Alpheus Water Blog

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Water Quality: Don't Count on It

Summary

With the Paris COP21 on climate change ratified, the world's prior focus on air quality will likely shift to water. It should. In the prior 15 years, air quality concerns (i.e., especially CO2 and global warming) have been addressed by higher energy prices and subsidies that have financed game-changing innovation in solar, wind, storage, and biofuels. However, the "perfect storm" of troublesome water-related data is accelerating and will need to be addressed by a similar level of increased financing and innovation.

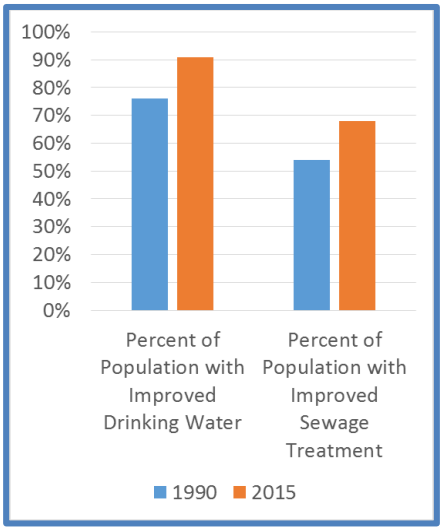
- **The Good:** Thankfully, most of the world has seen steady progress in the basic investments to make water safe—particularly in household sewage collection and treatment.
- **The Bad:** Nevertheless, the headline improvements in easy-to-measure water metrics are misleading and overly optimistic in view of:
    - The cumulative and continued degradation of "common" water supplies in aquifers, rivers, and oceans.
    - The headwind of dilapidated infrastructure in developed countries that rely on pipes and aqueducts that are well beyond their useful lives, allowing rust and contamination, and the likelihood of many more Flint, Michigan–type problems.
- **The Ugly (and Unknown):** Compared with air quality, water quality is less understood and more regional, leading to:
    - Some of the most populous and fastest growing countries of the world being left behind in improving access to safe water, leading to huge increases in water-borne illnesses.
    - The "known unknowns" of how an exponential increase in manmade chemicals, mostly untested even in developed countries, can affect human health. Because water is more dense than air, more heavy pollutants can end up in water. Moreover, with highly heterogeneous water contaminants globally, the science of linking water contaminants to increases in certain newer and rising health concerns (i.e., cancers, mental health, obesity/diabetes, fertility, etc.) is still embryonic.

The economic benefits of water quality investments are huge. A UN report estimates that every $1 invested generates a $3–34 economic development return. Another study estimates that poor countries with access to clean water and sanitation services generated 3.7% GDP, while those that do not have clean water access grew at just 0.1%.

The Good: Sanitation and Treatment

As is indicated on Figure 1,[1] the world has made significant progress in providing safe water to residential consumers and in treating this wastewater after use. However, residential water represents only about 7% of total water demand.

Figure 1: Improved Drinking Water and Sewage Treatment Globally



The Bad: Developed Market Challenges

Strong gains in residential water and sanitation (mainly in the emerging markets, totaling about 1% of total water demand) are more than offset by less visible problems in the rest of the much larger water markets (particularly for the developed countries):

- **River Pollution from Agribusiness (70% of water consumption).** As indicated in Figure 2,[2] global contamination from the main agricultural fertilizers (nitrogen, phosphorus) and biochemical oxygen demand (BOD[3]) is increasing. This trend reflects an increasing use of fertilizers to stimulate and nourish soil, which loses its natural nutrients after years of farming. Some fertilizers also help the plants use water more efficiently, thereby becoming more "drought resistant."

Figure 2: Population at High Risk* of Water Pollution

	Current			2050		
	Global Population (bn)	High Water Risk Population (bn)	% of Total	Global Population (bn)	High Water Risk Population (bn)	% of Total
Biochemical Oxygen Demand (BOD)						
	7,200	651	*9.04%*	9,800	1,481	*15.11%*
Nitrogen						
	7,200	973	*13.51%*	9,800	2,478	*25.29%*
Phosphorous						
	7,200	1,287	*17.88%*	9,800	2,735	*27.91%*

Note: medium economic growth scenario; average of drier and wetter water outcomes.
*Considers adverse impacts on humans, the environment and economy to be "likely."

- **Dilapidated Infrastructure.** As an arguably less worse[4] example in the OECD,[5] the United States has 1.2 million miles of water pipeline,[6] or about 26x the length of its interstate highways. At least 10% are past their useful age and the network is being replaced at a rate of over 100 years, even though their useful life is generally 50–70 years.[7] The system has become so old that pipes leak about 14% of their

[1] "Progress on Sanitation and Drinking Water: 2015 Update and MDG Assessment," a joint publication of UNICEF and the World Health Organization, p. 25, 2015.
[2] "The Murky Future of Global Water Quality," a whitepaper by the International Food Policy Research Institute and Veolia Co., Inc., 2016.
[3] Biochemical oxygen demand is a measure of how much oxygen is being consumed by decay and bacteria as a measure for the health of other living organisms such as fish.
[4] i.e., due to its more modern history and recent infrastructure build-out vis-à-vis Europe.
[5] Organization for Economic Development and Cooperation, including 34 member countries that are generally democracies with a relatively high standard of living.
[6] Charles Fishman, "13 Things You Probably Don't Know About the U.S. Water System (But Should)," voices.nationalgeographic.com, August 12, 2014.
[7] Steven, Folkman, "Water Main Break Rates in the U.S. and Canada: A Comprehensive Study," April 2012.

water, and, on average, every mile of pipe breaks once every six years.[8] As pipes degrade, lead and other contaminants rust and decay into the water, thus requiring more treatment chemicals (mainly chlorine derivatives), which in turn can accelerate the pipes' decay. Unfortunately, the recent Flint, Michigan, crisis is likely only a precursor for many of the country's 53,000 aging municipal water systems.

Flint, Michigan, drinking water pipes.
Photo by Min Tang and Kelsey Piper, FlintWaterStudy.org

As a predictable outcome of the "tragedy of the commons,"[9] the relatively good quality of the upstream personal-use water contrasts with the poor and worsening quality of the downstream common-use water found in the larger rivers, lakes, aquifers, and oceans (Figure 3).[10] The focus on supplying clean personal water to residential and commercial customers partly reflects the ease of purifying contaminated water versus preventing common-use water from becoming contaminated in the first place. In addition, the prior myopic view considered rivers to be naturally replenishing and oceans so large that contaminants would be diluted and naturally cleaned.

However, following the prior local-to-global shift with air pollution,[11] there is rising evidence that the larger common water supplies of aquifers and oceans are being contaminated at unsustainable rates.

- **Aquifers**[12] hold 96% of usable[13] freshwater supply and have become an increasing source of water due to above-ground water depletion. With bottled water companies boasting of the purity of aquifer water (i.e., from "springs" or "artisan wells"), it may be surprising that this water is also becoming increasingly polluted from seepage from above-ground pollution:

Figure 3: Troubling Metrics for Developed Market Water

	Source
GLOBAL	
• Industrialized countries make up 80% of global hazardous waste disposal.	3
• Globally, 2mn tons of sewage, industrial and agricultural waste are discharged into water each day, the equivalent weight of the earth's human population	1
United States	
• 66% of public water supplies sampled had at least one contaminant above EPA level for safe human consumption	6
• 20% of US aquifer water (30% of total water supply) has at least one contaminant over EPA standard. Figure has risen over the past two decades.	2
• 40% of rivers and lakes are unsafe for swimming or fishing	11
• 63% of 27 sampled municipalities' water had at least trace amounts of pharmaceuticals	4
• 165 pharmaceutical products have been found in N. American waters	5
Europe	
• 42% of freshwater sites have chemical levels high enough to cause chronic health effects	7
• 14% of freshwater have chemical levels high enough to kill aquatic species	7
Japan	
• 30% of water resources do not meet standards for organic pollution.	8
• Even after initial Fukushima meltdown, radioactive leakages continued from holding tanks and aquifers.	9, 10

[8] Ibid.

[9] Tragedy of the commons: an economic problem in which every individual tries to reap the greatest benefit from a given resource. As the demand for the resource overwhelms the supply, every individual who consumes an additional unit directly harms others who can no longer enjoy the benefits. Source: Investopedia.

[10] Sources for Figure 3: (1) UN WWAP 2003, United Nations Water Assessment Programme, "The World Water Development Report 1: Water for People, Water for Life," UNESCO, Paris, France; (2) USGS Study, 2015; (3) Maggie Black and Janet King, "The Atlas of Water," p. 76, 2008; (4) Martha Mendoza, "Pharmaceuticals Found in Drinking Water," September 2016, *Associated Press*; (5) M. Freeman, S. Collins, B. Barton, "An Investor Handbook for Water Risk Integration," CERES, March 2015, p. 14; (6) Lisa Rapaport, "Toxic Chemicals in Drinking Water," *Reuters Health*, August 10, 2016; (7) E. Malay, P. C. Von der Ohe, M. Grote, R. Kuhne, C.P. Money, P. Ussenglio-Polatera, W. Brack, R.B. Schafer, "Organic Chemicals Jeopardize the Health of Freshwater Ecosystems on the Continental Scale," Proceedings of the National Academy of Sciences of the United States of America, Vol. 111, no. 26, May 15, 2014; (8) "State of Japan's Environment at a Glance: Water Pollution," Ministry of the Environment, Government of Japan, env.go.jp; (9) Dr. Martini, "True Facts about Ocean Radiation and the Fukushima Disaster," *Deep Sea News*, November 28, 2013; (10) Patrick J. Kiger, "Fukushima's Radioactive Water Leak: What You Should Know," *National Geographic News*, August 9, 2013.

[11] For example, China became much more concerned about global air quality when local Beijing became so smoggy as to incite protests.

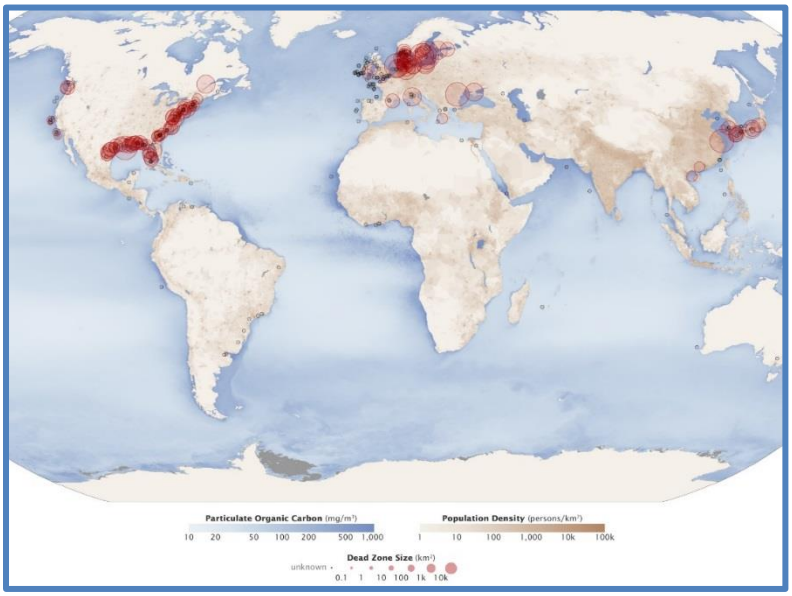
[12] Please also refer to the prior Alpheus report, "Depleting Aquifers: The End Game for Cheap Water," November 2016.

[13] i.e., excluding the polar ice packs.

- Globally, 50% of underground water is unsafe for drinking.[14]
- In the U.S., one study[15] found that over 20% of the wells contained at least one chemical in excess of the EPA maximum.[16]
- In China, the legacy of rain seepage through landfills has led to 60% of underground water being too contaminated for drinking (90% near urban areas), versus "only" 50% for lakes and 33% for rivers.[17] Other emerging markets such as Bangladesh and India are even worse.

- **Oceans** hold 98% of the world's total water, thus being an even more global tragedy of the commons. Most ocean pollution comes from the largest agricultural-economy rivers, leading to roughly 400[18] huge "dead zones" where these rivers meet the ocean. Dead zones occur when fertilizers feed huge algae "blooms," which in turn die and sink to the bottom. The algae decomposition sucks up so much oxygen that other organisms—even bacteria—can't survive. The largest dead zone is at the mouth of the Mississippi River in the United States, which carries 1.5 million tons of nitrogen annually to the ocean, creating a 6,747-square-mile dead zone about the size of Massachusetts.[19] Figure 4[20] shows that most of the largest dead zones are associated with developed market rivers.

Figure 4: Global Dead Zones



Further from the dead zones, other less concentrated pollution problems are pervasive and increasing. For example, plastics in the ocean, historically disregarded due to "dilution,"[21] are increasingly understood to have many negative consequences:

- There are an estimated 150 million tons of plastic in the ocean (2014), which are estimated to increase to about one-fourth of the weight of all of the ocean's finfish by 2025.[22] Plastics production is expected to double in the next 20 years after increasing 20x since 1964.[23]

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[14] Merlin Hearn, "20 Water Pollution Facts for the U.S. and Throughout the World," waterbenefitshealth.com.

[15] Note: Study included 6,600 wells and 64 principal aquifers. The United States has a population of 130 million that use ground water for a portion of their drinking water (through municipal distribution) and another 40 million that use private wells.

[16] DeSimone, L.A., McMahon, P.B., and Rosen, M.R. 2014, "The Quality of Our Nation's Waters: Water Quality in the Principal Aquifers of the United States, 1991–2000," U.S. Geological Survey Circular 1360, p. 2, D.C.doi.org/10/3133/cir1360.

[17] Chen, Trina, "China Environment Sector," Credit Suisse First Boston, August 14, 2014, p. 18.

[18] "Marine Pollution," *National Geographic Magazine*, ocean.nationalgeographic.com.

[19] Merlin Hearn, "20 Water Pollution Facts for the U.S. and Throughout the World," waterbenefitshealth.com.

[20] R. Simmon and Jesse Allen (map), NASA, Earth Observatory, data from R.J., and Rosenberg, R., "Spreading Dead Zones and Consequences for Marine Ecosystems," *Science*, 321(5891), 926–929, 2008.

[21] i.e., the amount of plastic debris is minuscule relative to the total size of the oceans. According to *National Geographic*'s "Marine Pollution" on its "Pristine Seas" website, the proponents of dumping in the ocean even had their own catchphrase: "The solution to pollution is dilution."

[22] "Stemming the Tide: Land-Based Strategies for a Plastic-Free Ocean," Ocean Conservancy in conjunction with McKinsey Center for Business and Environment, September 2015.

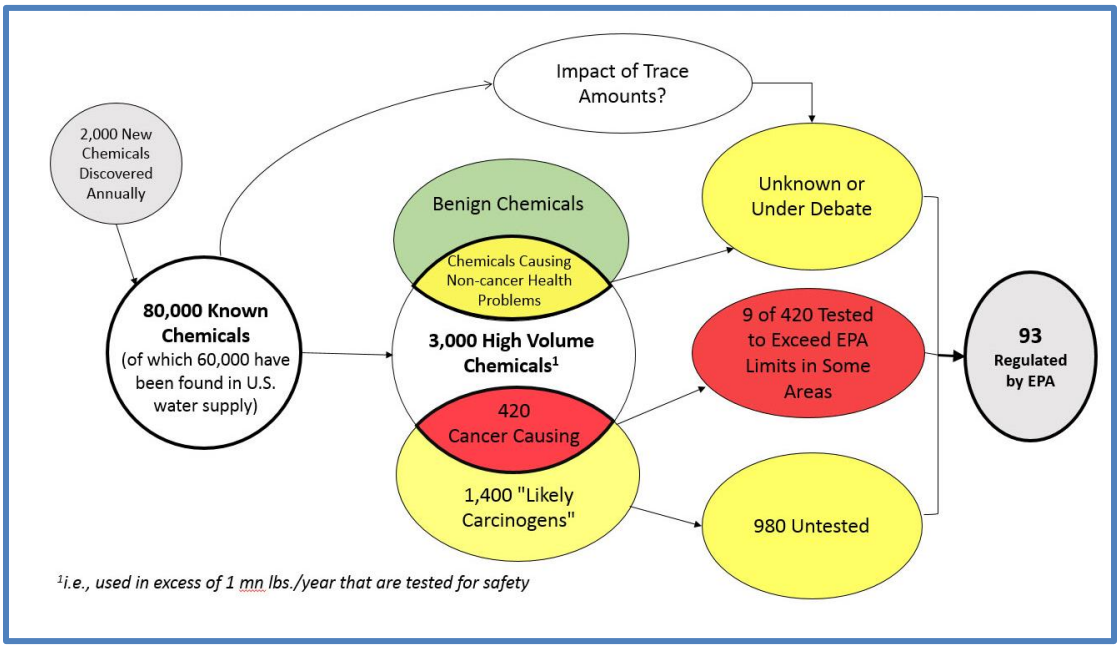
[23] "The New Plastics Economy: The Case for Rethinking Plastics," World Economic Forum, January 2016; and Hadley Leggett, "Toxic Soup: Plastics Could Be Leaching Chemicals Into Ocean," *Science* magazine, August 18, 2009.

- Plastics are akin to fishing lures for many fish, water mammals, and seabirds. One 2012 study estimated that 29% of all seabirds had plastics in their gut, and that based on the trend, the figure would be closer to 60% if this study were performed today.[24]
- Plastics were erroneously thought to be benign in their impact to water chemistry due to their long degradation cycle. However, new studies[25] indicate that plastics can last hundreds to thousands of years after being broken down into micro-plastics (<1 cm in diameter) and nano-plastics. As they become smaller, they look like plankton and can be ingested by an increasing number of ocean organisms, both at the beginning (krill, small fish) and at the end (whales) of the food chain.
- New studies also suggest that plastics can release toxic contaminants in the water or into their host. These contaminants include BPA, a known carcinogen, and various toxins from the plastics additives (estimated to be about 15% of the total weight of the plastics).[26]

The Ugly: Global "Known Unknowns" and the Emerging Markets

What is "known" is that the number of unregulated manmade chemicals and their quantities continue to rise,[27] and many of these compounds wind up in water and food (see Figure 5[28,29] below). Thus, arguably the biggest challenging in providing safe water will be to regulate an ever-increasing number of chemicals that are found in water, and, by extension, soil and food. In the U.S., about 2,000 new chemicals are introduced into commerce each year.[30]

Figure 5: The EPA Challenge: Regulating an Ever-Expanding List of Chemical Compounds



[24] C. Wilcox, E. Van Seville, B. D. Haresty. "Threat of Plastic Pollution to Seabirds is Global, Pervasive and Increasing," *Proceedings of the National Academy of Sciences*, vol. 112, no. 38.

[25] A. Cozar, F. Echevarria, J.I. Gonzalez-Gordillo, X. Irigoien, B. Bedazzled, S. Hernandez-Leon, A. Palma, S. Navarro, J. Garcia-de-Lomas, A. Ruiz, M. L. Fernandez-de-Puelles, and C. M. Duarte, "Plastics Debris in the Open Ocean," *Proceedings of the National Academy of Sciences*, vol. 111, no. 28, July 15, 2014.

[26] "The New Plastics Economy: The Case for Rethinking Plastics," World Economic Forum, January 2016; and Hadley Leggett, "Toxic Soup: Plastics Could Be Leaching Chemicals Into Ocean," Science magazine, August 18, 2009.

[27] Alexis Madrigal, "Humans Have Made, Found, or Used Over 50 Million Unique Chemicals," Science magazine, September 9, 2009.

[28] Dellavalle, Curt, "The Pollution in People: Cancer-Causing Chemicals in Americans' Bodies," Environmental Working Group, 2016.

[29] Richard Denison, Phd, "EPA's New Chemicals Program: TSCA Dealt EPA a Very Poor Hand," EDF Health, April 16, 2009.

[30] Elizabeth Grossman, "Getting Our (Toxic Substances) Act Together," *Ensia* magazine, August 13, 2013.

The U.S. EPA regulates 93 chemicals,[31] but this figure hasn't changed significantly in decades (Figure 6[32]).

Figure 6: Summary of EPA Regulated Water Contaminants in the United States

Contaminant Family	Number of Contaminants Included	Examples of Regulated Chemicals Included	Main Sources	Adverse Effects	Other
Micro organisms	11	General measures for turbidity and non-water particles, viruses, legionella, coliforms (incl. E. Coli), disinfection.	Industrial wastewater and domestic sewage, livestock	Decomposition leads to oxygen depletion, stressing or killing aquatic life, and "dead zones" in the ocean	Many are naturally occurring
Disinfectants	3	Various chlorines	Water additives to control microbes	Eye/nose irritation, stomach discomfort, fetal issues, and nervous system effects	Can accelerate degradation of lead pipes
Disinfection Byproducts	4	Bromate, chlorite, Haloacetic acids	Byproducts of water additives to control microbes	Anemia, many fetus and childhood effects, cancer.	Can accelerate degradation of lead pipes
Inorganic Chemicals	16	Various metals (lead, selenium, chromium, copper, beryllium, others), nitrogen, mercury, asbestos, arsenic)	Industrial waste and mining; nitrogen mainly from agricultural fertilizers	Many types of cancer, organ damage, brain development. Nitrogen leads to oxygen depletion, killing aquatic life, leading to oceanic "dead zones."	Meat contains 10x and dairy 5x the pesticide residue as plant foods. Nitrates also added to meats to give reddish color and to preserve shelf life.
Organic Chemicals	55	Atrazine, carbofuran, carbon tetracholride, chlorobenzene, alachlor, ... many others)	Industrial wastewater and domestic sewage, livestock	Many types of cancer, organ damage, fertility.	
Radionuclides	4	Radium, Beta photon emitters, alpha photon emitters, uranium	Meats	Cancer, kidney toxicity	Use to irradiate possible bacteria in meats

The vast majority of unregulated contaminants in water—including hormones, pesticides and industrial toxins—are not from residential water reuse, but from agribusiness and industry. Water reuse is only ~3% of U.S. drinking water, but this source will likely grow rapidly to address the country's increasing water shortages. Regardless, nearly all of the new chemicals being developed are likely to end up in the water supply through one of these three channels (agribusiness, industry, or residential water reuse), thus underscoring the challenge of regulators to keep up with innovation.

The EPA also "monitors" 97 chemicals or chemical groups and 12 microbial contaminants ("Contaminant Candidate List"). Figure 7[33] provides some examples of these pollutants and their health impact.

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[31] For a complete list of the compounds that are regulated by EPA: www.epa.gov/sites/production/files/2016-06/documents/npwdr_complete_table.pdf

[32] "National Primary Drinking Water Regulations," EPA, 2016; "Ground Water and Drinking Water: Table of Regulated Drinking Water Contaminants," EPA, 2016; Maggie Black and Janet King, *The Atlas of Water*, 2nd Edition, University of California Press, 2009.

[33] Sources for Figure 7: (1) "What's in My Water?" Dioxane, DrinkTap.org; (2) Brian Bienkowski, "Unregulated Chemicals Found in Drinking Water," *Scientific American*, December 5, 2013; (3) Lisa Rappaport, "Toxic Chemicals in Drinking Water," *Reuters Health*, printed in *Food Quality and Safety* magazine, August 10, 2016; (4) Susan Scutti, "New Report Has 'Erin Brockovich' Chemical in U.S. Drinking Water," CNN, September 21, 2016, and "EWG: 'Brokovich' Carcinogen Found in Tap Water of 200 Million Americans," Water Online, September 20, 2016; (5) Nsikan Akan, "Scientists Trace Cancer-Causing Chemical in Drinking Water Back to Methadone," *PBS NewsHour*, May 27, 2015; (6) Mark Scalia, "What are PFASs, the Toxic Chemicals Being Found in Drinking Water," *PBS NewsHour* Science Post, PBS.org, August 12, 2016; (7) E. M. Thuran, I. Ferrer, Y. Zhou, S. Andrews, J. Zheng, P. Herckes, and P. Westeroff, "Methadone Contributes to N-Nitrosodimethylamine Formationin Surface Waters and Wastewaters During Chloramination," *Environmental & Technology Letters*, Vol. 2, Issue 6, pages 151–157, May 8, 2015.

Figure 7: Examples of Unregulated Water Contaminants Found in U.S. Waters

Name of Contaminant	Commonly Used In	Found in US Water?	Adverse Effects / Likelihood	Other	Source
Chromium-6	Electroplating, coal/ash thermoelectric plants, stainless steel, leather tanning, textile mfg and wood preservation.	Yes, in most US water, but usually trace	Linked to cancer, liver damage, fertility, and child brain development. EPA standard is 100ppb, California max is 10ppb. Only 2% of water exceeds EPA standard (as an unregulated compound), but 75% exceed California standard.	The chemical in the 2000 movie *Erin Brokovich.* California the only state to enforce maximum limit (10ppm) as remains unregulated by EPA.	4
1,4-Dioxane	A byproduct of plastics manufacturing found in paints, varnishes, detergents, shampoos and cosmetics	Yes: widespread and often found in aquifers	"A likely carcinogen" per EPA	Does not readily biodegrade. On the EPA Contaminant Candidate List #3 for possible regulation.	1
Various Perfluorinated Compounds					
PFOA	Teflon and food packaging.	Yes: found in more than 1/3 of U.S. water utilities	"Probable" link to cancer, ulcerative colitis, thyroid disease, several cancers, hypertension	Based on study of mid-Ohio communities that had water polluted from a DuPont plant	2
PFAS	Industrial, fire-fighting foam	Yes, but only about 66 of 4,864 utilities studied (1.4%) had levels at-or-above what EPA considers "Safe"	Interferes with immune functions, reduces effectiveness of vaccines in children.	Significant quantities found near military bases, and in certain states: CA, NJ, NC, NY. Long chain PFAS began to be regulated in early 2000's, but short chain PFAS were considered safer and remain unregulated.	3,6
PFOS	Consumer products to make waterproof, stain-resistant, non-stick.	Yes: found in more than 1/3 of U.S. water utilities	Linked to ADD in children and thyroid disease in men.	3M stopped using in Scotchguard in '02, but still present in some water.	2
Stronium	A metal	Yes, widespread in trace amounts	Bone growth	Studies focused on quantities higher than what is found in U.S. water	2
Metolachlor	An herbicide	Yes, widespread in trace amounts	A possible carcinogen based on studies of rats	Included in EPA Candidate Lists 1,2, and 3 for possible future inclusion in regulated list	2
N-nitro-sodimethylamin ("NDMA")	Methadone (for chronic pain, heroin addition) and water disinfectant used in treatment	Yes, especially with wastewater re-use	Considered a "probable" potent carcinogen	NDMA is compound formed with a chemical reaction of Methadone (a pharmaceutical drug) and wastewater disinfection chemicals	5,7

What is also known is that many of these unregulated chemicals are being linked to cancer and other health problems. What is not agreed on (i.e., is unknown) is a full list of potentially dangerous chemicals that are found in water and, even more significantly, how much of a given chemical is unsafe in view of many known-unknowns:

- **Long-term health effects of even trace amounts:** With so many new chemicals being developed, there has been little actual study of the possible long-term side effects of small amounts. For example, hormones estrogen and synthetic estrogen[34] (allegedly in part from the urine of those taking birth control, but much larger quantities probably come from livestock hormones and synthetic estrogens found in fertilizers[35]) have been known to "wreak reproductive havoc on some fish, which spawn infertile offspring sporting a mixture of male and female parts."[36] Most regulators (including the EPA) believe that the amounts that could be consumed by humans are too small to have an impact. However, many scientists are beginning to draw probabilistic links of these hormones to cancers,

[34] Note: Estrogen is not currently regulated by EPA, but is on the Candidate List #3 for future inclusion.

[35] Kirsten Moore, Kimberly Inez McGuire, Rivka Gordon, Tracey J. Woodruff, "Birth Control Hormones in Water: Separating Myth from Fact," Association of Reproductive Health Professionals, August 2011.

[36] "Can Birth Control Hormones Be Filtered from the Water Supply?" Scientific American magazine, July 28, 2009.

rising infertility, and other gender-related issues. For example, University of Pittsburgh researchers found that breast cancer cells grew twice as fast when exposed to estrogens taken from fish in Pennsylvania.[37] Other studies point to a reduction in the proportion of males—both in animals[38] and humans[39]—that are born in areas with high estrogen levels.

- **The combined effect of chemicals from different sources:** Even though some contaminants are trace in water, they may also be absorbed by contact with other distribution channels (i.e., air, food, cosmetics), increasing the aggregate amount of the compound that people ingest.
- **The "stew effect" interactions:** Similar to many prescribed drugs, trace amounts of contaminants can interact with each other, leading to new compounds and health problems that wouldn't occur with just the single contaminant.[40] Researchers studying Italian rivers concluded that even scant traces of drugs can amplify the effect of other drugs.[41] In some cases, trace amounts mysteriously had an even greater effect than larger concentrations.[42]
- **Interactions with water treatment:** Water treatment (particularly chlorination) can sometimes transform benign compounds into new ones that have uncertain health effects. For example, the drug methadone[43] goes into the water system through wastewater as, like many drugs, about 28% does not get absorbed by the body. Methadone is not harmful for humans, but when it interacts with a common wastewater disinfectant, the combination morphs[44] into the potent carcinogen NDMA.[45] Another study[46] showed that a variety of manmade water processes[47] can alter water's chemical composition and enable it to more easily absorb naturally occurring pollutants, including radium and arsenic, or manmade contaminants such as nitrate.
- **Bacteria incubation:** To the extent low doses of antibiotics enter the water system (mainly through livestock excretion), the water becomes "an ideal petri dish for nurturing that perpetual public health nightmare—antibiotic resistant bacteria."[48] Put simply, bacteria can gradually become immune to antibiotics via exposure to the lower antibiotic concentrations in water.
- **Seepage lag effect:** Contaminants used today may not appear in water reservoirs—particularly in underground

> "TODAY, SCIENTISTS ARE LOOKING AT NEW WAYS IN WHICH CHEMICALS LIKELY CONTRIBUTE TO CANCER—RETHINKING THE VERY NOTION OF A CHEMICAL CARCINOGEN."
>
> —CURT DELLAVALLE, PHD
> SENIOR SCIENTIST
>
> ("THE POLLUTION IN PEOPLE: CANCER-CAUSING CHEMICALS IN AMERICANS' BODIES," ENVIRONMENTAL WORKING GROUP, JUNE 14, 2016.)

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[37] David Biello, "Bringing Cancer to the Dinner Table: Breast Cancer Cells Grow Under the Influence of Fish Flesh," Scientific American magazine, April 17, 2007.

[38] Nice H.E., Morritt D., Crane M., Thorndyke M., "Long-Term and Transgenerational Effects of Nonylphenol Exposure at a Key Stage in the Development of Crassotrea Gigas," Marine Eco Progress Series; 256: 293-300, 2003.

[39] Davis D.L., Gottlieb M.B., Sampinitzky J.R., "Reduced Ratio of Male to Female Births in Several Industrial Countries: A Sentinel Health Indictor?" Journal of the American Medical Association, 2009.

[40] "Can Birth Control Hormones Be Filtered from the Water Supply?" Scientific American magazine, July 28, 2009.

[41] Ettore Zuccato, Sara Castiglioni, Roberto Fanelli, Giuseppe Reitano, Renxzo Bagnati, Chiapas Chiabrando, Francesco Pomati, Carlo Rossetti, David Calamari, "Pharmaceuticals in the Environment in Italy: Causes, Occurrence, Effects and Control," 2006.

[42] Ibid.

[43] A pharmaceutical drug for treating chronic pain disorders and heroine addiction.

[44] Nsikan Adman, "Scientists Trace Cancer-Causing Chemical in Drinking Water Back to Methadone," PBS NewsHour, May 27, 2015.

[45] Nickname for N-nitrosodimethlamine.

[46] DeSimone, L.A., McMahon, P.B., and Rosen, M.R., "The Quality of Our Nation's Waters: Water Quality in the Principal Aquifers of the United States, 1991–2000," U.S. Geological Survey Circular 1360, p. 2, 2014, D.C.doi.org/10/3133/cir1360.

[47] Including draining land to plant crops, irrigating land, and pumping and mixing different layers of aquifer water.

[48] Brett Walton, "Unprescribed: Legislation to Keep Drugs Out of Water Thwarted by U.S. Pharmaceutical Lobbying," Circle of Blue Water News, November 10, 2011.

aquifers—for many years; in one study, for up to three decades.[49]

- **New industrial chemicals:** Unlike pesticides and pharmaceuticals, industrial chemicals do not have to be tested before being put on the market. These chemicals can also show up in the water systems, through a variety of possible channels, and operate under a "safe until proven dangerous" view.

In the United States, President-elect Donald Trump has indicated plans to roll-back the EPA, but the focus seems to be more on clean air aspects of the EPA mandate and less on the water sector. On the other hand, the new administration's calls for increased infrastructure spending, apparently targeted at highways and bridges, could also include the water sector.

Regardless, if and when the EPA and other global water regulators expand their lists of regulated chemicals, the actual enforcement will be extraordinarily difficult given:

1. **Diverse treatment technologies:** Each of the treatment technologies in Figure 8[50] has advantages and disadvantages in targeting certain contaminants, thus explaining why some contaminants are found in some waters and not in others. Pharmaceuticals are of particular concern since their numbers are growing rapidly yet many remain unregulated, and typical water treatments are generally not designed to filter them out.
2. **Regulating "off grid":** Nearly 20% of U.S. households use septic systems (i.e., not connected to sewage lines) that are at best regulated by state and local governments with spotty enforcement. This was less of an issue several decades ago with much fewer pharmaceutical and chemical products. However, with aging of the systems and natural seepage, the rising contaminants found in rivers, lakes, and shallow underground aquifers are increasingly linked to nearby septic systems.[51]

Even if developed market regulation improves, the poor performance of the emerging and frontier markets can still have an offsetting effect. This mirrors the difficulties of prior global CO_2 efforts—when developed countries began to regulate and dramatically reduce greenhouse gasses, much of the dirty manufacturing migrated to the poor countries. For water, the very poorest countries have already shown worsening water quality for the most harmful contaminants. (See Figure 9.[52])

Figure 8: U.S. Water Treatment Plants

Treatment Process	Ground Water Treatment	Surface Water Treatment
Disinfection - No Additional Treatment	48%	6%
Other Chemical Addition	23%	6%
Ion Exchange, Activiated Alumina, Aeration	10%	1%
Unconventioal or Indirect Filtration	13%	17%
Direct Filtration	1%	16%
Conventional Filtration (With and Without Softening)	1%	51%
Membranes	1%	4%
Other	3%	0%

[49] DeSimone, L.A., McMahon, P.B., and Rosen, M.R., "The Quality of Our Nation's Waters: Water Quality in the Principal Aquifers of the United States, 1991–2000," U.S. Geological Survey Circular 1360, p. 3, 2014, D.C.doi.org/10/3133/cir1360.

[50] Community Water System Survey Report, Volume 1, Environmental Protection Agency, Office of Water (4606M), February 2009.

[51] Brett Walton, "America's Spreading Septic Threat," Circle of Blue Water News, October 15, 2015.

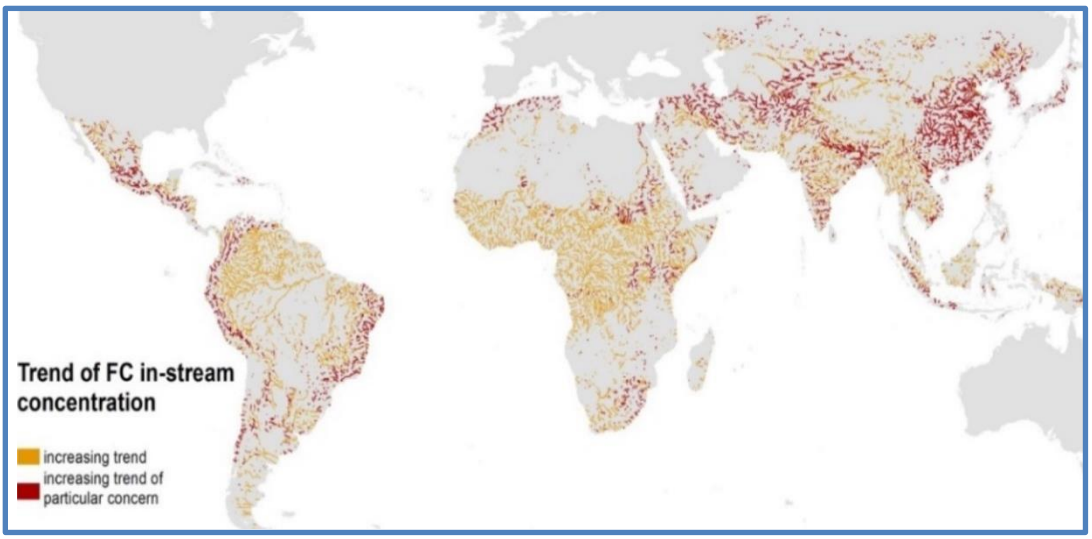
[52] Sources for Figure 9: (1) UNEP 2016, "A Snapshot of the World's Water Quality: Towards a Global Assessment," United Nations Environment Programme, Nairobi, Kenya, 162p; (2) UNWater.Org, Flyer on Sanitation, World Water Day 2013; (3) Merlin Hearn, "20 Water Pollution Facts for the U.S. and Throughout the World," waterbenefitshealth.com; (4) UNICEF WHO 2008, UNICEF and World Health Organization Joint Monitoring Programme for Water Supply and Sanitation, "Progress on Drinking Water and Sanitation: Special Focus on Sanitation," UNICEF, New York, and WHO, Geneva, 2008; (5) "Exploring the 'How' of ESG and Water Risk Integration"; (6) Chen, Trina, "China Environment Sector," Credit Suisse First Boston, August 14, 2014, p. 18; (7) T. Shias, A. Maddocks, C. Carson, E. Loizeaux, "Three Maps Explain India's Growing Water Risk," World Resources Institute, February 26, 2015.

Figure 9: Troubling Metrics for Emerging Markets Water

The "Headline" Statistics					Source
- ***2.5bn people live without basic sanitation.***					4
- ***3.5mn annual deaths due to inadequate or poor water.***					5
- ***Every 20 seconds, a child dies as a result of poor sanitation.***					2
- ***162mn children have stunted growth due to poor water, being a bigger cause than malnutrition.***					3
- ***On average, half of the world's hospital beds are occupied by patients with water-borne illness.***					3
- **Asian rivers have 3x the bacteria from human waste, and 20x the lead vs. industrialized countries.**					3
% of Rivers Classified as "Severe", from:	**Latin America**	**Africa**	**Asia**	**Comments**	
- Pathogens (i.e., mainly fecal bacteria)	10-25%	10-25%	33-50%	Leads to the most deaths, disease including diarrhea, cholera, typhoid.	1
- Organic (decay reduces oxygen, killing aquatic life)	14%	14%	14%	Increased by almost two-thirds 1990-2010 and is a concern as fish accounts for about 50% of animal protein in these areas.	1
- Salinity (a)	10%	10%	10%	Impairs use of water for agribusiness, industrial and drinking water.	1
Lakes and Aquifers					
- Bangladesh (pop. 165mn) - 85% relies on contaminated groundwater (mainly arsenic), which has been called the greatest environmental genocide in the world. One of every 5 deaths attributed to this					4
- China - 50% of lakes and 60% of ground water is not safe for drinking, mainly due to years of seepage through unregulated and unlined garbage dumps.					6
- India - Over 100mn people live in areas with unsafe drinking water.					7

Currently, 80% of developing country sewage is discharged directly into water bodies,[53] and 1.1 billion people practice open defecation,[54] leading to rising faecal coliform bacteria (Figures 10 and 11[55]).

Figure 10: Map of Increasing Faecal Coliform (FC) Bacteria in Global Rivers (Change from 1990–2010)

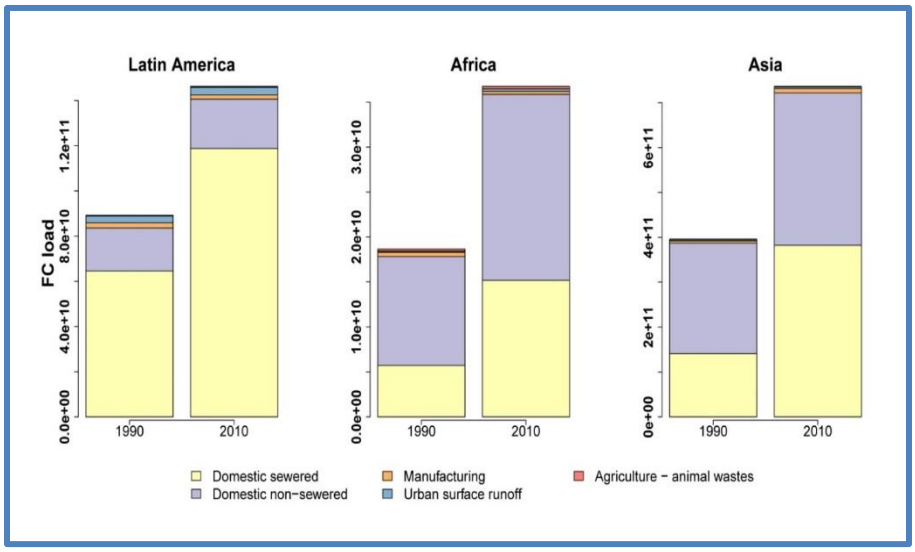


[53] UN Water.Org Water Quality brochure page for UN World Water Day 2013.

[54] ibid.

[55] UNEP 2016, "A Snapshot of the World's Water Quality: Towards a Global Assessment," United Nations Environment Program, Nairobi, Kenya, 162pp.

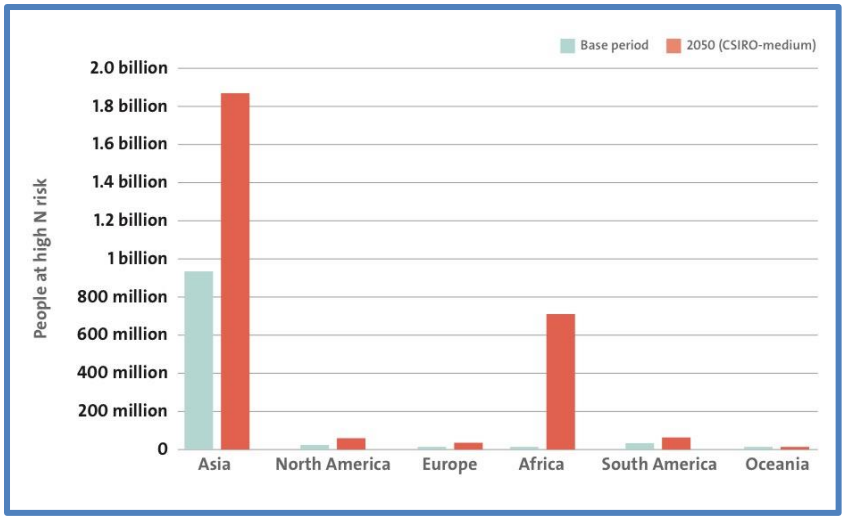
Figure 11: Increasing Freshwater Fecal Coliform Bacteria by Region and Source



Alarmingly, the sewage discharge problem is not just an emerging markets problem as many developed markets (and most of the large cities in the U.S.) discharge raw sewage into rivers whenever there is storm flooding. This is because many sewage treatment systems are built to also receive water collection from the streets. Hence, when there is a big storm, the sewage treatment capacity is insufficient, and the blend of raw sewage (from New York, for example) and storm water is allowed to flow directly into the rivers (such as the Hudson) and ocean.

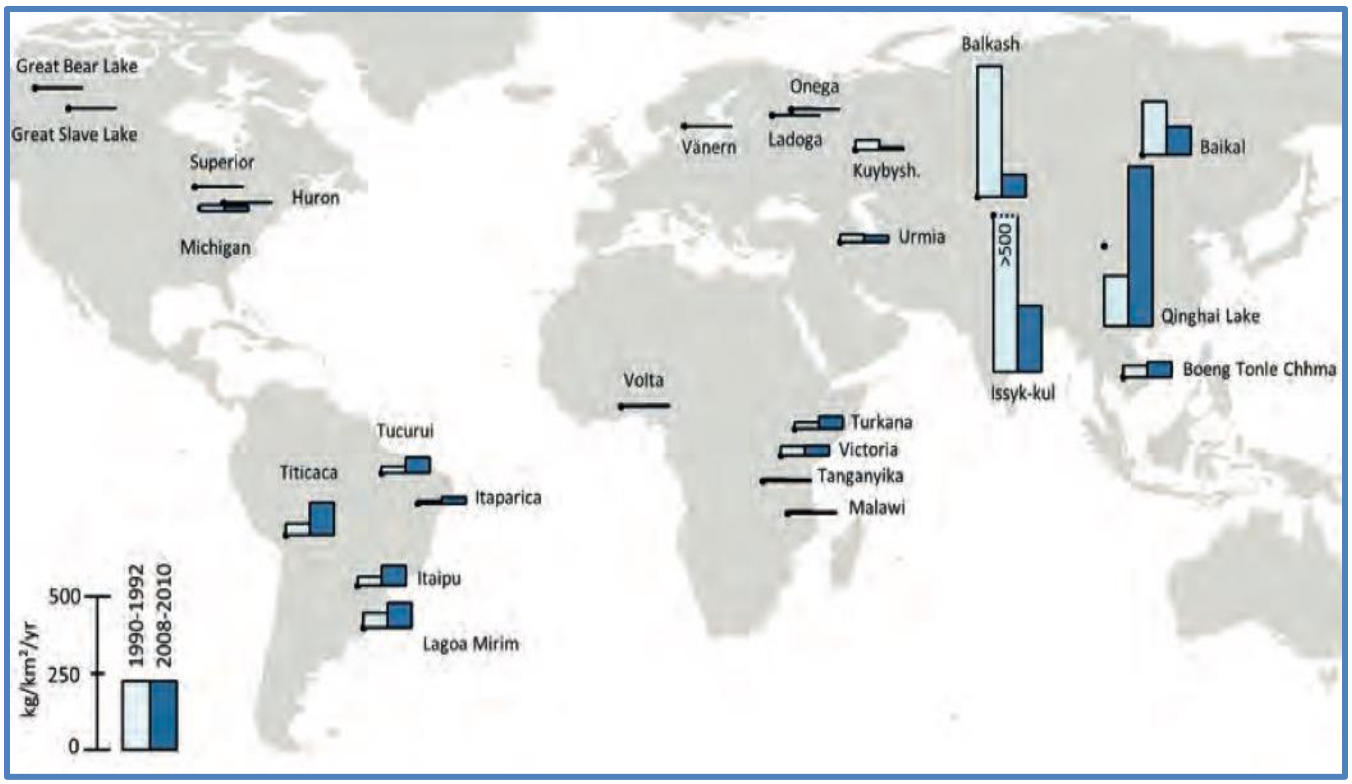
In addition to sewage discharge, emerging markets are also increasing their use of fertilizers as they try to catch up to the higher crop-per-acre yields of the developed markets. As a result, the developing countries are showing enormous increases in nitrogen (Figure 12[56]) and phosphorus (Figure 13[57]) pollution.

Figure 12: Nitrogen Levels Increasing in Emerging Markets



[56] UNEP 2016, "A Snapshot of the World's Water Quality: Towards a Global Assessment," United Nations Environment Program, Nairobi, Kenya, 162pp
[57] Ibid.

Figure 13: Phosphorus Levels Increasing in Emerging Market Lakes



Polluted rivers can also transfer contaminants via "virtual water" products such as crops and livestock that drink the water. Emerging markets produce a disproportionate amount of protein meats, with exports focused more on the highest value meats (i.e., beef) and local consumption skewed more to fish. Of all inland fishery production, 95% is from the developing world[58] as a lower cost means for fish farming and processing. However, this supply chain is already being challenged, both in the quantity and quality of fish produced. In addition to poor sewage treatment, developing countries are also using increasing amounts of contaminant fertilizers to increase crop yields.

"FISH ARE REALLY A SENTINEL, JUST LIKE CANARIES IN THE COAL MINE 100 YEARS AGO."

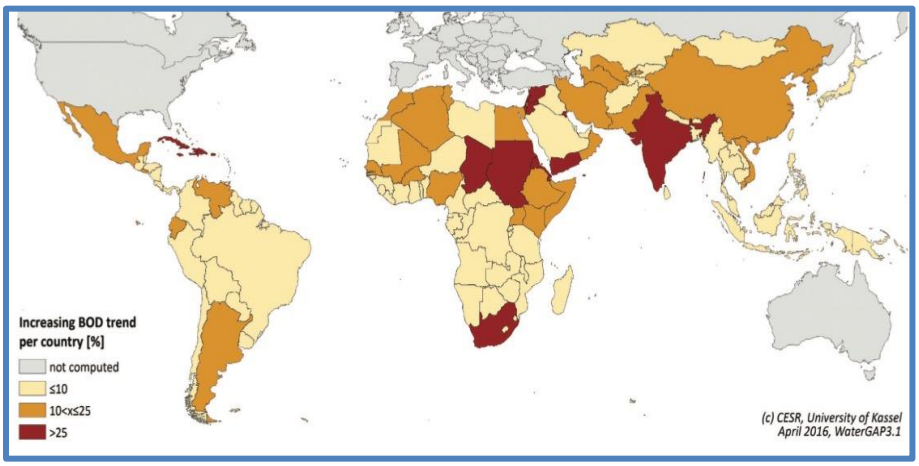
—CONRAD VOLZ, UNIVERSITY OF PITTSBURGH CANCER INSTITUTE'S CENTER FOR ENVIRONMENTAL ECOLOGY

"BRINGING CANCER TO THE DINNER TABLE: BREAST CANCER CELLS GROW UNDER INFLUENCE OF FISH FLESH," *SCIENTIFIC AMERICAN*, APRIL 17, 2007.

[58] "Pre-Study for a World Water Quality Assessment," Helmoltz Centre for Environmental Research-UFZ, Center for Environmental Systems Research, UNEP and UNWater, 2013.

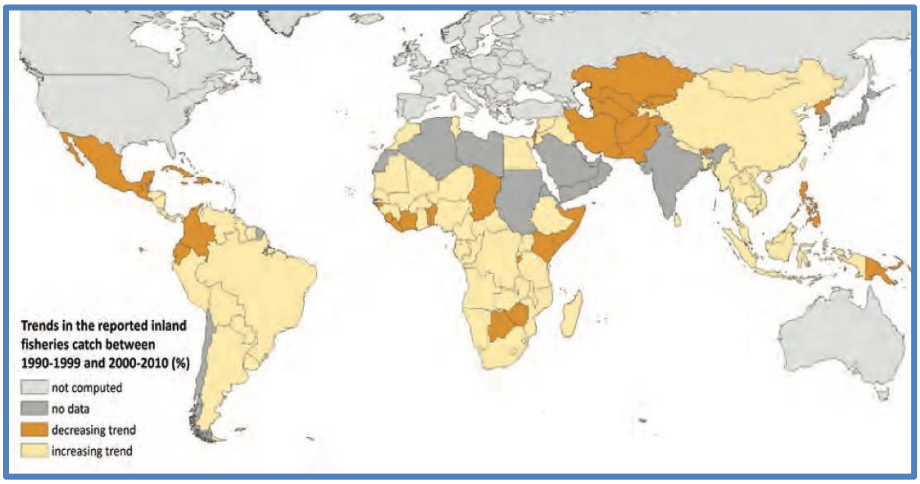
As a result of increasing nitrogen and phosphorus fertilizer use (and faecal bacteria in the emerging markets), the BOD oxygen levels in the lakes (Figure 14[59]) and rivers, as well as the downstream ocean dead zones are increasing.

Figure 14: Global BOD Levels Increasing (i.e., Less Oxygen for the Fish)



Thus, it is no surprise that the fish yield (as one of the most inexpensive and important proteins) from these polluted and oxygen-starved waters is declining (Figure 15[60]).

Figure 15: Fishing Yields Declining in Many Emerging Markets



[59] CESR, University of Kassel, April 2016, WaterGAP3.1.

[60] UNEP 2016, "A Snapshot of the World's Water Quality: Towards a Global Assessment," United Nations Environment Program, Nairobi, Kenya, 162pp.

Conclusion

As a renewable resource, the world's water supply has long been taken for granted, requiring little investment except to distribute the naturally occurring water over greater distances. Similarly, the safe water aspect has been a secondary issue given the trace amount of manmade chemicals emitted versus the vastness of the world water supply.

However, the cumulative effect of years of contamination, coupled with an exponential increase in the variety and quantity of manmade chemicals, is now leading to widespread shortages of clean water. To remedy the prior damage and restart with a sustainable supply model, the water sector will require huge investments in eco-friendly goods, water contaminant detection and monitoring, and a vast array of water efficiency and purification technologies.

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