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# The increasing impact of food production on nutrient export by rivers to the Bay of Bengal 1970–2050

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ABSTRACT

The objective of this study is to assess the impact of food production on river export of nutrients to the coastal waters of the Bay of Bengal in the past (1970 and 2000) and the future (2030 and 2050), and the associated potential for coastal eutrophication. We model nutrient export from land to sea, using the Global *NEWS* (Nutrient Export from WaterSheds) approach. We calculate increases in river export of N and P over time. Agricultural sources account for about 70–80% of the N and P in rivers. The coastal eutrophication potential is high in the Bay. In 2000, nutrient discharge from about 85% of the basin area of the Bay drains into coastal seas contributes to the risk of coastal eutrophication. By 2050, this may be 96%. We also present an alternative scenario in which N and P inputs to the Bay are 20–35% lower than in the baseline.



## 1. Introduction

Nutrient export by rivers to the coastal waters of the Bay of Bengal have been increasing during the past decades (Das et al., 2004; De et al., 2011; Mahanta et al., 2005; Mukhopadhyay et al., 2006; Prasad, 2011; Subramanian, 2008). Food production is one of the reasons for increased river transport of nutrients such as nitrogen (N) and phosphorus (P) to many coastal waters (Bouwman et al., 2009; Han and Allan, 2011; Heisler et al., 2008; Rabalais et al., 2010; Srinivas et al., 2011; Yang et al., 2010). Synthetic fertilizer use and the number of animal stocks have been increasing rapidly in the drainage basin of the Bay of Bengal (Jain, 2002; Panigrahi et al., 2007; Singh and Ramesh, 2011; Srinivas et al., 2011; Subramanian, 2008). The same holds for the use of N and P feed in aquaculture (Biplob et al., 2004; Deb, 1998). In addition, India and Bangladesh are major fertilizer consuming regions in South Asia (FAO, 2008; Sharma and Thaker, 2011) which cover a large part of the drainage basin of the Bay of Bengal. These high nutrient inputs to agricultural land potentially lead to high nutrient concentrations in surface waters as a result of runoff and leaching (Bouwman et al., 2009; Subramanian, 2008; van Breemen et al., 2002).

The economies and population in many Asian countries are growing fast (Bloom and Williamson, 1998; Freeman, 2002). Increased food production is linked to population growth as well as economic growth. Qu and Kroeze (2012) show that population and economic growth are major drivers of increasing nutrient loads at river mouths in China. This is not only because with an increasing population the demand for food increases, but also because economic growth is associated with increased per capita meat consumption (Gerbens-Leenes et al., 2010). As a result, food production has been increasing throughout Asia. Governments in the Bay of Bengal area subsidize synthetic fertilizers to ensure sufficient food production (Fan et al., 2008). The contributing countries are exporting part of their agricultural and aquaculture products. This all creates competition for land, especially in regions with rapid population growth (FAO, 2008).

Economic growth and increased population have led to rapid urbanization in the drainage basin of the Bay of Bengal (Rana, 2011). An increase in urban population is observed in the past and may continue in the future in many Asian countries (Cohen, 2004, 2006; UN, 2012). A likely consequence of urbanization is an increase in the number of people connected to sewerage systems (Van Drecht et al., 2009). Uncontrolled wastewater disposal (containing human waste and detergents from laundry and dishwashers) is an important cause of increased nutrient exports to the Bay of Bengal. Consequently, nutrient export to the coastal waters from urban sewage has been increasing during the past decades (Grimm et al., 2008; Groffman et al., 2004; Wickham et al., 2002).

The effects of increased nutrient loads to coastal waters are observed worldwide (Barile, 2004; Bouwman et al., 2009; Nixon, 1995; Seitzinger et al., 2005, 2010). Increasing nutrient loads may alter the nutrient stoichiometry in the coastal waters, which in turn may cause the growth of harmful algal blooms in the

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marine ecosystem (Billen and Garnier, 2007; Glibert et al., 2006; Heil et al., 2005; Howarth, 2008; Yang et al., 2010). Coastal eutrophication has also been observed in the coastal waters of Asia (Diaz, 2001; Hallegraeff, 1993; Selman et al., 2008). To our knowledge, the eutrophication potential of rivers draining into the Bay of Bengal has not been studied extensively. Some studies report eutrophication problems in small ponds and in shallow lakes that are located in our study area (Agrawal, 1999; Ambasht, 2008; Jahan et al., 2010). Poor water quality and algal blooms in rivers in Bangladesh and India occur as a result of dumping urban sewage and effluents of shrimp farming (Pote et al., 2011). The nutrient pollution of the drainage basin of the Bay of Bengal is expected to increase in the near future (Tripathy et al., 2005; Vass et al., 2010). Many local and national initiatives and laws (about one hundred), and about 40 international agreements have been dedicated for managing land-based pollution of the Bay (L.Kaly, 2004). So far, these initiatives have not been effective to reduce nutrient loads to the Bay of Bengal to a large extent. Besides, no studies exist on a systematic assessment of the past and future trends in nutrient export by the rivers to the Bay of Bengal and their main sources that could support these initiatives. Furthermore, the associated potential for coastal eutrophication has not been studied either. Such integrated analysis would help in exploring management strategies to protect coastal ecosystems (Tare et al., 2003). Without effective policies, coastal eutrophication may threaten ecosystems services in the future with negative societal consequences (Das et al., 2004; Vass et al., 2010).

The objective of this study is, therefore, to assess the impact of food production (agriculture and aquaculture) on river export of nutrients to the coastal waters of the Bay of Bengal in the past and future (1970–2050) and the associated potential for coastal eutrophication. In addition, the effects of selected environmental policies to reduce nutrient export to the Bay of Bengal are analyzed.

## 2. Methodology

### *2.1. Study area*

The Bay of Bengal is the world largest bay and forms the northeastern part of the Indian Ocean (Fig. 1). It is bordered by India and Sri Lanka to the west, Bangladesh to the north and Myanmar and Thailand to the east. It occupies almost 2.2 million $km^2$. The Andaman and Nicobar Islands separate the Bay of Bengal and the Andaman Sea. The study area includes selected sixty exoreic river basins, which occupy 2.9 million $km^2$ (Mayorga et al., 2010) draining into coastal waters of the Bay of Bengal (Table 1). These basins were selected from the Global *NEWS* (Nutrient Export from WaterSheds) model that is described below (Fig. 1). The Ganges river is the largest of the sixty rivers and covers more than half of the total drainage basin of the Bay of Bengal (Fig. 1).

### *2.2. Global Nutrient Export from WaterSheds (Global NEWS) model and Millennium Ecosystem Assessment (MEA) scenarios*

We used the Global *NEWS* model to analyze the impact of food production on nutrient export by rivers to the coastal waters of the Bay of Bengal (Mayorga et al., 2010; Seitzinger et al., 2010). In addition, data on nutrient export from aquaculture were derived from Bouwman et al. (2011). We used data for aquaculture to calculating the relative contribution of this sector to the nutrient export to the Bay of Bengal.

The Global *NEWS* model estimates nutrient export by rivers to coastal waters (at the river mouth) for more than 6000 rivers worldwide. The model was developed in 2002 by a working group of *UNESCO–IOC* (Intergovernmental Oceanographic Commission) using consistent global databases (Seitzinger et al., 2005) and was updated in 2009 (Seitzinger et al., 2010). The model estimates river export of N, P, carbon (C) and silica (Si) including dissolved inorganic (DIN, DIP, and DSi), dissolved organic (DON, DOP, and DOC) and particulate (PN, PP, and POC) forms. The Global *NEWS* model outputs include river export of nutrients at the river mouth in loads (Mg $yr^{-1}$) and yields (kg $km^{-2}$ $yr^{-1}$) by river, as well as the shares of different sources in these nutrient exports (Mayorga et al., 2010; Seitzinger et al., 2010).

The Global *NEWS* model consists of two sub-models: one for dissolved nutrients and one for particulates.

In the dissolved sub-model, river export of dissolved inorganic and organic N and P is estimated. Nutrient fluxes are calculated as a function of socio-economic drivers (e.g. gross domestic product, population density) and human activities on land (e.g. agriculture and sewage) while taking into account hydrological characteristics of river basins (e.g. river discharge, runoff, and precipitation). The dissolved sub-model considers point and diffuse sources of nutrients. Point sources include human waste (for N and P forms) and detergents (for P forms) entering rivers from sewage facilities (Van Drecht et al., 2009). Diffuse sources include fertilizer and manure use in agriculture, biological $N_2$ fixation and atmospheric N deposition over agricultural and natural areas, soil weathering, and leaching from agricultural and natural areas (Bouwman et al., 2009). Nutrient export due to soil weathering and leaching of organic matter is estimated based on an export-coefficient approach as a function of annual runoff from land to streams (Mayorga et al., 2010). Dissolved silica export is calculated on the basis of a regression analysis following after Beusen et al. (2009).

The particulate sub-model calculates river export of PN, PP and PC as a function of total suspended solids (TSS) in rivers, based on linear regression and geophysical (e.g. lithology, land use class) and hydrological characteristics of river basins (e.g. precipitation) (Beusen et al., 2005; Mayorga et al., 2010).

The Global *NEWS* model calculates river export of nutrients for the past (1970 and 2000) and future (2030 and 2050). Global databases on past trends were used as inputs to model nutrient export by rivers since 1970. For the future, the four Millennium Ecosystem Assessment (MEA) scenarios (Alcamo et al., 2006) were used as a basis to generate input data sets for diffuse sources of nutrients in rivers (Bouwman et al., 2009), point sources (Van Drecht et al., 2009) and hydrology (Fekete et al., 2010). Most input data are provided with a resolution of 0.5° longitude by 0.5° latitude (Seitzinger et al., 2010).

The four MEA scenarios are named Adapting Mosaic (AM), Global Orchestration (GO), Order from Strength (OS) and Techno-Garden (TG). The MEA scenarios differ from each other with respect to assumptions on socio-economic developments (globalization or regionalization) and environmental management strategies (proactive or reactive). A globalized world is assumed in scenarios GO and TG, and a regional world in scenarios OS and AM. A reactive approach towards environmental management is assumed in scenarios GO and OS, and a proactive management in scenarios AM and TG (Seitzinger et al., 2010). Bouwman et al. (2009) interpreted the MEA scenarios with respect to agricultural trends. For instance, crop productivity is assumed to be higher in scenario GO than in OS, and intermediate in AM and TG. A rapid increase in N and P fertilizer use in countries with soil nutrient deficits is assumed in the globalized scenarios GO and TG. This is not the case in AM and OS. Scenario AM is characterized by local, pro-active solutions to environmental problems, and assumes improved integration of animal manure, human sewage and households' wastage in agriculture to reduce the use of synthetic fertilizer. The TG scenario focuses more intensively on technological solutions which can be