., 2007; Zhang et al., 2013). These environmental problems pose a threat to ecosystems, and decrease the suitability of water for, for instance fishing and recreation (Vörösmarty et al., 2010). Food production and urbanization contribute largely to these nutrient pollution problems where animal production plays a leading role (Bai et al., 2015; Liu and Diamond, 2005; Ma et al., 2012; MEP et al., 2010; Strokal et al., 2016b). Agriculture has been under transitions with changes in farming practices from traditional- to industrial-dominated systems (Strokal et al., 2016b). Animal production started industrializing during the 1990s to produce more food especially for cities. Large industrial animal farms became disconnected from crop production. Farmers prefer synthetic fertilizers over manure because of lower prices and lower labor demand for transportation and application. Manure management is generally poor. Thus, animal manure is currently often not applied on land, but largely discharged to nearby water systems, causing nutrient pollution (Bai et al., 2015; Ma et al., 2012; MEP et al., 2010; Strokal et al., 2016b). These point source inputs of manure to rivers exceed the diffuse losses of nutrients from fertilized soils in large parts of China (Strokal et al., 2016b). Human waste is another important source of increasing nutrients in rivers. Sewage systems discharge in many rivers and are an important source of nutrients in rivers (Strokal et al., 2015; Strokal et al., 2014; Van Drecht et al., 2009). Rural people in China, however, often lack sewage connections. For example, in 2000 < 5% of rural people were connected to sewage systems (WHO/UNICEF, 2014). As a result, human waste is often also directly discharged to rivers, but untreated. Thus, human excreta pollute rivers all over China (Ju et al., 2005; Morée et al., 2013; Strokal et al., 2014).

In the future, the potential for coastal water pollution may increase. This is because both industrialization of animal production and urbanization will likely further develop. River pollution and thus coastal eutrophication will depend on how efficiently nutrients are managed in both sectors. Various studies analyzed different scenarios for nutrient management in China. However, these studies are either limited to agriculture and fresh waters (no connection with coastal waters) or do not account for effects of industrialized animal production on coastal waters in China. For example, several studies (Bai et al., 2015; Ma et al., 2013a; Ma et al., 2013b) analyzed effects of efficient nutrient management in animal (e.g., precisions feeding, more manure use on land instead of synthetic fertilizers) and crop production (e.g., balanced fertilization) on nutrient losses to fresh waters by 2030. However, their national and provincial analyses do not account for urbanization. Other studies (Qu and Kroeze, 2010; Qu and Kroeze, 2012) analyzed effects of nutrient management strategies in agriculture and urbanization on reducing river export of nutrients and thus coastal water pollution by 2050. However, they do not account for effects of industrialized animal production in China. As a result these studies may underestimate nutrient pollution and thus may overestimate the effectiveness of their strategies.

In this study we explore the future from an optimistic perspective to reduce river export of nutrients and thus coastal eutrophication in China by 2050. Optimistic perspectives are limited in existing scenario studies (e.g., (Ma et al., 2013b; Qu and Kroeze, 2012)). We developed optimistic scenarios that assume more efficient nutrient management in agriculture and sewage than typical business as usual scenarios. In addition, we analyzed effects of the recently introduced policy on "Zero Growth in Synthetic Fertilizers after 2020" aiming at reducing water pollution from agriculture by increasing nutrient use efficiencies (MOA, 2015a; MOA, 2015b). We compared effects of this policy with effects of optimistic scenarios, and discuss whether this policy is sufficient to reduce coastal water pollution in 2050. We used the Global Orchestration (GO) scenario of the Millennium Ecosystem Assessment as a basis for our scenarios because it assumes an economy-driven world with a rapid urbanization (see Section 2.3). We used the *MARINA* Nutrient Model (a *M*odel to *A*ssess *R*iver *I*nputs of *N*utrients to se*A*s) to quantify river export of nutrients and the associated coastal eutrophication (Strokal et al., 2015; Strokal et al., 2016a; Strokal et al., 2016b).

2. Methodology

2.1. Study area

We study six large rivers draining into the three major seas of China (Fig. 1). The Yellow (Huang He), Hai and Liao drain into the Bohai Gulf, and the Yangtze (Changjiang) and Huai drain into the Yellow Sea. The South China Sea receives nutrients from the Pearl River. The total drainage area of the rivers covers around 4 million km^2 (around 40% of China). The Yangtze, Yellow and Pearl rivers account for 80% of the total drainage area studied here. The drainage area of Yangtze is divided into ten sub-basins. The Yellow River and the Pearl each have six sub-basins. These sub-basins are classified as up-, middle- and downstream sub-basins, based on literature (Cui et al., 2007; Huang et al., 2009; Niu and Chen, 2010; Wang et al., 2010; Yang and Lu, 2014; Zhou et al., 2013). This is done to account for upstream impacts of human activities on downstream coastal water quality. This is especially needed for large basins such as of the Yangtze, Pearl and Yellow since these rivers transport relatively large amounts of nutrients (see Section 3). In this study, the Huai, Hai and Liao are considered as individual downstream sub-basins. Thus, in total the study area consists of 25 sub-basins draining into the Bohai Gulf, Yellow Sea and South China Sea (Fig. 1).

The study area has been developing towards intensive agricultural activities and urbanization (see also Section 1). Since 1970, the total population has being increasing. By 2000, the total population reached 199 inh. km^{-2} in the drainage area of the Bohai Gulf with the range of 42–680 inh. km^{-2} for the sub-basins (Table B.2 in Appendix B). For the South China Sea, the total population was 211 inh. km^{-2} in the drainage area with the range of 136–473 inh. km^{-2} for sub-basins. For the Yellow Sea, this number was 283 (34–654) inh. km^{-2} (Table B.2). However, not all population was connected to sewage systems in 2000 (Table B.2, Strokal et al., 2016b). The downstream sub-basins are usually more urbanized, densely populated areas than upstream sub-basins. Examples are large cities located in the downstream sub-basins of the Yangtze (e.g., Shanghai), Pearl (e.g., Shenzhen), Hai (e.g., Beijing) rivers (Strokal et al., 2016a; Strokal et al., 2016b).

Agriculture has been intensifying since the 1970s as a result of increasing food demand (see also Section 1). In 2000 over two-thirds of the study area was used for agricultural activities (e.g., for cereals, legumes, rice) with the range of 50–99% for the sub-basins (Table B.2). Industrial farms for livestock production have been growing in size and in number to fulfill the demand for meat products (see Section 1). However, nutrient management in agriculture and urban areas has not been very sophisticated, causing nutrient losses to water systems and thus costal eutrophication (see Sections 2.3 and 3 on future projections).

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