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Human waste: An underestimated source of nutrient pollution in coastal seas of Bangladesh, India and Pakistan

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ABSTRACT

Many people practice open defecation in south Asia. As a result, lot of human waste containing nutrients such as nitrogen (N) and phosphorus (P) enter rivers. Rivers transport these nutrients to coastal waters, resulting in marine pollution. This source of nutrient pollution is, however, ignored in many nutrient models. We quantify nutrient export by large rivers to coastal seas of Bangladesh, India and Pakistan, and the associated eutrophication potential in 2000 and 2050. Our new estimates for N and P inputs from human waste are one to two orders of magnitude higher than earlier model calculations. This leads to higher river export of nutrients to coastal seas, increasing the risk of coastal eutrophication potential (ICEP). The newly calculated future ICEP, for instance, Godavori river is 3 times higher than according to earlier studies. Our modeling approach is simple and transparent and can easily be applied to other data-poor basins.

1. Introduction

River export of nutrients to the coastal waters of south Asian seas has been increasing during the past decades, causing marine pollution (De et al., 2011; Diaz, 2001; Karn and Harada, 2001; Sattar et al., 2014; Subramanian, 2008; BOBLME, 2014). Human waste is one of the causes of this increase (Bouwman et al., 2009; Morée et al., 2013; Suwarno et al., 2014; Van Drecht et al., 2009). The amount of human waste entering rivers differs among many countries as a result of differences in population growth, sewage treatment and other socio-economic developments (Morée et al., 2013; Qu and Kroeze, 2010; Suwarno et al., 2014). To quantify river export of nutrients from human waste is challenging, especially in Asian developing countries like India, Pakistan and Bangladesh. This is because of lack of data, and because of the complexity of waste water systems. Human waste enters rivers through different pathways such as open defecation, sewage systems, or wastewater treatment plants. Information on human waste production and management is, however, scarce in many countries.

Several studies address human waste as a source of nutrients in rivers indifferent world regions (van der Struijk and Kroeze, 2010; Van Drecht et al., 2009; Suwarno et al., 2014; Yasin et al., 2010; Kroeze et al., 2013). Suwarno et al., (2014) quantified inputs of nutrients from human excrements to 19 rivers in Indonesia, and distinguished between sewage inputs and direct inputs (e.g. from hanging toilets). They showed how important it is to include direct inputs of human waste in calculations of nutrient inputs to rivers. They calculate an increase in N and P inputs to Indonesian rivers with a factor of 17–40 between 2000 and 2050. Van Drecht et al. (2009) calculated that between 2000 and 2050 river export of N and P from human waste in south Asia are projected to increase by 20% and 33%, respectively, in the Global Orchestration (GO) scenario of the Millennium Ecosystem Assessment (MA). They estimate the share of human waste in the total nutrient loads around 10% for rivers draining into the coast of Bangladesh, and >50% for rivers draining into the coast of Pakistan for GO scenario. Zinia and Kroeze (2015) and Sattar et al. (2014) calculated the export of nutrients by rivers draining into the Bengal Gulf from point (sewage systems) and diffuse (agricultural and aquaculture) sources respectively. The results indicate that the coastal eutrophication potential in the Bengal Gulf may be increasing in the future. All these studies, however, underestimate nutrient export to river mouths, because they ignore open defecation as a source of nutrients in rivers.

Existing nutrient export models like Global NEWS typically consider human excrements and detergents a point source of nutrients in rivers, assuming that these waste streams only reach rivers through sewage systems (Kroeze et al., 2012; Seitzinger et al., 2010). However, this may underestimate the associated water pollution, because many people are practicing open defecation, both in rural and urban world regions. A considerable part of this waste may end up in rivers, contributing to marine pollution. In India even close to 80% of the rural population practice open defecation, and in rural Bangladesh or Pakistan

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around 23% (WHO/UNICEF, 2014). This study, therefore, aims to analyze future water pollution from human waste exported by large rivers into the coastal seas of Bangladesh, India and Pakistan while considering open defecation as a source of nutrients in rivers. To this end, we quantify total N and P export to rivers from human waste following a new approach that accounts for open defecation. We first describe our new approach. Next, we use this approach to calculate inorganic and organic N and P export to coastal waters of the Bengal Gulf, East and West Deccan Coast, and Indus Delta Coast and the associated eutrophication potentials in 2000 and 2050.

2. Methods

2.1. Study area

In this study, we focus on the coastline of the most densely populated developing countries in South Asia: Bangladesh, India and Pakistan (Baird, 2009). Our study area covers 14 river basins that drain into the coastal waters of Bangladesh, Indian and Pakistan (Fig. 1 and S3). We selected river basins from Mayorga et al. (2010) and included only relatively large basins, covering >10 grid cells (0.5 degree latitude by 0.5 degree longitude). We consider three sea regions in the area: the Bengal Gulf, East and West Deccan Coast and Indus Delta Coast. The 14 rivers drain into these sea regions. The rivers draining into the Bengal Gulf are considered as the river basins of the Bangladesh coast; rivers draining into the East and West Deccan Coast are considered as river basins of the Indian coast; and the rivers draining into the Indus Delta coast are considered as the river basins of the Pakistan coast (Fig. 1).

2.2. Modeling river export of nutrients from open defecation

We developed a new approach to model inputs of nutrients from human waste to rivers, including sewage inputs and open defecation (Box 1). We applied the method to quantify nutrient export by rivers to the coastal waters of Pakistan, India and Bangladesh. Our approach includes modified equations for point source inputs from sewage from Van Drecht et al. (2009), and new equations for direct inputs of human waste through open defecation. The parameter values are largely from Van Drecht et al. (2009) (Box 1).

The equations presented in Box 1 were implemented in the Global NEWS (Nutrient Export from Watersheds) model (Seitzinger et al., 2010; Mayorga et al., 2010). Global NEWS is a spatially explicit model that calculates nutrient export from land to sea as a function of human activities on the land and river basin characteristics. It can be used to calculate past and future trends in nutrient export by rivers, and the associated coastal eutrophication. It considers diffuse and point sources of dissolved inorganic, dissolved organic and particulate forms of N, P and C in rivers. In Global NEWS both natural and anthropogenic sources of nutrient are considered (Seitzinger and Mayorga, 2008; Mayorga et al., 2010) (see Supplementary material for detail). However, it does not include open defecation as a source of nutrients.

We analyzed past (1970, 2000) and future (2030, 2050) trends in river export of nutrients to the coastal waters of Pakistan, India and Bangladesh. For future years the Global Orchestration (GO) scenario of the Millennium Ecosystem Assessment (MA) was taken as a starting point. The GO scenario assumes that the world will develop with reactive approaches towards ecosystem management, and with globalizing socio-economic developments. In GO, population growth and urbanization are assumed to slowly increase over time. In this scenario, the incomes of people, agricultural productivity, greenhouse gas emissions, and fertilizer use are assumed to be high. MA scenarios are described in detail in Alcamo et al. (2005) and Seitzinger et al. (2005).

We thus run Global NEWS while considering open defecation as a source of nutrients in rivers. The population defecating in the open areas in is considered a potential source of direct nutrient inputs to the rivers draining to the coastal seas in the study area. We derived

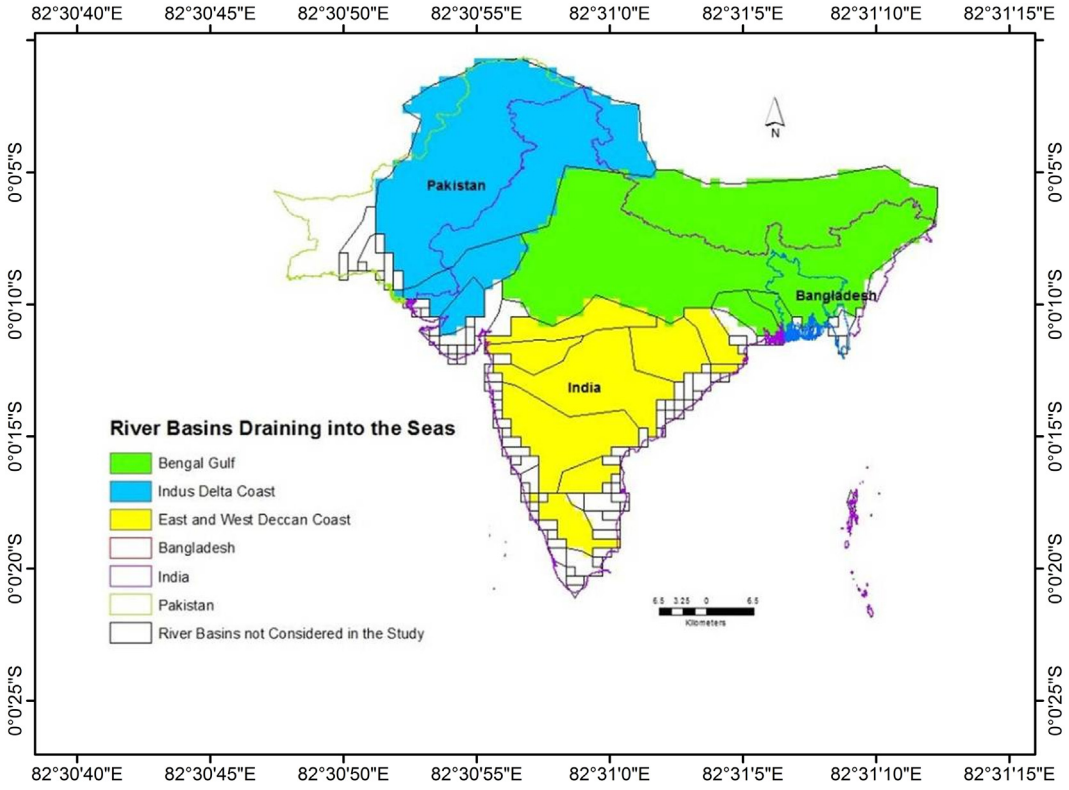

Fig. 1. Study areas covering 14 river basins that drain into the three selected sea regions of Bangladesh, India and Pakistan coast.
(Source: Delineations of river basins are from Global NEWS and administrative boundaries are from the Global Administrative Areas (Mayorga et al., 2010, GADM, 2012).)

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