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Modelling the impact of future socio-economic and climate change scenarios on river microbial water quality

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ABSTRACT

Microbial surface water quality is important, as it is related to health risk when the population is exposed through drinking, recreation or consumption of irrigated vegetables. The microbial surface water quality is expected to change with socio-economic development and climate change. This study explores the combined impacts of future socio-economic and climate change scenarios on microbial water quality using a coupled hydrodynamic and water quality model (MIKE21FM-ECOLab). The model was applied to simulate the baseline (2014–2015) and future (2040s and 2090s) faecal indicator bacteria (FIB: *E. coli* and enterococci) concentrations in the Betna river in Bangladesh. The scenarios comprise changes in socio-economic variables (e.g. population, urbanization, land use, sanitation and sewage treatment) and climate variables (temperature, precipitation and sea-level rise). Scenarios have been developed building on the most recent Shared Socio-economic Pathways: SSP1 and SSP3 and Representative Concentration Pathways: RCP4.5 and RCP8.5 in a matrix. An uncontrolled future results in a deterioration of the microbial water quality (+75% by the 2090s) due to socio-economic changes, such as higher population growth, and changes in rainfall patterns. However, microbial water quality improves under a sustainable scenario with improved sewage treatment (-98% by the 2090s). Contaminant loads were more influenced by changes in socio-economic factors than by climatic change. To our knowledge, this is the first study that combines climate change and socio-economic development scenarios to simulate the future microbial water quality of a river. This approach can also be used to assess future consequences for health risks.

1. Introduction

Concerns are growing over surface-water quality due to widespread microbial contamination of water systems. An effective water management infrastructure is lacking in most developing countries and a large portion of their population relies on untreated and highly contaminated surface water. This increases the outbreaks of waterborne diseases, such as diarrhoea. Globally, 1.8 million people are estimated to die annually from waterborne diseases and most of them are children from developing countries (WHO, 2012). Most of those deaths are caused by unsafe water supply and poor sanitation (Rochelle-Newall et al., 2015). Also in Bangladesh, access to clean water and adequate sanitation remains a major problem despite recent improvements.

The potential future impact of socio-economic development and climate change on river water quality is a key concern worldwide (Whitehead et al., 2015). Increasing temperatures and change in rainfall patterns combined with socio-economic factors, such as human and animal population growth and land use changes will continue to affect flows and water quality in river systems globally (Jin et al., 2015). Under future climate change scenarios, tropical systems will likely be subject to increased temperature and shifts in the frequency and intensity of extreme rainfall events (Rochelle-Newall et al., 2015). These projected increases in precipitation and floods combined with population growth, urbanization and agricultural intensification are expected to accelerate the transport of waterborne pathogens to aquatic systems (Rose et al., 2001; Hofstra, 2011) and thereby deteriorate future scenarios of contamination and increase risk of waterborne diseases. This contamination is aggravated in the developing countries like Bangladesh, because of their high susceptibility to climate change, high population growth, rapid urbanization, agricultural intensification and poor water treatment facilities.

Over the past few decades, with rapid population growth, urbanization and agricultural intensification, most Bangladeshi rivers have received enormous inputs of microbial contaminants and the microbial water quality has been impaired. Recent measurements in the Betna River in southwestern Bangladesh revealed very poor microbial water quality due to widespread faecal contamination. Bathing water-quality criteria were found to be violated year round (Islam et al., 2017a). The

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highly contaminated river water is also used for irrigation, domestic purposes and shellfish production; people bathe in the river and consume contaminated shellfish. This increases the people's vulnerability to waterborne diseases. Deterioration of water quality may also influence safe food production and livelihoods of the people. In the future, the river water will be severely affected by changing climatic and socio-economic conditions. Therefore the hydro climatic and anthropogenic changes will have substantial impacts on the agricultural sector and thousands of people living on the river basin. Therefore, understanding the link between human activities, environmental changes and microbial spreading are prerequisites for reducing the risks of microbial exposure (Rochelle-Newall et al., 2015).

Climate change combined with socio-economic factors is a key concern of the Intergovernmental Panel on Climate Change (IPCC) (IPCC). Socio-economic scenario analysis is found to be a useful tool for exploring the long-term consequences of anthropogenic change and response options (Kriegler et al., 2012). Scenarios should account for future changes in both climatic and socio-economic factors, because to evaluate the impact of climate change on future societies, combination of the two groups of factors is important (Berkhout et al., 2002). The IPCC report has proposed development of a new scenario framework in which Shared Socio-economic pathways (SSPs) and Representative Concentration Pathways (RCPs) are combined (Van Vuuren et al., 2012, Kriegler et al., 2012). The SSPs provide narratives and quantifications of future possible developments of socio-economic conditions (e.g. population growth, urbanization, economic and technological development, change in land use) that describe challenges to mitigation and adaptation (O'Neill et al., 2017). The RCPs describe trajectories for the development of emissions and greenhouse gas concentrations (consistent with radiative forcing) and the consequent changes in climate factors (e.g. temperature and precipitation) (Van Vuuren et al., 2011). The SSPs and RCPs can be combined in a matrix. The scenario matrix is useful to look into future impact of climate and socio-economic changes on human society and the environment and to evaluate specific policies for mitigation and adaptation.

Changes in socio-economic conditions are often not adequately incorporated in climate change impact assessment and scenario analysis (Berkhout et al., 2002). Some studies focused on assessing the impacts of climate change only on river hydrodynamic characteristics (Elshemy and Khadr, 2015; Kuchar and Iwański, 2014) or waterborne pathogens/FIB (Jalliffier-Verne et al., 2016; Rankinen et al., 2016; Liu and Chan, 2015; Sterk et al., 2016) without considering socio-economic changes (i.e. the SSPs). Few studies have applied the new SSPs without including the climatic factors. For instance, Van Puijenbroek et al. (2015) studied nutrients and Hofstra and Vermeulen (2016) Cryptosporidium emissions to surface waters globally. Some studies assessed future impact of climate and socio-economic changes on water flow and water quality separately, without combining both groups (Whitehead et al., 2015; Jin et al., 2015). Moreover, these limited approaches have been evaluated with respect to flows and nutrient flux, but have not been used to study changes in microbial water quality. Applying combined scenarios is rare. Only a couple of recent studies have applied this approach. For instance, Borris et al. (2016) applied this combined approach in assessing urban storm water quality (with respect to suspended solids and heavy metals) in Sweden and Zhuo et al. (2016) assessed changes in agricultural water availability for China. To our knowledge, our study is the first study that applies a process based model to simulate the combined impacts of climate change and socio-economic development scenarios on microbial water quality in a river basin. Identifying trends and implementing them in future scenarios to assess future microbial water quality is required to address changes in widespread microbial contamination. The Betna River basin is an ideal site for this study because firstly, the river is situated in a subtropical developing country, where microbial water quality is not adequately studied. Secondly, the basin flooded almost every year during the last decade and its diversified water uses (e.g. domestic, irrigation, shellfish growing and bathing) require much better water management. Thirdly, due to climate change, more frequent and intense flooding is expected in this basin (floods have a strong impact on the spread of infectious diseases). Finally, socio-economic developments are happening fast. All this signifies the importance of our socio-economic and climate change impact assessment on the Betna River's microbial water quality.

Mathematical model-based scenario analysis can be a useful tool to investigate the impacts of socio-economic development and climate change on the hydrology and transport of waterborne pathogens. Despite their inherent uncertainties, models can estimate future changes in the concentration of waterborne pathogens due to climate change (Hofstra, 2011). Microbial contamination studies are usually based on Faecal Indicator Bacteria (FIB). *E. coli* and enterococci are the two most widely used indicators of microbial water quality (Lata et al., 2009). This paper aims to assess the impact of socio-economic development and climate change scenarios on FIB (*E. coli* and enterococci) concentrations in the Betna River basin using a process based model (MIKE 21 FM) coupled with a water quality module (ECOLab). These coupled models were initially calibrated and validated using observed water level, discharge, water temperature, salinity and FIB data (Islam et al., 2017b). Then, socio-economic development and climate change projections for the near (2040s) and far (2090s) future were made. The model was run for these futures using the projections in different scenarios. Finally, the future scenarios were discussed and guidelines were proposed to address changes in microbial water quality induced by socio-economic development and climate change. This study illustrates the application of future microbial water-quality scenarios in the context of a subtropical river system in a developing country. The findings will help water managers and public health professionals in assessing health risks, and policy makers to formulate policy and reduce the elevated health risks. The results can also be utilized by a broad scientific community involved in water, climate, food security and socio-economic research.

2. Methodology

2.1. Study area and sources of contaminants

The study area covers an area of 107 km^2 in the Betna River catchment in southwestern Bangladesh (Fig. 1). The total length of Betna River is about 192 km with an average width of 125 m. The maximum water depth is 9 m. Our modelling study focuses on the downstream 30 km of the Betna River. In this part of the river the tide influences the discharge. The study area has a typical monsoon climate with a hot season March–May, followed by a rainy season June–October and a cool period November–February. Mean annual rainfall in the area is about 1800 mm, of which approximately 70% occurs during the monsoon season. This area is affected by both inland flooding due to heavy incessant rainfall during the monsoon in August–September and during the cyclone season (pre-monsoon) in April–May (CEGIS, 2013). Mean annual air temperature is 26 °C with peaks of around 35 °C in May–June. Temperature in winter may fall to 10 °C in January.

The study area is densely populated, with 2.23 million people. Sewage and manure are the main bacteria sources in this catchment. In the study area, sewage, in particular from the town of Satkhira (0.4 million inhabitants), is discharged into the river without treatment. The manure sources include manure applied to the paddy rice fields as organic fertilizer, and direct deposition of manure to the river and canals. Various waterborne diseases, including gastrointestinal and skin diseases, have been observed in this area throughout the year, but with peaks during and after flooding (CEGIS, 2013).

2.2. Coupled hydrodynamic and water quality model

A two dimensional hydrodynamic model, MIKE 21 FM (DHI, 2011) coupled with the water quality module (ECOLab) was applied to