Illuminating the ‘invisible water crisis’ to address global water pollution challenges

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COMMENTARY

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Illuminating the 'invisible water crisis' to address global water pollution challenges

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> The world faces an invisible crisis of water quality. Its impacts are wider, deeper, and more uncertain than previously thought and require urgent attention—The World Bank— (Damania et al., 2019).

1 | THE 'WATER QUALITY CRISIS': THREE PHASES OF RIVER POLLUTION

Healthy rivers provide vital services for humans and other life on Earth. Water pollution can seem like a 20th century problem: solved and sorted. In reality, gains in water quality have been hard won and far from universal, with many pollutants persisting or even increasing. Without widespread awareness and action, growing anthropogenic pressures could threaten anew the integrity of our water resources.

Over the last half century, water quality has improved—most notably in upper income countries (UICs)—with declining pollution attributed to better monitoring, treatment and regulation such as the EU Water Framework Directive, US Clean Water Act, Chinese Water Pollution Control Law, and Ghana National Water Policy. Globally, there are fewer deaths now from waterborne pathogens, it is rare for rivers to catch fire from industrial waste, and advisories against swimming and fishing have been lifted in many regions (Landrigan et al., 2018). As we congratulate ourselves on abatement of 'classical' pollutants (human waste, nutrients, sediment), it is tempting to assume that adequate standards of water quality have been achieved.

Unfortunately, poor water quality remains a pervasive problem. Water pollution still causes 2 M deaths each year and yields an additional critical burden of chronic diseases (Landrigan et al., 2018). Across Europe, 34% of the 130 000 water bodies surveyed in 2020 failed to meet "*good*" chemical status. Notably, 100% of rivers in England, Germany, Belgium and Sweden failed standards, and less than one-third of rivers met comparable ratings used in the USA (Kristensen et al., 2018). Moreover, deteriorating water quality is evident for Asian, African and South American rivers (UNEP, 2016). These reports demonstrate that we have not solved our water quality woes.

The current state of river water quality reflects an intertwined history of human development and governance. We propose river pollution can be conceptualized in three historical 'Phases', characterized by distinct contaminant types and mitigation methods:

Phase 1. Chronic organic pollution and pathogens associated with limited treatment of faecal waste, exacerbated by a rapidly increasing population density.

Phase 2. Point source and diffuse pollution associated with the intensification of primary (agriculture, mining, forestry) and secondary (textiles, manufacturing, petroleum refining) industry.

Phase 3. Emerging contaminants associated with industrial (per- and poly-fluoroalkyl substances, nanomaterials), medical and veterinary (pharmaceuticals) advances.

In UICs, these Phases occurred sequentially over several decades or even centuries, tracking industrialisation and technological advances (Figure 1; Arden & Jawitz, 2019). This enabled development of infrastructure such as wastewater treatment facilities and capacity to monitor and regulate contaminants in Phases 1 and 2 (Figure 2). Today, many lower- and middle-income countries (LMICs) are facing pressures from compressed and overlapping water pollution phases. Sanitation challenges from rapid urbanization coincide with industrial development fuelled by outsourcing of manufacturing and agriculture from UICs to LMICs. With even the highest income countries struggling to reduce Phase 2 and 3 pollutants, it is unsurprising that many countries lack the resources to address the multiplicative pressures of all three Phases simultaneously.

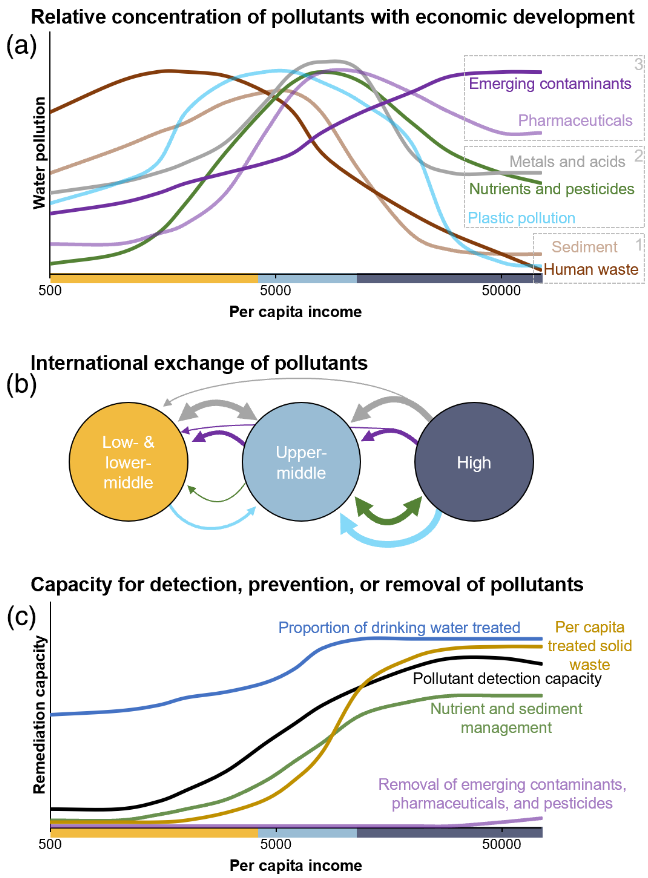

FIGURE 1 Relationships between water pollution and economic development. (a) The mean amount of each pollution type in freshwaters (rivers, lakes, groundwater) expressed on a relative scale. The World Bank thresholds for per capita annual income are indicated by the colors on the axis. The gray boxes indicate the three pollutant phases with example pollutants. (b) The exchange of pollutants across economic development levels, including physical transport (e.g. shipping of plastics, livestock, or e-waste) and virtual exchange (e.g. resource extraction in one level due to demand in another). Size of arrows represents magnitude of exchange and colors correspond to the pollutant categories in panel (a). (c) Local capacity to prevent or remediate pollution expressed on a relative scale. Data are primarily from the World Bank and Our World in Data. Panels (a) and (c) show the smoothed means for a subset of countries where data were available. Most categories include multiple parameters, which were scaled and averaged, and patterns should be interpreted qualitatively

2 | 'INVISIBLE' BUT IMPOSSIBLE TO IGNORE

With water technologies at an all-time high, what accounts for this lack of progress and even degradation of water quality worldwide? While water quantity challenges have attracted attention due to their visually dramatic manifestation (floods, drought), water quality issues are often inconspicuous or invisible. Several converging factors are making the three Phases of water pollution increasingly visible and impossible to ignore:

2.1 | We are polluting more rapidly and diversely than ever

Thousands of pollutants now exist at detectable concentrations in the environment (Figure 1a). Agricultural applications (fertilizers, pesticides, pharmaceuticals) are increasing worldwide, and freshwater environments are affected by salinization due to irrigation and sea level rise. Meat consumption continues to increase, with its associated nutrient and pharmacological burdens. Surges in pollution are generated by unforeseen global crises, such as plastic pollution linked to personal protective equipment against COVID-19 (Prata et al., 2020). The diversity and concentration of pollutants can result in non-additive interactions—mixtures that affect mobility, toxicity and bioavailability of the various ingredients (Niu et al., 2020).

2.2 | Environmental change and globalization are focusing impacts of pollution in space and time

Land use and climate change are short-circuiting the water cycle (Levia et al., 2020). Extreme storms and altered surface and subsurface drainage accelerate pollution transport and reduce ecosystem removal processes. Moreover, human disturbance can result in long-term release of legacy contaminants into soils, aquifers, and rivers (Van et al., 2018). At the same time, abrupt increases in global trade have supercharged transnational transport of livestock, crops, manufactured goods, and waste. This has resulted in imbalances in nutrients, metals, plastics, and other contaminants (Figure 1b). Because resource extraction and waste disposal are concentrated in LMICs, they bear the water quality burden of global markets and consumption in UICs. As LMICs typically have less capacity to treat waste

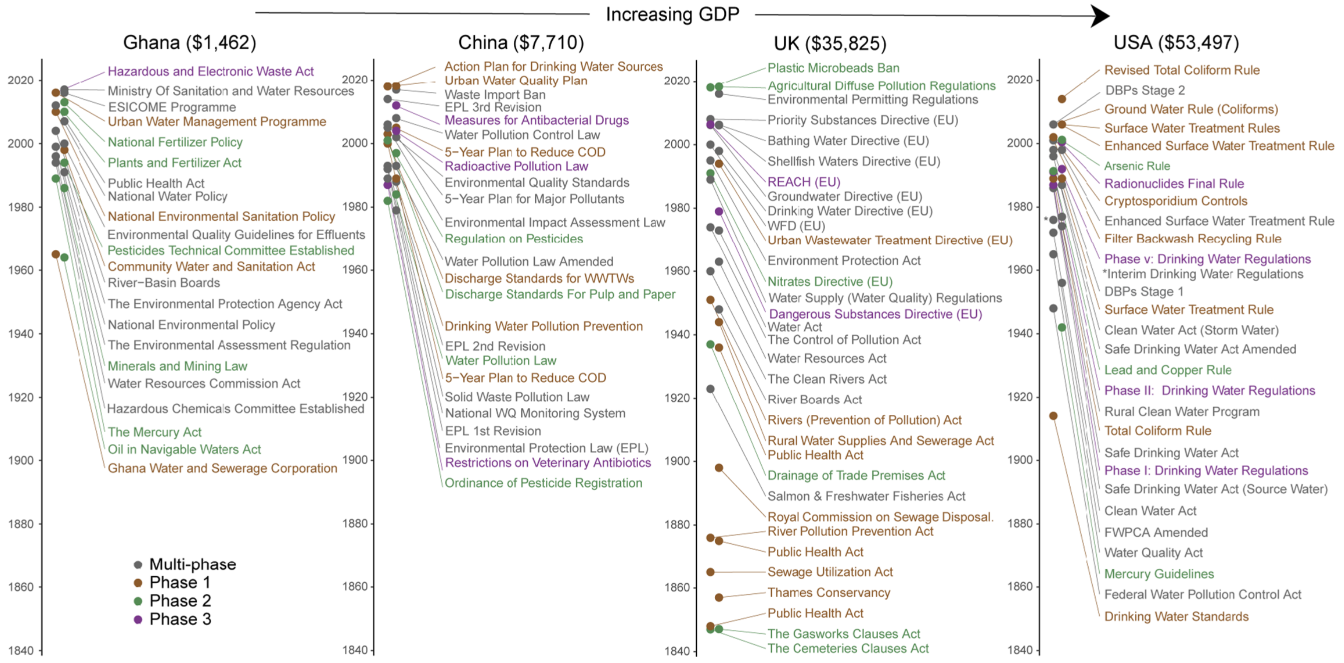

FIGURE 2 Timeline of legislation and regulations related to the pollution of freshwaters. Four countries (Ghana, China, UK and USA) were selected to represent a gradient of economic development, with the UK included specifically due to its longer regulatory history. Legislation and regulations are categorized by the pollutant Phases (Phase 1 - wastewater related, Phase 2- intensification of primary and secondary industry, Phase 3 - emerging contaminants). When legislation and regulations were not linked distinctly to a pollutant Phase (e.g. when associated with specific habitats such as the EU Groundwater Directive), they were classified as multi-phase. For the UK, legislation and regulations associated with the European Union (EU) are noted. The World Bank's US$ GDP estimate for each country is displayed in parentheses. The information displayed was compiled by authors from government and other authoritative sources

(Figure 1c), this results in more water pollution per tonne and much higher human exposure.

2.3 | Growing pollutant knowledge has improved regulation with more stringent standards

Although the widespread detection of long-banned pollutants such as Polychlorinated biphenyls could signal worsening pollution, often it reflects improved measurement capabilities. Sensitive methods now detect a wide array of pollutants at low concentrations. As egregious water pollutants have declined, we have tightened acceptable exposure standards with new knowledge of lethal and detrimental impacts on the environment and society (Ward et al., 2018). In some cases, our failures are a consequence of better-informed and increasingly stringent standards rather than absolute decreases in water quality.

3 | FROM CRISIS TO SOLUTIONS

The last two centuries of water problems and solutions (Figure 2) demonstrate that we must be proactive in managing river pollution rather than create new pollution legacies for future generations. In the face of intermeshed phases of pollutants, we need compressed and overlapping solutions that:

3.1 | Integrate understanding of human activity into holistic water management

To address complex water quality challenges, rivers and their hinterlands must be managed as connected systems. This requires improved understanding of linkages between human activities on the landscape and water quality across space–time scales. Knowledge of water science is needed to balance public expectations and inform policy. Short-term interventions may take decades to result in improvements, while mismanagement may trigger new issues far into the future (Van et al., 2018). Actions to address poor water quality should begin with identifying the specific places, times and conditions that degrade disproportionately water quality and work to redress stoichiometric imbalances introduced by globalized manufacturing and trade (Figure 1b; Peters et al., 2008).

3.2 | Move beyond regulating individual chemicals

To date, most chemicals are regulated individually. This can initiate a legislative wild-goose chase whereby slight changes to chemical composition circumvent regulation. A new EU model is emerging whereby chemicals are regulated based on their combined impact, such as regulating 'total estrogenicity' as opposed to individual compounds. For this approach to be effective for more emerging contaminants, we need improved knowledge of potential acute and chronic toxicity of multi-contaminant cocktails. This will account for cumulative risks from exposure to many stressors, such as the emerging 'exposome concept' (Landrigan et al., 2018).

3.3 | Leverage long-term and novel data sources

Environmental regulation has been informed by manual sampling and in situ monitoring. Insights from satellite imagery and unoccupied aerial vehicles are expanding monitoring in inaccessible areas, enabling detection of sources and consequences of pollution (Huang et al., 2018). CubeSat missions are complementing longstanding satellite missions with higher spatial resolution and higher frequency data (Cooley et al., 2017), providing new pathways for regional to global monitoring and modelling. Yet, there is a parallel need to extend long-term monitoring to track progress and ground-truth newer methods. However, these records' integrity is threatened by declining funding for monitoring networks, inconsistent approaches to data collection and lack of open data sharing (Lovett et al., 2007). A combination of conventional and cutting-edge monitoring methods is needed.

3.4 | Engage and empower communities and decision makers

Working directly with impacted communities to monitor water quality augments observational capabilities and empowers local people (Nardi et al., 2021). Stakeholder engagement and citizen science initiatives can lead to improved decision-making and behavioural change through community cohesion around relevant issues, particularly when information is transparent and accessible to stakeholders. Equally important is building trust and data literacy for decision makers and stakeholders, to ensure findings are understood and the best available science is used in decision-making.

3.5 | Share knowledge to boost human wellbeing

If knowledge and management actions are aligned with well-designed, effectively implemented and enforceable regulations, we can illuminate invisible water challenges, producing healthier river environments for the benefit of ecosystems and society. Through support of international cooperation and by considering water pollution challenges in their global context, LMICs may benefit from the experiences in UICs as well as from technological and legal advances (Figure 2), resulting in faster progress on solutions with less environmental degradation to generate a leapfrog effect for human wellbeing.

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REFERENCES

Arden, S., & Jawitz, J. W. (2019). The evolution of urban water systems: Societal needs, institutional complexities, and resource costs. *Urban Water Journal*, *16*(2), 92–102. https://doi.org/10.1080/1573062X.2019.1634109

Cooley, S. W., Smith, L. C., Stepan, L., & Mascaro, J. (2017). Tracking dynamic northern surface water changes with high-frequency planet CubeSat imagery. *Remote Sensing*, *9*(12), 1306. https://doi.org/10.3390/rs9121306

Damania, R., Desbureaux, S., Rodella, A.-S., Russ, J., & Zaveri, E. (2019). *Quality unknown: The invisible water crisis*. World Bank.

Huang, C., Chen, Y., Zhang, S., & Wu, J. (2018). Detecting, extracting, and monitoring surface water from space using optical sensors: A review. *Reviews of Geophysics*, *56*(2), 333–360. https://doi.org/10.1029/2018RG000598

Kristensen P., Whalley C., Zal F.N.N., Christiansen T., (2018). European waters assessment of status and pressures 2018. EEA Report (7/2018).

Landrigan, P. J., Fuller, R., Acosta, N. J. R., Adeyi, O., Arnold, R., Basu, N. N., Baldé, A. B., Bertollini, R., Bose-O'Reilly, S., Boufford, J. I., Breysse, P. N., Chiles, T., Mahidol, C., Coll-Seck, A. M., Cropper, M. L., Fobil, J., Fuster, V., Greenstone, M., Haines, A., & Hanrahan, D. (2018). The lancet commission on pollution and health. *The Lancet*, *391*(10119), 462–512. https://doi.org/10.1016/S0140-6736(17)32345-0

Levia, D. F., Creed, I. F., Hannah, D. M., Nanko, K., Boyer, E. W., Carlyle-Moses, D. E., van de Giesen, N., Grasso, D., Guswa, A. J., Hudson, J. E., Hudson, S. A., Iida, S.'., Jackson, R. B., Katul, G. G., Kumagai, T., Llorens, P., Ribeiro, F. L., Pataki, D. E., Peters, C. A., … Bruen, M. (2020). Homogenization of the terrestrial water cycle. *Nature Geoscience*, *13*(10), 656–658. https://doi.org/10.1038/s41561-020-0641-y

Lovett, G. M., Burns, D. A., Driscoll, C. T., Jenkins, J. C., Mitchell, M. J., Rustad, L., Shanley, J. B., Likens, G. E., & Haeuber, R. (2007). Who needs environmental monitoring? *Frontiers in Ecology and the Environment*, *5*(5), 253–260. https://doi.org/10.1890/1540-9295(2007)5[253:WNEM]2.0.CO;2

Nardi, F., Cudennec, C., Abrate, T., Allouch, C., Annis, A., Herman, A. T., Aubert, A. H., Berod, D., Braccini, A. M., Buytaert, W., et al. (2021). Citizens AND HYdrology (CANDHY): Conceptualizing a transdisciplinary framework for citizen science addressing hydrological challenges. *Hydrological Sciences Journal*. https://doi.org/10.1080/02626667.2020.1849707

Niu, L., Carmona, E., König, M., Krauss, M., Muz, M., Xu, C., Zou, D., & Escher, B. I. (2020). Mixture risk drivers in freshwater sediments and their bioavailability determined using passive equilibrium sampling. *Environmental Science & Technology*, *54*(20), 13197–13206. https://doi.org/10.1021/acs.est.0c05124

Peters, D. P. C., Groffman, P. M., Nadelhoffer, K. J., Grimm, N. B., Collins, S. L., Michener, W. K., & Huston, M. A. (2008). Living in an increasingly connected world: A framework for continental-scale environmental science. *Frontiers in Ecology and the Environment*, *6*(5), 229–237. https://doi.org/10.1890/070098

Prata, J. C., Silva, A. L. P., Walker, T. R., Duarte, A. C., & Rocha-Santos, T. (2020). COVID-19 pandemic repercussions on the use and management of plastics. *Environmental Science & Technology*, *54*(13), 7760–7765. https://doi.org/10.1021/acs.est.0c02178

UNEP. (2016). *Snapshot of the World's water quality: Towards a global assessment*. United Nations Environ. Program.

Van Meter, K. J., Van Cappellen, P., & Basu, N. B. (2018). Legacy nitrogen may prevent achievement of water quality goals in the Gulf of Mexico. *Science*, *360*(6387), 427–430. https://doi.org/10.1126/science.aar4462

Ward, M. H., Jones, R. R., Brender, J. D., de Kok, T. M., Weyer, P. J., Nolan, B. T., Villanueva, C. M., & van Breda, S. G. (2018). Drinking water nitrate and human health: An updated review. *International Journal of Environmental Research and Public Health*, *15*(7), 1557. https://doi.org/10.3390/ijerph15071557

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