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Future trends in urbanization and coastal water pollution in the Bay of Bengal: the lived experience

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Abstract The Bay of Bengal includes coastal seas of several countries, including Bangladesh, India, and Myanmar. We present scenarios for future river export of eutrophying nutrients into the Bay of Bengal, and the role of urbanization therein. We used *NEWS* (Nutrient Export from WaterSheds) model to analyze trends over the period 1970–2050. The scenarios are based on the Millennium Ecosystem Assessment and indicate the number of people living in urban areas may increase from 22 % in 1970 to about 50 % in 2050. We show that this may considerably increase nutrient levels in rivers from sewage and other sources. For 2050, we calculate that harmful algal blooms may be a potential problem in coastal waters of about 95 % of the total drainage basin of the Bay of Bengal. In addition, we analyze Bangladeshi citizens' expectations of future trends and how citizens with different worldviews would experience environmental changes (i.e., their lived experience). The citizens indicate that trends as envisaged in our scenarios may be a negative experience. However, some people may experience the trends as positive, because they expected worse.

Keywords Urbanization · Sewage systems · Eutrophication · Cultural Theory · Scenario · Bay of Bengal

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1 Introduction

In many less developed countries, urbanization has reached an uncontrollable level. This is especially the case in South Asia (Khadka and Shrestha 2011; Rana 2011). Global urban population may reach around 5 billion in 2030, and, by 2050, more than 60 % of the total Asian population may be living in urban areas (Zhang 2008; UN 2010).

Urbanization has several impacts on the environment. One of these is that cities are generally sources of nutrients in rivers (Seitzinger et al. 2010; Grimm et al. 2008). Both point and non-point sources contribute to increased levels of nitrogen (N) and phosphorus (P) in rivers that are eventually transported to coastal waters (Mayorga et al. 2010; Wickham et al. 2002). Van Drecht et al. (2009) projected that rapid urbanization would lead to increase in sewage N and P emissions in developing countries in the coming decades.

Increased nutrients inputs to coastal waters is a worldwide problem (Qu and Kroeze 2010; Carpenter et al. 1998; Bouwman et al. 2005). Increases in nutrients levels may result in coastal eutrophication that in turn affects water quality, aquatic life, aquaculture, fisheries, tourism, as well as ecosystems and human health (Van der Struijk and Kroeze 2010; Diaz and Rosenberg 2008; Wickham et al. 2002). According to Garnier et al. (2010), harmful algal blooms may develop in seas and oceans when N and P are available in excess over silicon (Si).

In this study, we focus on the rivers draining into the northern Bay of Bengal. The Bay is suffering from coastal eutrophication (Sattar et al. 2014), but no experimental studies exist on the causes of increased nutrient inputs to the bay. Models may help to understand pollution problems in data-poor regions and to identify the likely causes of the problem (Scheren et al. 2004).

We use *NEWS* (Nutrient Export from WaterSheds) model to analyze past and future trends in nutrient export from land to the Bay of Bengal. Future trends are based on Millennium Ecosystem Assessment (MA) scenarios. This model estimates trends in river export of different forms of N and P, and their sources as functions of human activities on the land, hydrology, and basin characteristics (Mayorga et al. 2010). Population growth and economic development are important drivers in this model. Recent studies analyzed trends in nutrients export by rivers to coastal waters by applying *NEWS* at global scale (e.g., Mayorga et al. 2010; Seitzinger et al. 2010; Van Drecht et al. 2009). However, some studies performed similar analyses at regional scale focusing on Southeast Asia, indicating *NEWS* performs well for regions therein (Qu and Kroeze 2010; Yan et al. 2010; Suwarno et al. 2013). Similarly, it has been successfully applied to Africa (Yasin et al. 2010), South America (Van der Struijk and Kroeze 2010), and the Black Sea (Strokal and Kroeze 2013). In addition, *NEWS* has been used to analyze trends in coastal eutrophication potential (e.g., Garnier et al. 2010).

We add to *NEWS* approach an analysis of how people would experience coastal water pollution. Following Wilson (2012), we refer to this as the ‘lived experience’ of global change. Several studies on lived experience exist (Teixeira et al. 2012; Abbott 2012; Wilson et al. 2012; Pérez Salgado et al. 2012). The lived experience is challenging to analyze. We do this by applying perspectives used in Cultural Theory (Mamadouh 1999). Such societal perspectives are driven by how people view the world, and what their preferred management strategies are (Offermans and Corvers 2012). Previous studies have applied the perspectives method, for instance, to flood management in Rhine and Meuse rivers (Middelkoop et al. 2004), biodiversity conservation (Beumer and Martens 2010), and water management (Offermans et al. 2011). In this study, we additionally analyze

Bangladeshi citizens' expectations of future trends in region wide socio-economic and environmental changes and compare their expectations with their lived experience. We take Bangladesh as an illustrative example in our analysis as it is highly vulnerable to global change yet one of the least studied areas in South Asia with respect to these issues. This is one of the first attempts toward this kind of analysis in South Asia, especially Bangladesh, which illustrates the need for further research in this area.

The objective of our study is to analyze past and future trends in nutrient inputs to the Bay of Bengal. We focus in particular on the role of urbanization in nutrient export by rivers to the coastal waters of the Bay of Bengal and the potential coastal eutrophication. Our analysis of past and future trends covers the period 1970–2050. A second objective of our study is to analyze Bangladeshi citizens' expectations of future trends in coastal water pollution, and the lived experience of future global change as envisaged in our scenarios.

2 Methods

2.1 Study area

The northern Bay of Bengal is our study area, with a focus on Bangladesh. The People's Republic of Bangladesh with a total land area of 147,570 km^2 is bordered by India on the west, north, and east, by Myanmar on the southeast and by the Bay of Bengal on the south (BBS 2011). It is a densely populated country ($\sim$1,000 $person^{-1}$ km^{-2}) with an annual GDP growth rate of almost 7 % (MoF 2011). Currently, 27 % of the total population lives

Table 1 Basin areas of the selected nineteen rivers draining into the Bay of Bengal and their discharge in 2000

Basin ID or name[a]	Area (km^2)	Basin discharge (km^3 $year^{-1}$)
14 (Ganges)	1,626,470	703
267 (Damodar)	59,591	16
434	31,150	4
642 (Kaladan)	20,033	47
858 (Lemro)	14,426	41
865	14,247	22
1,770	5,929	12
1,853	5,746	14
1,863	5,705	4
3,205	2,957	6
3,219	2,949	6
3,234	2,941	6
3,266	2,924	7
3,284	2,915	8
3,285	2,915	8
3,310	2,906	9
3,395	2,858	6
3,403	2,858	4
3,423	2,847	3

[a] Basin identification (ID) number and name (when available) according to *NEWS* Run 5, (Mayorga et al. 2010). See Fig. 1 for locations of basins

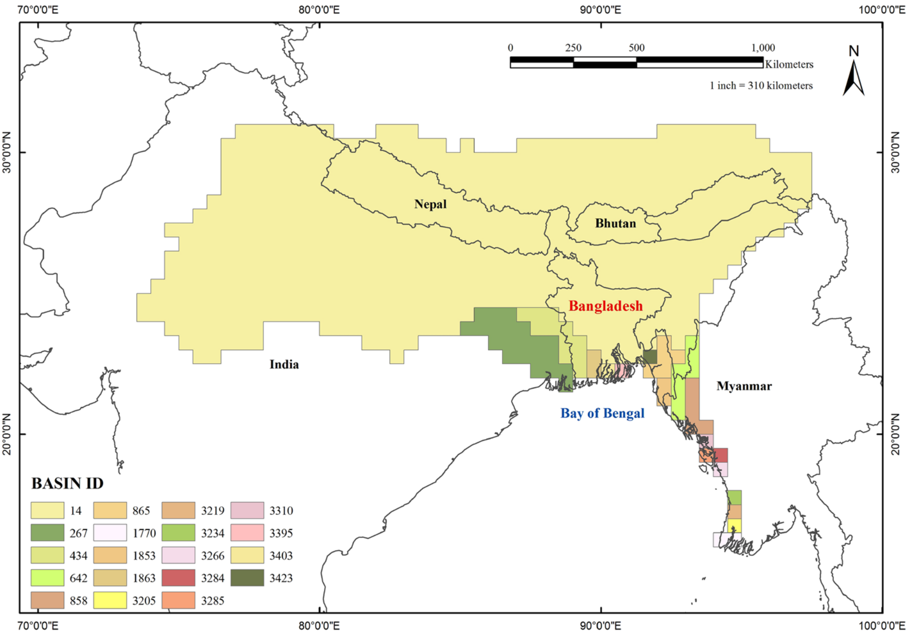


Fig. 1 Geographic location of the study area indicating selected river basins. See Table 1 for basin details

in urban areas, of which 60 % in four major cities: Dhaka, Chittagong, Khulna, and Rajshahi (Rana 2011; Chowdhury and Amin 2006). The UN (2010) projected urban population to double by 2050. High population growth, economic development, and unplanned rapid urbanization are posing increasing pressure on socio-economic and environmental aspects of Bangladesh.

We select nineteen river basins from *NEWS* based on latitudes and longitudes of the river mouths. These rivers are in South Asian countries and Myanmar and ultimately draining into the Bengal Gulf in the Bay of Bengal. The Ganges, the Damodar, and the Kaladan are the largest river basins among the nineteen (Table 1; Fig. 1). Sattar et al. (2014) also included these nineteen rivers in their model analysis of sixty Asian rivers draining into the bay. Our study differs from this as we focus on Bangladesh, urban sources of nutrients in rivers and the lived experience of future trends.

2.2 *NEWS* and MA scenarios

NEWS is a global, spatially explicit nutrient export model. It includes over 6,000 river basins worldwide. It calculates nutrient export by rivers for the past (1970 and 2000) and the future (2030 and 2050) (Mayorga et al. 2010). *NEWS* uses consistent global databases (typically on a 0.5° × 0.5° grid) to predict dissolved organic, inorganic, and particulate forms of nutrient (N, P, and carbon) export by rivers (Seitzinger and Mayorga 2008). These predictions are done based on natural and anthropogenic drivers including non-point and point watershed sources, physical and hydrological factors, and removal within the river system (*ibid*, 2008).

The MA scenarios were implemented in *NEWS* (Mayorga et al. 2010). To this end, spatially explicit model input had to be developed for the past and the four MA scenarios—

Global Orchestration (GO), Order from Strength (OS), TechnoGarden (TG), and Adapting Mosaic (AM), based on the scenario storylines (Van Drecht et al. 2010 and Fekete et al. 2010). These scenarios differ with respect to the assumed socio-economic trends and environmental managements. GO and TG scenarios represent globalized worlds, whereas OS and AM scenarios represent regionalized worlds. In addition, GO and OS scenarios undertake reactive approaches while TG and AM scenarios undertake proactive approaches for managing environmental changes (Seitzinger et al. 2010).

2.3 An indicator for coastal eutrophication potential (ICEP)

ICEP is an indicator for new production of non-siliceous algal biomass that can potentially sustain in the coastal waters bodies when either N or P is available in excess over Si (Garnier et al. 2010). We apply ICEP in the same way as it is applied in *NEWS*:

$$\text{N - ICEP} = [\text{N}_{\text{Flx}}/(14 \cdot 16) - \text{Si}_{\text{Flx}}/(28 \cdot 20)] \cdot 106 \cdot 12 \tag{1}$$

If N/P < 16 (N limiting),

$$\text{P - ICEP} = [\text{P}_{\text{Flx}}/31 - \text{Si}_{\text{Flx}}/(28 \cdot 20)] \cdot 106 \cdot 12 \tag{2}$$

If N/P > 16 (P limiting),

$$\text{N:P} = (\text{TN}_{\text{yld}}/14)/(\text{TP}_{\text{yld}}/31) \tag{3}$$

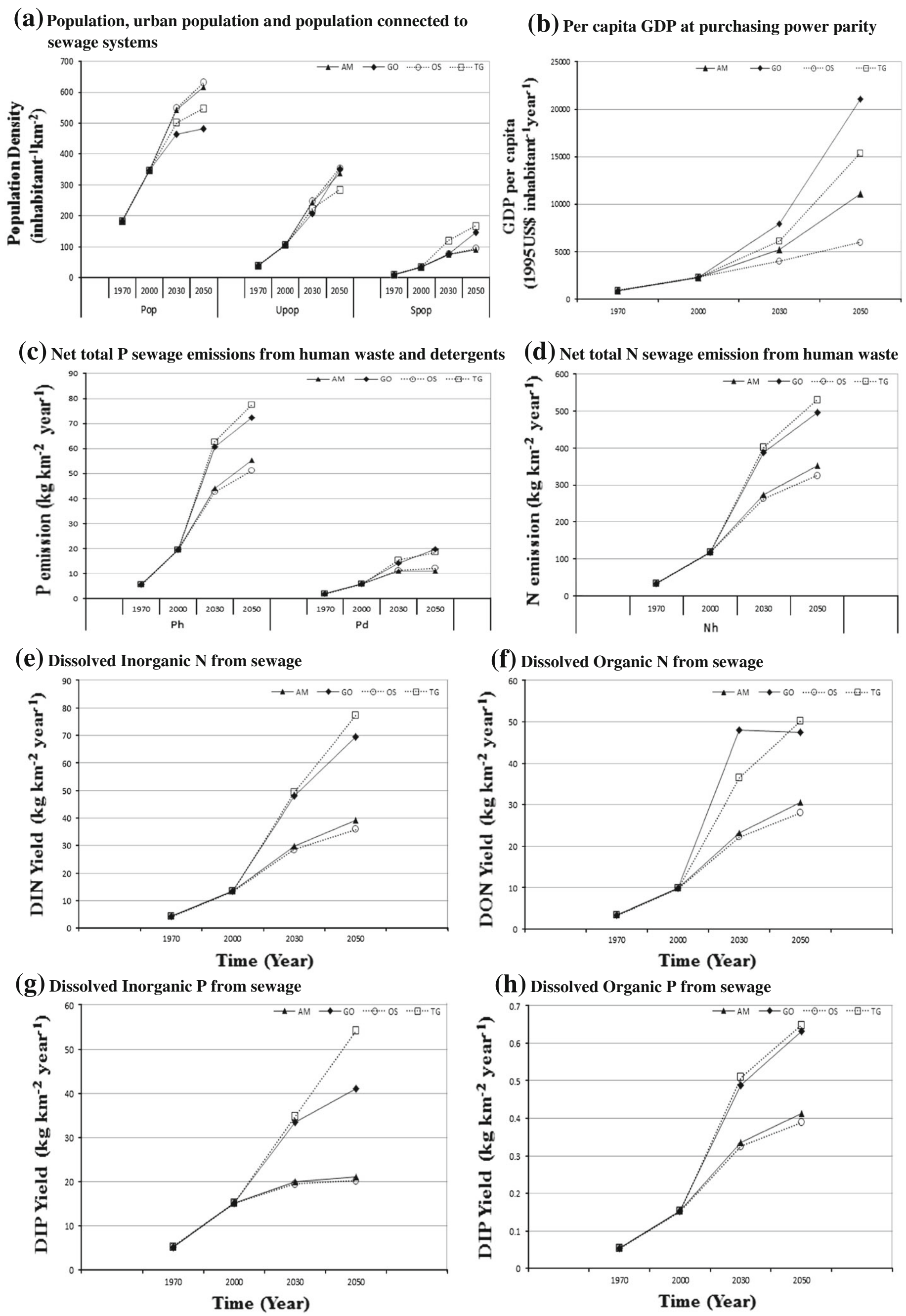
Here, N_{Flx}, P_{Flx}, and Si_{Flx} are mean specific fluxes of total N, P, and Si, respectively, that are delivered at the estuaries of rivers (kg C km^{-2} day^{-1}). TN_{yld} and TP_{yld} are total N and P fluxes, respectively (kg km^{-2} $year^{-1}$). In *NEWS*, either N-ICEP (when N is limiting) or P-ICEP (when P is limiting) is calculated for total N (TN = DIN + DON + PN) and total P (TP = DIP + DOP + DP) fluxes. Equation 3 is used to determine which nutrient (N or P) is limiting.

Negative values of ICEP (ICEP < 0) indicate Si is in excess of N and P, and, thus, there is a low risk for eutrophication. Positive values (ICEP > 0) indicate conditions are potentially favorable for harmful non-siliceous algal blooms. We apply the ICEP approach to analyze potential coastal eutrophication in 1970 and 2000 and for the year 2050 (scenarios GO and AM).

2.4 Perspectives method of Cultural Theory to analyze the lived experience

We adopt worldviews from Cultural Theory to classify citizens into four groups: *hierarchist* (who consider nature is tolerant within limits and believe outcomes can be managed to be sustainable), *egalitarian* (who consider nature as vulnerable and believe outcomes require altruism and common effort), *individualist* (who consider nature is resilient and believe outcomes are personal responsibilities), and, lastly, *fatalist* (who consider nature as a lottery and outcomes as function of chance) (Mamadouh 1999; O'Riordan and Jordan 1999; Tansey and O'Riordan 1999). The four categories of citizens prefer different environmental management styles. The *individualists* favor adaptive styles, the *hierarchists* prefer regulatory or control strategies, the *egalitarians* prefer preventive measures, and, lastly, the *fatalists* prefer passive environmental management styles since they believe that they are unable to influence any event (Hoekstra 1998).

Next, we analyze what changes citizens with different worldviews expect and how they may experience the expected future changes in the environment, i.e., their lived experience



of global change. 'Lived experience' comprises an individual's, a community's, or an organization's perceptions and responses toward a change, in other words, their views regarding a change and preferred management styles (Wilson 2012 and Offermans and Corvers 2012). This may involve environmental, social, economic, and other aspects of a

◀**Fig. 2** Past and future trends in selected demographic and economic parameters, associated with sewage inputs of N and P to rivers and nutrients export (yield) originating from sewage from the nineteen selected river basins to the Bay of Bengal in 1970, 2000, 2030, and 2050 for the four MA scenarios. Shown are **a** Pop = population, Upop = Urban population, Spop = Population connected to sewage systems; **b** GDP = Gross Domestic Product; **c** Ph = Net total P sewage emission from human waste, Pd = Net total sewage emission from detergents; **d** Nh = Net total N sewage emission from human waste; **e** DIN, **f** DON; **g** DIP; and **h** DOP from sewage (Source: deduced from *NEWS* Run 5, Seitzinger et al. 2010)

change (Willems et al. 2012). Our analyses of citizens expectations and lived experience are based on in-depth interviews with experts mostly from environmental research institutes, government and non-government organizations, and universities in Bangladesh,[1] expert judgment complemented by information derived from the literature (e.g., Offermans and Corvers 2012; Offermans et al. 2011; Middelkoop et al. 2004 and Hoekstra 1998). We select the interviewees randomly considering their expertise in environmental field and used a semi-structured questionnaire based on the trend analyses of the MA scenarios. We focus in particular on citizens in Bangladesh and on changes in socio-economic and environmental aspects associated with urbanization and coastal eutrophication up to 2050. Results from the interviews indicate their lived experience, i.e., whether they are optimistic or pessimistic about the expected trends. This may influence whether they would undertake regulatory, preventive, or adaptive management styles.

3 Past and future trends in socio-economic and environmental indicators

3.1 Urbanization, GDP, and sewage emissions

Figure 2a presents demographic trends in the nineteen selected basins. Population density almost doubled between 1970 and 2000 and is projected to continue increasing until 2030. The rate of increase will slightly slow down after 2030. By 2050, scenarios GO (483 inhabitants km^{-2}) and TG (548 inhabitants km^{-2}) show lower average population densities than AM (618 inhabitants km^{-2}) and OS (632 inhabitants km^{-2}). Urban population increases between 1970 and 2050 in all the scenarios. In 1970, 22 % of total population lived in urban areas. The scenarios indicate a faster increase in urban population after 2000. By 2050, approximately 50 % of the people will live in urban areas in these basins.

The number of people connected to sewage systems is relatively low (Fig. 2a). TG scenario projects the largest number of people connected to sewage systems in 2030 (24 %) and 2050 (31 %). This is slightly more than in scenario GO (17 and 30 % in 2030 and 2050, respectively). The results indicate that the number of people connected to sewage systems increases less fast than the total and urban population. Sewerage is assumed to be developed faster in the globalized scenarios (GO and TG) than in the regionalized scenarios (AM and OS).

All the MA scenarios project a steady economic growth from 1970 till 2030. Per capita GDP at purchasing power parity (GDPppp) in all the nineteen river basins (Fig. 2b) increases by at least a factor of 7 between 1970 and 2050. Between 2030 and 2050, a relatively fast increase in per capita GDP is projected for GO scenario, reaching more than 20,000 (1995) US$ inhabitant^{-1} year^{-1} in 2050.

[1] Interviewees from "IUCN-Bangladesh," "Center for Environmental and Geographic Information Services," "Institute of Water Modelling," "Waste Concern Consultants," "Bangladesh Energy Regulatory Commission," "Bangladesh University of Engineering and Technology," and "Southeast University".

Next, we analyze net total P and N emissions to rivers from sewage systems after treatment (Fig. 2c, d). These emissions were relatively low between 1970 and 2000. From 2000 onward, we see large increases. Emissions from human waste (excrement) increase by a factor of 3–4 and emissions from detergents (laundry and dishwashers) at least double. We calculate larger increases for the globalized scenarios than for the regionalized. This may seem surprising, since TG and AM are the scenarios assuming proactive environmental management. The explanation is that the assumptions on the increase in the number of people connected to sewage systems are driving the results more than the N and P removal in waste water treatment.

3.2 River export of nutrients

We analyze river export of dissolved inorganic N and P (DIN and DIP) and dissolved organic N and P (DON and DOP) originating from sewage (Fig. 2e–h).

River export of dissolved N and P from sewage increased by a factor of 3 between 1970 and 2000, and, between 2000 and 2050, it will further increase by up to a factor of 6, depending on the scenario and nutrient form. This increase can be largely explained by increased sewerage connection. Interestingly, in 1970 and 2000, sewage contributed to around 20 % of total DIP export, whereas in 2030 and 2050 we estimate this to reach 40–50 %. Sewage thus substantially contributes to DIP export by rivers.

River N and P export from sewage increases faster in the globalized scenarios (171–478 % between 2000 and 2050 in GO and TG) than in the regionalized scenarios (33–210 % in AM and OS).

3.3 Coastal eutrophication potential

For most rivers, we calculate an N/P ratio > 16, i.e., N is the limiting element. Therefore, we calculate N-ICEP for most of the river basins. The ICEP values are relatively high for many rivers draining into the Bay of Bengal, indicating a risk for coastal algal bloom (Fig. 3).

Between 1970 and 2000, there was little change in the risk of coastal algal blooms: ICEP values > 0 are calculated for more than 95 % of the drainage basin throughout this period. Negative ICEP values are calculated for a number of relatively small basins at the eastern coast of the bay. Most of these basins also have negative ICEP values in 2050. For the largest basins, we calculate increasing positive ICEP values in the future. The differences among scenarios are small. The risk of algal blooms is the highest in the globalized scenarios GO and TG. In the regionalized scenarios AM and OS, the risk is somewhat smaller, although their ICEP values for 2050 are considerably higher than in 2000. These results indicate that socio-economic trends tend to have larger effect on coastal water pollution than environmental management. The scenarios assuming a globalized world (GO and TG) describe worlds with a focus on economic and technical developments that drive nutrient export by rivers. In these scenarios, sewerage may be developed to a larger extent than in the other scenarios, resulting in increased point sources inputs. Also assumptions on damming of rivers and consumptive water use depend highly on the socio-economic trends. The scenario with the lowest ICEP values for most basins is AM scenario, in which ICEP values do not change much between 2000 and 2050. Thus, in the coming decades, the risk of coastal eutrophication may stabilize, but may also increase in the Bay of Bengal, depending on the economic and technical developments, and

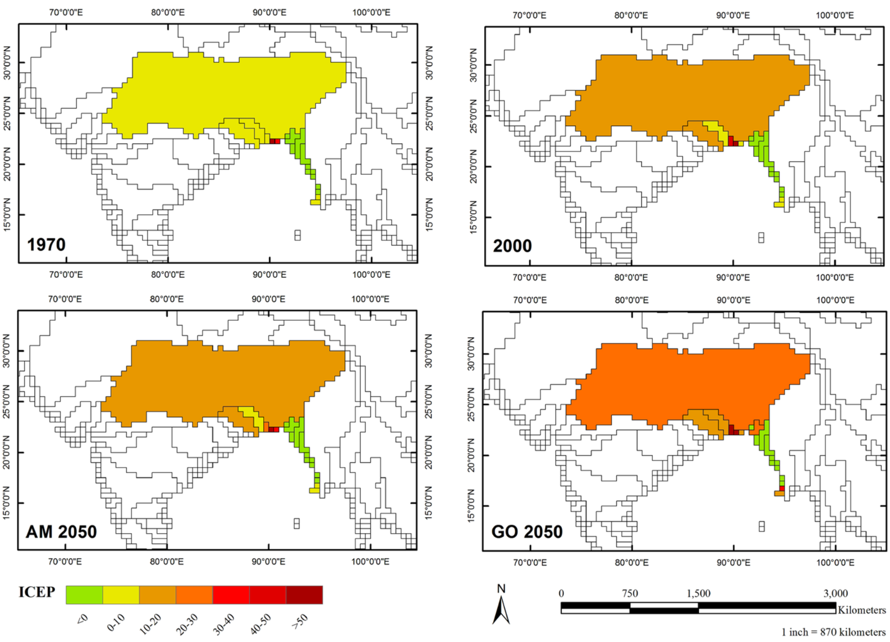


Fig. 3 Coastal eutrophication potential (ICEP) in the nineteen river basins in 1970, 2000, and 2050 for the MA scenarios AM and GO (*NEWS* model output)

environmental policies. It should be noted that ICEP is determined not only by point sources, but also by diffuse sources, agriculture in particular.

3.4 Expectations about future trends

So far, we presented trends in coastal water pollution as calculated by *NEWS* for different scenarios. In the following, we analyze what future changes selected Bangladeshi citizens may expect (Table 2), and, next, how they would experience the changes that we envisage in the MA scenarios (Annex).

We first describe what Bangladeshi citizens with different worldviews expect about future trends in population and economic growth, urbanization, river pollution, sewage systems, coastal ecosystem services, and relevant indicators (Table 2). We do this by an interpretation of the worldviews from Cultural Theory. For each indicator, we also indicate the management styles as preferred by selected Bangladeshi citizens.

The analysis reveals how expectations are driven by peoples' worldviews. For example, the *hierarchists* expect moderate trends in urbanization and population growth accompanied by moderate to high GDP growth in future. They also expect river pollution from sewage to be moderate and health problems due to coastal water pollution to be serious, yet manageable. The *hierarchists* perceive the risk of future coastal eutrophication as moderate but expect coastal ecosystems to face serious problems, with serious consequences for ecosystem services. On the other hand, the *egalitarians* expect low increases in population, urbanization, and GDP. They expect serious and unmanageable health problems because of high levels of river pollution from sewage. They also believe that coastal ecosystem

Table 2 Expectations of the interviewed Bangladeshi citizens' about socio-economic and environmental trends up to 2050. The table shows what changes citizens with different worldviews expect (based on Offermans and Corvers 2012; Offermans et al. 2011; Middelkoop et al. 2004; Hoekstra 1998). The shaded cells also indicate management styles that are considered *preferable* by selected Bangladeshi citizens (based on interviews and expert judgment)

Indicators	Hierarchist	Egalitarian	Individualist	Fatalist
Expectation about population growth	**Moderate** Population must be controlled strictly by government regulations.	Low	High	Unmanageable
Expectation about urbanization	Moderate	Low	**Rapid** Measures for decentralization of population should be undertaken immediately.	Unmanageable
Expectation about GDP growth	Moderately high	Low	High	No expectation
Efficiency of public sewage treatment	Moderate	**Low** Decentralized sewage treatment is a better and more cost effective option than centralized public sewage treatment to mitigate emissions.	High	Irrelevant
Wastewater policy	Treatment to meet standards	Treatment to decrease production	'Polluters pay' principle	No policy
Trust in technology	Moderate	Low	**High** It is true that advanced technologies can solve pollution problems; however, it should be cheap so that govt. or individuals can easily afford these.	No trust
River pollution from sewerage	Moderate	**High** Increased waste water or sewage treatment facilities along with awareness building (to mitigate pollutions) are necessary.	Low	Unpredictable
Availability of coastal ecosystem services	Scarce, manageable	Depleting, unmanageable	Abundant, manageable	Lottery, unmanageable
Value of coastal ecosystem services	Reliable source for fulfillment of functions	Source for rest and well-being	Source of prosperity and self-development	Source of profit for a few
Use of coastal ecosystem services	Inevitable	Below sustainable level	Desirable if cost-effective	Profitable to a few
Coastal ecosystem services problems vs. manageability	**Serious problem but manageable** Proper implementation of laws/ rules can prevent over exploitation of these services.	Serious problem, not manageable	No problem	Irrelevant
Coastal ecosystem services priorities	Preservation of current functions	Compensation and ecology	Innovation and economy	Irrelevant
Coastal eutrophication risk	Moderate	High	Low	Unpredictable
Health problem due to coastal water pollution	Serious problem, but manageable	Serious problem, not manageable	No problem	Irrelevant
Responsibility	National governments	Regional governments and NGOs	Private companies and Individuals	No one

services will be depleted in future and that ecosystems will face unmanageable and serious problems. The *egalitarians* think there will be high risk of coastal eutrophication.

3.5 Lived experience of future trends

Next, we analyze how Bangladeshi citizens would experience the future trends along with their preferred management styles in the four MA scenarios (Annex). We do this based on a further interpretation of the scenarios and interviews and focus on selected indicators: Gross Domestic Product at purchasing power parity (1995US$ inhabitants^{-1} year^{-1}), urban population (inhabitants km^{-2}), population connected to sewage (inhabitants km^{-2}), river export of DIN, DON, DIP, and DOP from sewage (kg km^{-2} year^{-1}), and the potential for coastal eutrophication (kg C km^{-2} day^{-1}).

The interviewees prefer different management styles. For the regionalized scenarios (AM and OS), the following measures seem to be preferred (Tables A.1, A.3). The *hierarchists* consider regulations as appropriate measure mainly in the fields of population control and decentralization and implementation of laws. In contrast, the *egalitarians* consider preventive measures, for instance, advanced technology to prevent environmental problems such as river and coastal pollution, raising public awareness, or cooperation between government and non-government organizations, as only ways to cope with these extremely negative scenarios. The *individualists* prefer adaptive measures such as increased wastewater treatment facilities, increased number and access to hygiene sanitation and advanced technology to minimize environmental problems. The *fatalists* think that nothing can improve these situations.

For the globalized scenarios (GO and TG), somewhat different management styles are preferred, since more of the interviewees seem to experience these scenarios as positive (Tables A.2, A.4). In particular, the *hierarchists* are positive about these scenarios. They think regulations are necessary particularly in population control and decentralization, urban planning, expansion of cities, and implementation of laws for further improvement. Likewise, the *individualists* experience these scenarios in a positive way, yet consider some adaptive measures as necessary. Such adaptive measures are increased wastewater treatment facilities, advanced technology to minimize environmental problems, more research, and development. In contrast, the *egalitarians* consider these scenarios a negative experience, since the ecosystems are adversely affected due to high levels of river and coastal waters pollution. They prefer preventive measures such as river and coastal pollution management, use of P free detergents, awareness building, public–private cooperation, more research, and development to cope with these situations. The *fatalists* view the scenarios mostly as negative and do not prefer any particular measure. They believe that it is unpredictable how the environmental consequences of any measure would be.

Our result indicates that in reality there are more worldviews than the four we used in our analysis. In fact, most interviewees are found to reflect a mix of worldviews. Moreover, their preferred management styles not always follow logically from their worldviews. Some measures seem to be preferred by many of them, regardless their worldviews (e.g., implementation of laws and decentralization of population).

3.6 Citizens’ expectations versus lived experiences

Finally, we analyze how Bangladeshi citizens would experience the future trends they are expecting and how they would experience changes that they do not expect (Table 3).

Table 3 A comparison of the interviewed Bangladeshi citizens' expectations of trends up to 2050 and their lived experience (i.e., whether these expected trends would be a positive or negative experience for them). Gray-shaded cells indicate when worldviews underlying the expected trends are the same as the worldviews of citizens experiencing future trends. In the gray-shaded cells also the corresponding management styles are indicated (in *italics*)

Expected Trends*	Lived Experience of Expected Trends**			
	Hierarchist	**Egalitarian**	**Individualist**	**Fatalist**
Population growth: Moderate (Hierarchist)	**Moderately negative** *Population is as expected. Regulatory measures are preferred to limit population growth..*	**Negative** Population growth is higher than expected.	**Positive** Population growth is lower than expected.	**Indifferent**
Urbanization: Rapid (Individualist)	**Negative** Urbanization is faster than expected.	**Unpleasantly Surprised** Urbanization is much faster than expected	**Negative** *Urbanization trends are as expected. Adaptive measures are preferred to reduce associated problems.*	**Indifferent**
Public sewage treatment: Inefficient (Egalitarian)	**Negative** Sewage treatment is less efficient than expected, but the associated problems are not considered major issues.	**Very negative** *Sewage treatment is as inefficient as expected. Preventive measures are preferred.*	**Unpleasantly surprised** Sewage treatment is much less efficient than expected, but the associated problems are not considered major issues.	**Indifferent**
Trust in technology: Great trust (Individualist)	**Positive** Technological developments are better than expected.	**Pleasantly surprised** Technological developments are much better than expected.	**Positive** *Technological developments are in line with expectations. Adaptive measures can reduce problems.*	**Indifferent**
River pollution from sewage: High (Egalitarian)	**Negative** Rivers are more polluted than expected.	**Very negative** *Pollution levels are as bad as expected, and nature is considered vulnerable Preventive measures are preferred.*	**Unpleasantly Surprised** Rivers are more polluted than expected, but nature is considered robust.	**Indifferent**
Coastal ecosystem services vs. manageability: Serious problems but manageable (Hierarchist)	**Moderately negative** *Problems are as expected. Regulatory measures are preferred.*	**Positive** Problems are more easy to manage than expected	**Negative** Problems are larger than expected.	**Indifferent**

* According to the majority of the interviewed citizens, between brackets: corresponding worldview

** These columns indicate how citizens with different worldviews would experience the expected future trends

Table 3 indicates the trends that are expected by most of the interviewed citizens, and how they with their different worldviews would experience these futures.

Citizens with different worldviews experience the expected future trends in different ways. For instance, most interviewed citizens expect a moderate population growth in line with the hierarchist worldviews. Because of the increasing population pressure, this would be a moderately negative experience for citizens with a *hierarchist* worldview. For *egalitarians*, however, it would be more negative experience because they expected a lower population growth and also consider nature as vulnerable. Therefore, they foresee large problems associated with unexpectedly high population densities. The *individualists* would experience these trends in a more positive way since they expected a lower population growth. The expected rapid urbanization is in line with the *Individualist* perspective. Both *individualists* and *hierarchists* would experience this as negative. Such a rapid urbanization would surprise the *egalitarians*, who expected a lower trend. The expectations about sewage treatment are that the system will remain inefficient, in line with the *egalitarian* perspective. *Egalitarians* consider this a large problem, because of river pollution. Also, *hierarchists* would experience this as negative, while *individualists* would be surprised as they expected more efficient technologies to treat wastewater.

Table 3 includes gray cells. These indicate when the worldviews underlying the expected trends are the same as the worldviews of the citizens experiencing these trends. For these situations, we identify management styles that are preferred by the majority of interviewed citizens. *Regulatory measures* are preferred for moderately negative population growth and coastal ecosystem services. In cases of inefficient public sewage treatment and high river pollution, citizens prefer *preventive measures*. Citizens prefer *adaptive measures* when urbanization and trust in technology are high.

Our analysis indicates that when the expected trends indicated in Table 3 become reality, they may be a negative experience for many of the Bangladeshi citizens.

4 Conclusion

We analyzed past and future trends in socio-economic and environmental indicators associated with urbanization and coastal eutrophication in basins of rivers draining into the Bay of Bengal using *NEWS* model. Urbanization is often considered closely associated with economic growth and with improved sanitation. These are important anthropogenic drivers of nutrient export to the bay by rivers. In 1970, the percentage of urban population was smaller (22 %). The calculated increase in urban population is particularly large after 2000. The scenarios indicate that by 2050 about 50 % of total population in the drainage basin of the bay will live in urban areas. The percentage of the population connected to sewage system, however, stays low, which is giving a poor impression of the public sewerage development in the study area. Regarding economy, all the MA scenarios show a steady economic growth from 1970 till 2050 with the highest per capita GDP in GO scenario.

Nutrient inputs to rivers from sewage change over time. River export of these nutrients from sewerage is larger in the globalized scenarios (GO and TG) than in the regionalized scenarios (AM and OS). These inputs are largely determined by the net effect of assumed waste water treatment and number of people connected to sewage. Between 1970 and 2000, dissolved N and P export by rivers draining into the Bay of Bengal increased considerably. These increasing trends will continue in the future up to 2050; however, the magnitudes will depend on the scenario and nutrients form. Sewage substantially contributes especially to DIP export by rivers. In 1970 and 2000, sewage accounted for 20 % of total DIP export. This amount increases to about 50 % in all scenarios in 2030 and 2050.

As a result of the polluted rivers, the bay is at risk of coastal eutrophication. This was the case in 1970 and may stabilize in the future or may also increase, depending on the economic and technical developments, and environmental policies. For about 95 % of the total drainage basin of the Bay, we calculate ICEP values indicating that conditions are favorable for harmful algal blooms. Highest risks are calculated for GO scenario and lowest for AM scenario. This is associated not only with point sources from urban areas, but also with diffuse sources of nutrients from agricultural areas.

Citizens have different expectations about future changes, and they also experience these differently. Our case study for Bangladesh shows that citizens may expect moderate population growth, rapid urbanization, and inefficient waste water treatment. They expect highly polluted rivers, but have a high trust in technology, which may explain why they consider coastal ecosystem problems serious, but manageable. If these expected trends become reality, they may be a negative experience for many of the citizens of Bangladesh. Some may experience the trends as positive, because they expected worse. But, most trends that we investigated are considered negative. Citizens prefer different management styles since they often have mixed worldviews. Preference of management styles is driven not only by worldviews, but also by the lived experience.

Even though *NEWS* was developed to analyze nutrient export by rivers at global scale, our study demonstrates its usefulness for analyzing coastal waters of the Bay of Bengal. The future is always uncertain. It is impossible to say what will happen exactly in future particularly considering climate change, as it will change demographic patterns, economic contexts, and environmental dynamics significantly. Any strategies taken at present will have an impact to some extent in future and causes created in one country will certainly create consequences in another country. Our analysis of the lived experience based on the trends can be useful for regional assessments and evaluation of management options in policymaking. When decision makers know how people experience environmental change, they may focus their policies on aspects that are experienced as highly negative. We consider our analysis as a first step only, which could lead to a more in-depth analysis of lived experience of environmental change.

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