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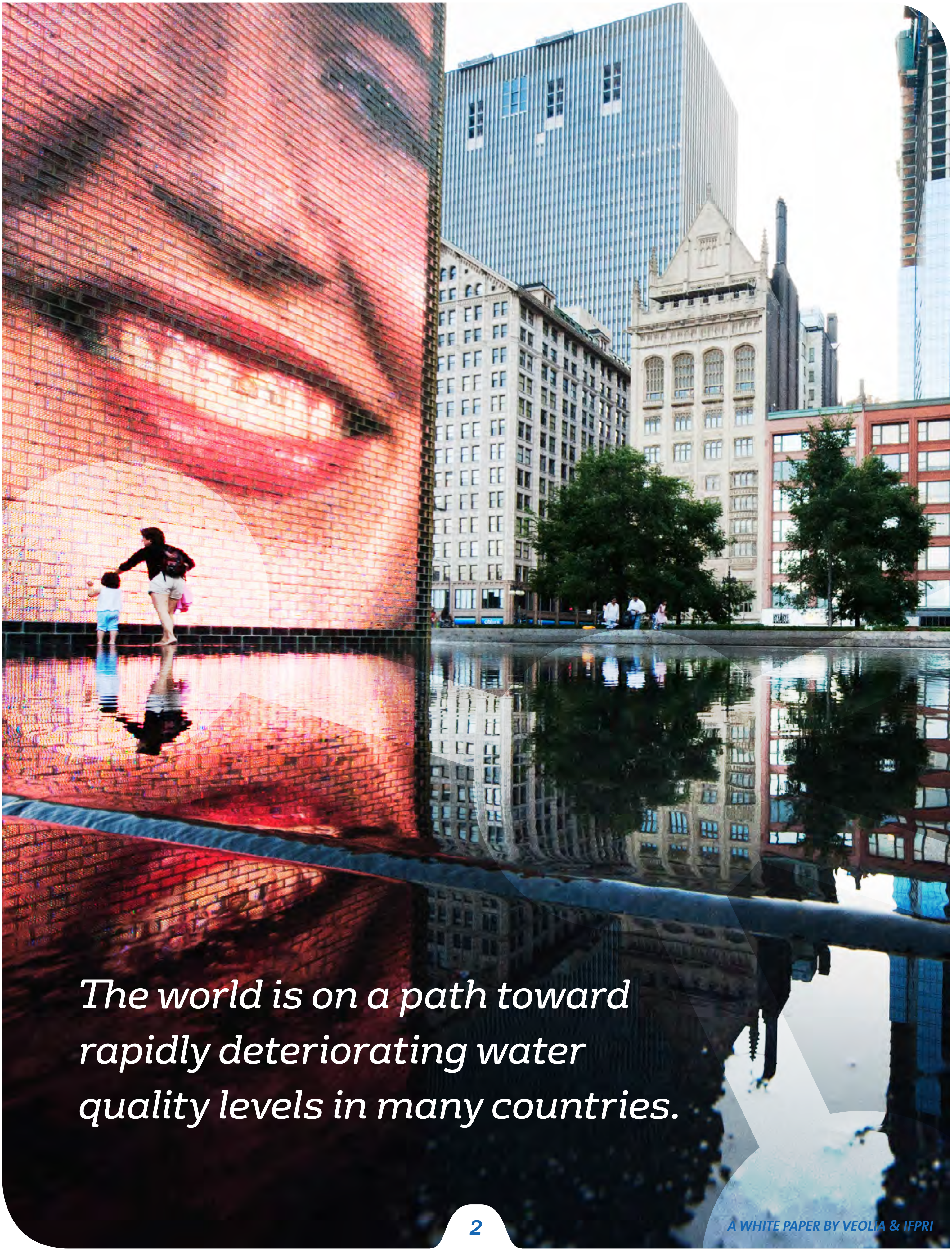
The murky future of global water quality

New global study projects rapid deterioration in water quality

A WHITE PAPER BY VEOLIA & IFPRI



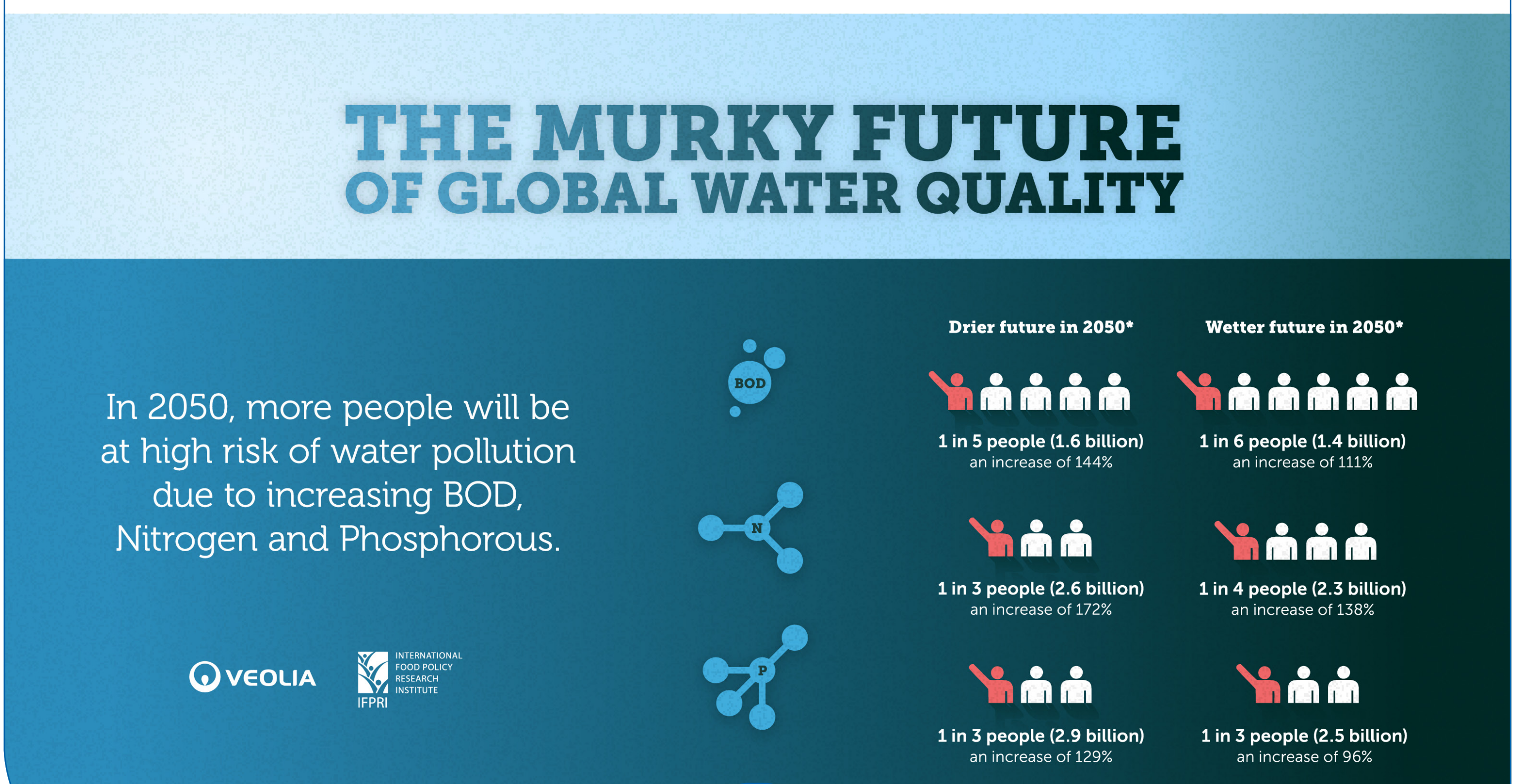
The world is on a path toward rapidly deteriorating water quality levels in many countries.

EXECUTIVE SUMMARY

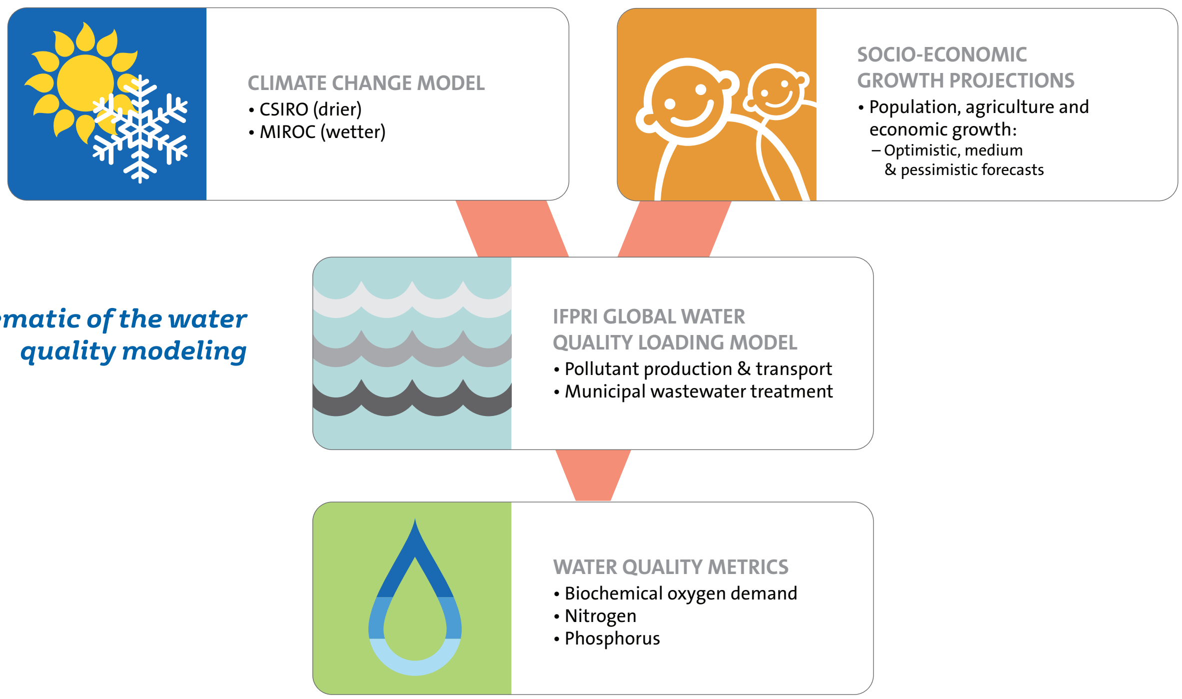
Even using the most optimistic projections, the world is on a path toward rapidly deteriorating water quality levels in many countries, according to a new study conducted by the International Food Policy Research Institute and Veolia. The study uses robust mathematical modeling to contrast specific biophysical water quality modeling on a global scale with three global economic projections, two sets of climate change projections and projected future agricultural production activities. Water quality deterioration is projected to rapidly increase over the next several decades which, in turn, will increase risks to human health, economic development and ecosystems. The findings in this study serve as a call to action to contain water pollution to ensure that future generations can enjoy the many benefits associated with clean water.

Highlights

- Rapid water quality deterioration is projected through 2050 in this first-of-its-kind global study linking economic and biophysical water quality modeling by IFPRI and Veolia.
- Today, human activities contribute significant amounts of Biochemical Oxygen Demand (BOD), Nitrogen (N) and Phosphorus (P), which make their way into water bodies around the world. Globally, 1 in 8 people are at high risk of water pollution from BOD; 1 in 6 people are at high risk of N pollution and 1 in 4 people are at high risk of P pollution. Most of these people live in developing countries in Asia.
- Increased global discharge of BOD, N, and P is projected for 2050 under all three economic growth scenarios (socio-economic models include “optimistic,” “medium” and “pessimistic” growth projections) and two climate change scenarios. Under all scenarios, more people will be exposed to risks from deteriorated water quality.
- By 2050, a drier climate change scenario coupled with medium levels of income and population growth projects that 1 in 3 people will be at high risk of nitrogen pollution (2.6 billion people or an increase of 172%); 1 in 3 people will be high risk of phosphorous pollution (2.9 billion people or an increase of 129%); and 1 in 5 people will be at high risk of water pollution from BOD (1.6 billion people or an increase of 144%).



- Using the same data under a wetter climate change scenario produces similar results, with 1 in 4 people at high risk of nitrogen pollution, 1 in 3 people at high risk of phosphorous pollution, and 1 in 6 people at high risk of water pollution from BOD
- In all cases, the most rapid increases in exposure to pollutants will occur in low- and lower-middle income countries due to higher population and economic growth in these countries.
- Solutions exist that can improve both social and ecological resilience under intensified efforts to practice sustainable agricultural methods including enhanced nutrient use efficiency, phased out fertilizer subsidies, no-till or reduced tillage and other conservation measures, and closing the nutrient cycle.
- Sustainable solutions also exist for cities and industry, including more aggressive investment in wastewater treatment (over improvements already assumed in this study), improved home design to minimize pollution, and increased recycling and reuse.
- Other solutions can reduce pollution across sectors, such as water quality trading, increased implementation of the polluter-pays-principle, enhanced monitoring of both point and non-point sources and enforcement of existing regulations on water pollution.



Schematic of the water quality modeling

Background

Population growth, economic development and climate change are placing increasing pressure on our planet's water resources. Many studies, including one conducted by IFPRI and Veolia in 2011, depict a future world with elevated tensions due to growing demand for a limited supply of water.

Just as they affect the water balance, human activities and climate change also have a large impact on water quality. Water quality refers to the physical, chemical, and biological properties of water. Many substances that influence water quality, such as nitrogen (N), phosphorus (P) and organic matter, are naturally present in water bodies. Their enrichment in water bodies is largely influenced by temperature and precipitation. At the same time, human activities may cause an excessive amount of these substances to be discharged into aquatic systems, which leads to water quality degradation. Human sources of water pollution include household and industrial waste, agricultural chemicals, and livestock waste, when not properly managed and treated.

While numerous projections of future water scarcity focus on water quantity, much less is known about how the quality of the global water environment will change. To what extent will human activities and climate change alter future water quality? Answering this question will help us to better target investments to ensure that future generations can also enjoy the benefits of clean water.

Studies on water quality are traditionally limited to the local or regional scale. Thanks to advances in computer power and data availability, it is now possible to evaluate trends of future water pollution for some parameters at a larger spatial extent.

Using a variety of compiled data sets on population, agriculture, economic growth, climate, municipal wastewater treatment facilities and a newly developed global quality loading model (IGWQLM, IFPRI Global Water Quality Loading Model), this IFPRI-Veolia study examines the status of three key water quality parameters – biochemical oxygen demand (BOD), nitrogen, and phosphorus *(see Box 1)* – by estimating their loadings into the water environment in a base period (2000-2005) and in 2050 under six alternative future scenarios focusing on domestic pollution as well as agricultural pollution from livestock and eight key staple crops. The assessment is linked to IFPRI's global economic modeling activities, which provide projections on pathways of agricultural intensification as key inputs in the loading estimation of the three water quality parameters by taking the long-run dynamics of global food production, consumption and trade into account.

Box 1

Key Water Pollutants

BOD is the amount of dissolved oxygen required by microorganisms in the water to break down organic material. It measures the level of organic pollutants in the water. High BOD levels can indicate contamination with fecal matter that can adversely affect children's physical and intellectual growth and development. Moreover, increased concentrations of dissolved organic carbon can create problems in the production of safe drinking water if chlorination is used, as compounds harmful to humans may be produced.

N and P are essential nutrients for sustaining plant life and the health of aquatic ecosystems. However, too much N and P in water equates to pollution. A major consequence of excessive N and P in water bodies is eutrophication, i.e. when algae grow faster than normal, killing other aquatic life by depleting oxygen. The presence of nitrogen-based compounds in drinking water can be harmful to human health. High levels of nitrates can have harmful effects on infants, such as the so-called 'blue-baby' syndrome, which triggers oxidation of the hemoglobin in the blood resulting in dark blue coloration and sometimes death.

SCENARIOS

The scenarios used in this study result from a combination of three alternative sets of assumptions on the rate of socioeconomic growth and two sets of climate change projections with associated changes in population, GDP, crop harvested area, livestock animal counts, levels of municipal wastewater treatment and nitrogen use efficiency in crop production.

• *Climate change*

Two sets of climate change projections are used from two general circulation models: CSIRO-Mk3.0 and MIROC 3.2. These models were selected because they project the most extreme future climate outcomes in terms of dryness/wetness compared to other model projections (Jones et al., 2009). The CSIRO model projects a drier climate in 2050 whereas the MIROC model projects a wetter future.

• *Socioeconomic growth*

Given projected population and GDP growth rates, the three socioeconomic pathways adopted in this assessment can be described as "optimistic," "medium" and "pessimistic." Under medium growth rates, the world's population will reach 9.3 billion people by 2050 and the annual global GDP growth rate is 3.2%. The optimistic projection combines lower population growth with higher GDP growth, and the pessimistic projection is characterized by higher population growth and lower economic growth.

How can we achieve a greener world, reduce water pollution and support the Sustainable Development Goals? The optimistic scenario requires accelerated municipal wastewater treatment, improvements in nutrient use efficiency, slower population growth and faster growth in the global economy. Under the "optimistic" scenario, the rate of municipal wastewater treatment will increase by 30% over the base period, and nutrient use efficiency (NUE) in crop production (expressed in kg crop yield per kg nutrients applied) is assumed to improve by 40% (except for the least developed countries).

With medium population and GDP growth, on the other hand, the assumed rate of increase in municipal wastewater treatment is 15% and the NUE improvement is only 20%. No changes in the municipal wastewater treatment rate and NUE are assumed under pessimistic projections.

Food production systems expand to meet effective demand of the growing population, largely through further intensification of existing agricultural systems. Under the drier future projected by the CSIRO global circulation model, global crop harvested area expands by 15-18%, and livestock numbers increase by 14-28%. The anticipated expansion rates of crop harvested area and animal counts under the wetter MIROC model range from 17-21% and 16-27%, respectively. Under both future climate projections, people tend to consume less livestock products under pessimistic socioeconomic assumptions than under medium and optimistic socioeconomic assumptions.

The changes in key socioeconomic variables under the six scenarios for 2050 are summarized in *Table 1*.

Elements of the six alternative scenarios assessed out to 2050

Table 1

	CSIRO medium	CSIRO optimistic	CSIRO pessimistic	MIROC medium	MIROC optimistic	MIROC pessimistic
Population in 2050	9.3 billion	8.1 billion	10.6 billion	9.3 billion	8.1 billion	10.6 billion
Annual, average rate of GDP growth	3.2%	3.6%	1.9%	3.2%	3.6%	1.9%
Crop harvest area	+17.5%	+14.7%	18.4%	+20.0%	+17.2%	20.9%
Nutrient use efficiency (expressed in crop yield (kg) per kg nutrient applied)	+20%	+40%	No change	+20%	+40%	No change
Livestock numbers	+26%	+28%	+14%	+25%	+27%	+16%
Improvement in municipal wastewater treatment levels	+15%	+30%	No change	+15%	+30%	No change

RESULTS

The estimated annual loadings of BOD, N and P during the base period (2000-2005) amount to 209, 131 and 10 million tons per year, respectively. The largest amounts of these pollutants are discharged in northern and eastern China and in the Indo-Gangetic plains in South Asia. High levels of N and P are also emitted in the midwestern United States, in central Europe, and in central-eastern South America. All of these regions are densely populated, are large agricultural production centers, or both. *(see Figure 1)*

The environmental consequences of these pollutant loadings also depend on the dilution capacity of receiving water bodies. Using information on water resource abundance (Rosegrant et al., 2012), water quality indices are calculated for major river basins in the world (except for desert and arctic regions) and are used to classify levels of water pollution risk caused by the excessive discharge of BOD, N and P. A larger value of the index implies a higher level of risk resulting from the discharge of the three water quality constituents, or that adverse impacts on humans, the environment and the economy are likely to occur.

According to the classification, currently, about 1/8th of the global population or 650 million people live in river basins in which water quality risks from excessive BOD are high, and 1/6th and 1/4th of the world's population (970 million and 1300 million people, respectively) live in river basins with high water quality risks due to excessive N and P loadings. Most of the people facing serious water quality risks live in Asia where 580 million, 900 million, and 1100 million people are at high risk from pollution from BOD, N, and P, respectively.

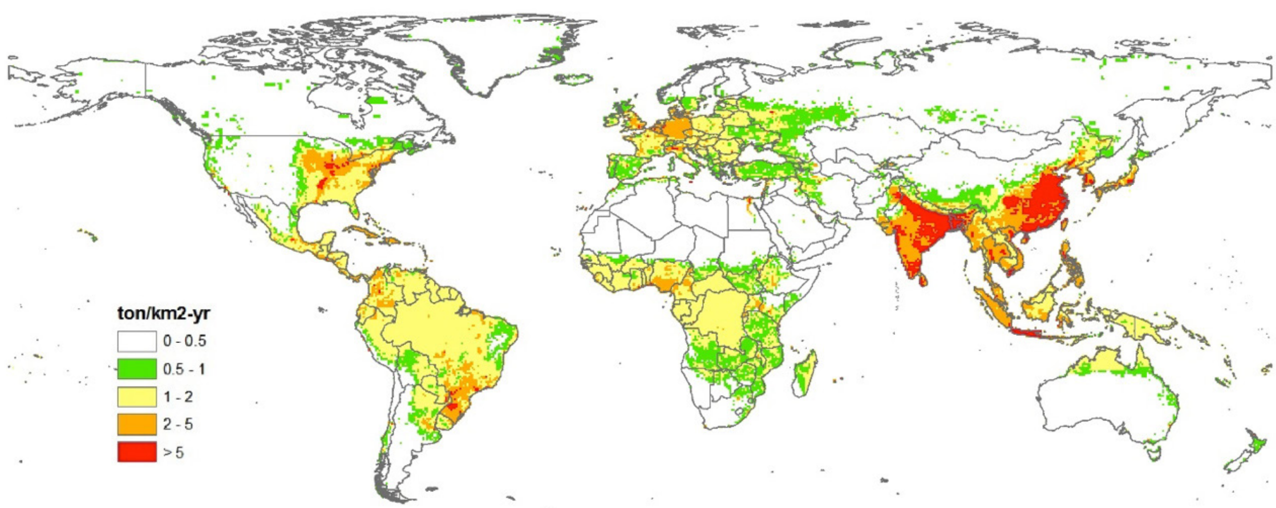
(see Figure 1 and also see Figure 4)

CSIRO model. Under the CSIRO scenario, global BOD levels are estimated to increase to between 227 and 270 million tons by 2050, or by 9-29% over the base period, depending on the scenario assumptions *(Table 2)*. Similarly, it is anticipated that global loadings of P will increase by 15-31%. The most significant increases are projected for N discharge; by 2050, global loadings of N are expected to grow between 35-50% *(Figure 2)*. Thanks to lower population pressure and more investments in environmental conservation, loadings are projected to increase less under the optimistic scenarios compared to the medium and pessimistic scenarios.

MIROC model. Climate change projections have considerable impacts on estimated loadings of water pollutants. Under the wetter MIROC climate change scenario, by 2050, levels of BOD, N, and P discharged into water bodies around the world are projected to increase by 11-32% (BOD), 46-62% (N) and 24-40% (P).

Figure 1

Estimated global N loadings in the base period (2000-2005)



***Note:** Data for BOD and P loadings are available upon request.*

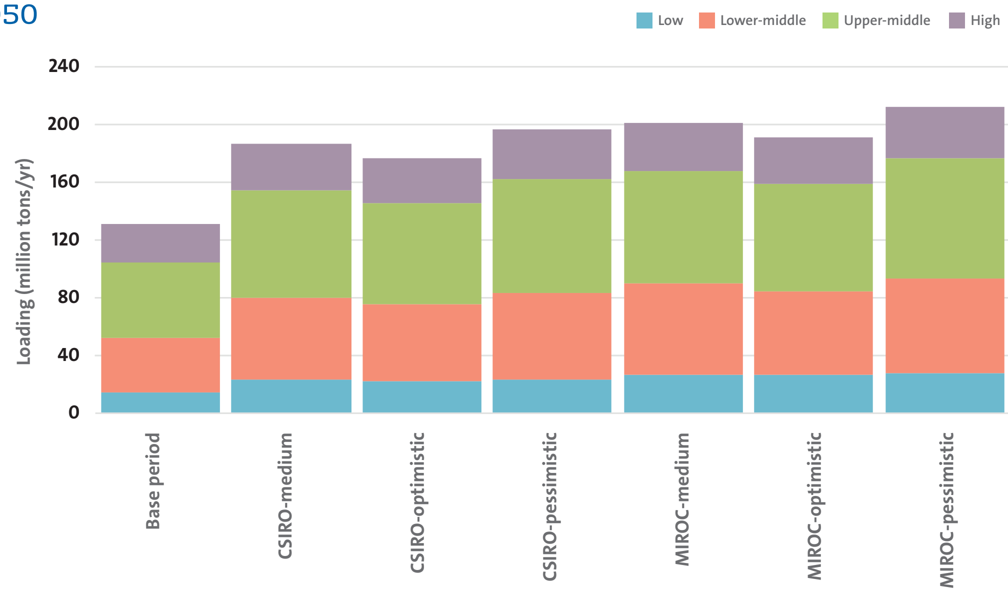
Percentage increases in pollution loads between the base period and 2050

Table 2

	CSIRO (drier future)	MIROC (wetter future)
BOD	9-29%	11-32%
P	15-31%	24-40%
N	35-50%	46-62%

Increased N loadings: a look ahead to 2050

Figure 2



***Note:** Low, lower-middle, upper-middle and high refers to country income levels. Lower and lower-middle income countries experience the fastest increases in loadings. Data for BOD and P changes are available upon request.*

As a result of increased levels of BOD, N, and P, more people will be exposed to the health risks associated with poor water quality. We differentiate between low, moderate, elevated and high risk of exposure to water pollution *(Figure 3)*. The estimated population at high risk of water pollution varies by scenario. Under the scenario with a drier future (projected by the CSIRO model) and medium socioeconomic growth, the number of people living in environments with high water quality risks due to excessive BOD will raise to 1/5th of the global population in 2050, while those facing risks from excessive N and P will raise to 1/3rd of the global population by 2050 *(Table 3)*.

Population at high risk of water pollution

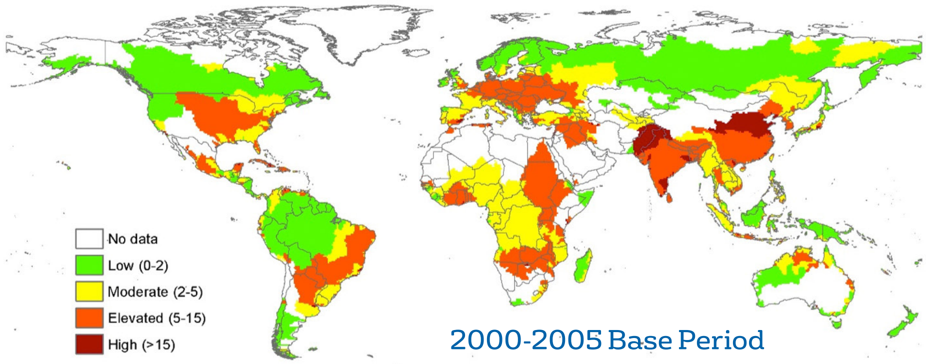
Table 3

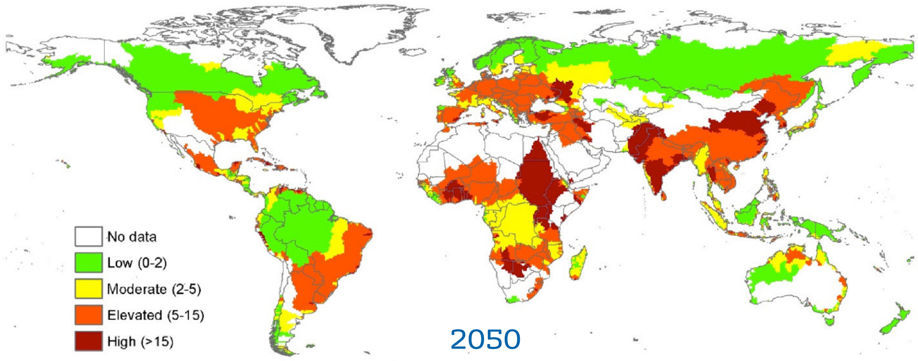
	BOD	N	P
Today	1 in 8 people or 651 million	1 in 6 people or 973 million	1 in 4 people or 1,287 million
2050 CSIRO-medium	1 in 5 people or 1,589 million	1 in 3 people or 2,645 million	1 in 3 people or 2,948 million
2050 MIROC-medium	1 in 6 people or 1,372 million	1 in 4 people or 2,311 million	1 in 3 people or 2,522 million

***Note:** High risks from water pollution means that adverse impacts on humans, the environment and the economy are likely to occur. Population in basins without water quality data is excluded.*

Water quality risk indices for major river basins during base period compared to 2050 (N index under the CSIRO-medium scenario)

Figure 3



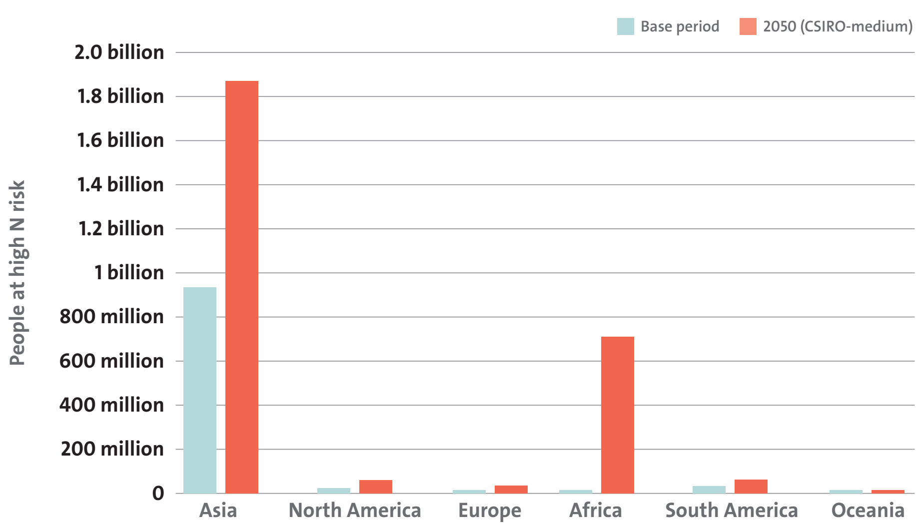


Note: *Maps for P and BOD index and for the MIROC scenarios are available upon request.*

Projected changes in water quality risks vary at the country level. In all cases, the most rapid increases in exposure to pollutants will occur in low- and lower-middle income countries primarily due to higher population growth in these countries. Correspondingly, the increase in the number of people facing high water quality risks is much greater in those countries, especially in Africa *(Figure 2 and 4 and Box 2)*.

Population living in high N risk river basins- an illustrative comparison between base period (2000-2005) and 2050 (under the CSIRO-medium scenario)

Figure 4



Note: *Population in basins without water quality data is excluded. Data for other regions and scenarios are available upon request.*

Box 2

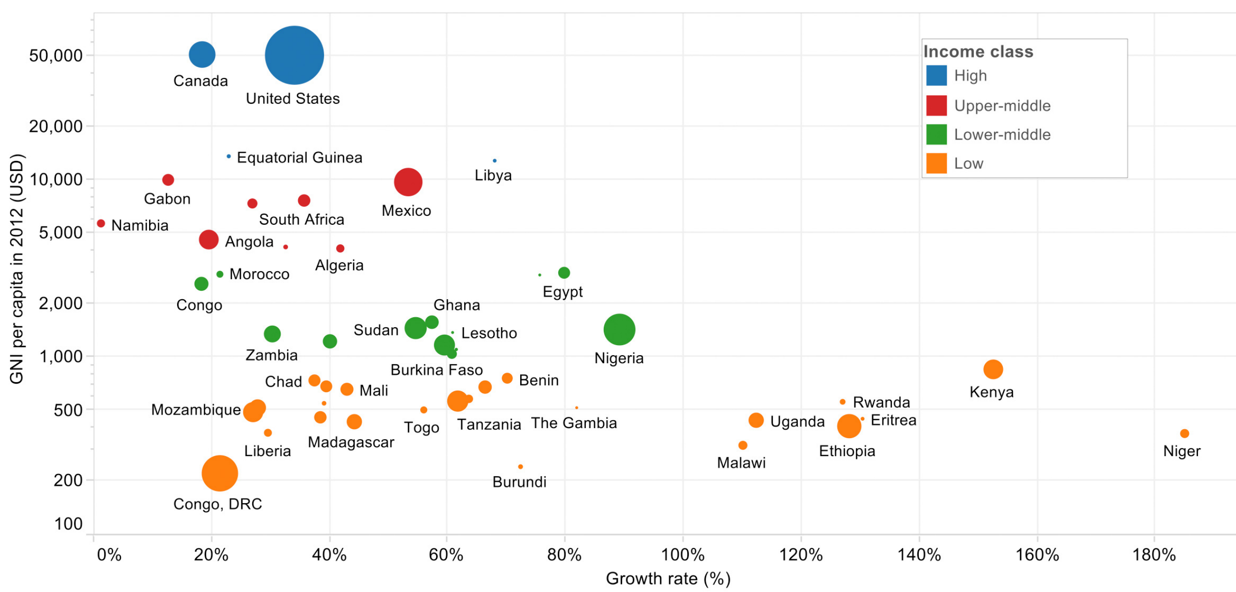
Growth of nitrogen loadings in North America and Africa

A closer look at projected growth rates of N loadings in North American and African counties serves to illustrate how the projected growth of water pollutants tends to be correlated with national income levels. The three countries in North America are categorized as high income (the United States and Canada) and upper-middle income (Mexico) countries, while the majority of African countries belong to the group of low and lower-middle income countries.

Moderate growth rates of N emissions are projected for the United States, Canada and Mexico. Under the CSIRO-climate change scenario and medium growth, for example, the N loadings in the three countries will rise by 34% (United States), 18% (Canada) and 53% (Mexico), respectively. As a contrast, a number of low-income African countries will witness a doubling of their nitrogen loadings over the next few decades. Thus, loadings increase virtually everywhere but developing countries are more affected.

Projected growth rates of N loadings in North American and African countries under the CSIRO-medium scenario

Figure 5



CONCLUSIONS

This assessment reveals that levels of BOD, N, and P discharged into water bodies around the world are already alarmingly high, particularly in Asia. This situation is projected to worsen substantially over the next several decades as loadings of these substances will continue to increase, posing greater risks to aquatic environments and human health, especially in developing countries. While emissions increase at a slower rate under the optimistic scenario due to slower population growth and greater investments in environmental conservation (particularly improvements in nutrient use efficiency and wastewater treatment), water quality is still projected to deteriorate dramatically under this best-case scenario.

This alarming trend calls for a rethinking of our current development pathway, and even greater investments in the environment and water supply infrastructure. Several solutions exist, however, to improve both social and ecological resilience through enhanced water quality management in the domestic, industrial and agricultural sectors:

For consumers, cities and industrial sectors, solutions include:

1. More aggressive investment in wastewater treatment (over the improvement already assumed in this study), not just for developed economies but also for developing countries. The widespread development of wastewater collection and treatment can efficiently remove various pollutants before discharge into the environment. Adequate management of wastewater requires the planning and construction of new treatment facilities where they do not exist and the upgrade of existing sanitation infrastructure that is aging in parts of North America and Europe.
2. Adoption of innovative and alternative approaches, such as the use of Green Infrastructure (for example, urban forests or constructed wetlands) can increase non-point source pollution control in both urban and rural environments.
3. Improved home and industrial design to minimize pollution. For home design, this includes re-cycling of grey-water and separation of various water sources; for industrial design, this includes re-cycling and reuse of water on site and safe disposal of polluted water.
4. Enhanced management of stormwater runoff to avoid contamination of treated water supplies.
5. Close nutrient cycles: While agriculture accounts for much of the loadings of N and P, industries and households also produce large quantities of these pollutants, which can be recovered more easily from effluents and sewage and reused in agriculture. New technologies continue to be developed and applied in most developed countries, but much more needs to be done in the low-income countries where most future emissions are projected to occur.
6. Continued development of new models of water management such as watershed scale approaches, alternative utility governance that includes improvement of upstream practices, as well as nutrient trading to encourage upstream best practices and reduce non-point source runoff of contaminants.

For the agricultural sector, solutions include:

1. Enhanced nutrient use efficiency: Higher nutrient use efficiency in crop production can substantially reduce loadings and has already been incorporated in our projections. Nutrient use efficiency is a trait that is under development for key staple crops, which are the major consumers of fertilizers. Other strategies in this area include enhanced fertilizer management, with practices such as deep placement of urea; increased use of precision agriculture methods, such as yield monitors, to apply fertilizers where they are needed most or where they generate the highest yield impacts; and replacement of furrow irrigation with drip, which allows direct fertilizer application to the crops and their root systems.
2. Phased out fertilizer subsidies: Many studies have shown that fertilizer subsidies—generally for urea (N) —lead to over-application of the cheaper input and, thus, unbalanced application of fertilizers (as generally only N is subsidized). Subsidies also are often ineffective at reaching the poor, i.e. they tend to mostly support rich farmers, who are least in need of such support.
3. No-till or reduced tillage and other conservation measures, such as terraces, soil or stone bunds, or buffer strips along water bodies have been shown to dramatically reduce erosion and thus protect water bodies from the adverse effects of P and N runoff. Crop rotations with nitrogen-fixing (cover) crops are also an important conservation measure.

Other solutions can reduce pollution across sectors, such as water quality trading; increased implementation of the polluter-pays-principle; enhanced monitoring of both point and non-point sources and enforcement of existing regulations on water pollution.

While all these options exist and many new ones are being developed, the capacity of environmental management in many of the countries where water quality conditions are expected to deteriorate most remains limited. Cooperation with the international community is needed to help these countries in their efforts to fight against water pollution.

Without significant attention to this looming crisis, the future deterioration of water quality will pose a major threat to aquatic environments and the people that depend on them.

References

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(*) 2014 pro-forma figures, including Dalkia International (100%) and excluding Dalkia France.