The Future of Urban Clean Water and Sanitation

Billions of people currently lack clean water and sanitation. By 2050 the global population will have grown to nearly 10 billion, over two-thirds of whom will live in urban areas. This Voices asks: what are the research and water-management priorities to ensure clean water and sanitation in the world's cities?

Shift to Circular Approaches

Priyanka Jamwal
Ashoka Trust for Research in Ecology and the Environment

Providing clean water and sanitation to all is one of the biggest challenges of the 21st century—especially in developing countries, where 50% of the population is projected to live in cities by 2050. One way to address issues of water security is by shifting from linear to circular water-economy approaches. Understanding, assessing, and managing both water quality and the related risks to human health as water moves within the system are crucial to the successful implementation of circular approaches.

This raises four priorities for research: understand the risks of emerging and existing contaminants in the reuse of treated effluent; develop low-cost water-quality sensors to monitor contaminants in treated effluent and surface water; deploy decentralized treatment solutions, such as provisional green infrastructure, to address water pollution; and engage communities to manage and sustain local solutions to water problems.

Finding solutions to water-related problems requires a multi-disciplinary approach that engages both natural and social scientists and stakeholders from various fields. In addition to government agencies, citizen groups and local private organizations have a vital role to play in the management of local water sources. To ensure that solutions are suited to their context, there should be an emphasis on empowering citizens by promoting citizen science, enhancing the role of local private research organizations in decision making, and encouraging informed decision making by providing access to data and research via online platforms.

Water-Sensitive Settlements

Rebekah Brown
Monash University

The conventional "big-pipes" approach to water provision and sanitation has changed little in 150 years. It relies on centralized, energy-intensive infrastructure to provide, capture, treat, and dispose of water and human waste. But this is failing to meet the challenges posed by rapid urbanization, limited water resources, and climate change in urban informal settlements in low- and middle-income countries.

These settlements are currently home to more than a billion people and projected to double by 2030. Informal settlements are characterized by significant housing, land tenure, and water and sanitation issues, which threaten human exposure to harmful pathogens, pollutants, and disease vectors in water, food, air, and soil.

The "water-sensitive cities" approach uses "nature-based" technologies (such as constructed wetlands, rainwater harvesting, and bio-filtration gardens) to provide clean water and sanitation. These have been proven to deliver sustainable, cost-effective health and environmental improvements in many developed countries but have not been tested in developing countries—where the water and sanitation challenges are immense and where populations cannot wait generations for conventional "big-pipes" infrastructure. How does the "water-sensitive cities" approach perform in urban informal settlements? How can we improve human health, restore the environment, and mitigate the effects of climate change? Answering such questions calls for interdisciplinary research and new modes of engagement between theory and practice and between developed and developing countries.

No Such Thing as Waste

Rai Kookana
Commonwealth Scientific and Industrial Research Organization

Imagine a million people cramped in a tiny area of two square kilometers with little urban infrastructure (e.g., water and sanitation). This is the Dharavi slum of the Mumbai metropolis—a case of urbanization gone wrong. Urbanization in Africa will soon outpace other regions of the world, and currently 60% of its urban population lives in slums. Globally, about 5 billion people will be living in cities by 2030, mostly in less developed regions (e.g., Asia and Africa) and in areas already under water stress. Several cities in the world have extreme scarcity of drinking water already, e.g., Cape Town (South Africa) and Chennai and Bengaluru (India). Climate change is likely to make the situation worse. Clearly every drop of water must be saved, recycled, and reused. Reuse of urban wastewater and solid waste poses major challenges given that currently only about 30% of the sewage effluent is treated. Untreated effluents discharged in rivers and on land cause adverse impacts on human and ecosystem health. Vegetables irrigated with untreated sewage in peri-urban areas are often contaminated with pathogens and chemicals. The obvious questions include: How do we minimize the wastage of water and reclaim and recycle every drop of water for a beneficial and safe reuse? How do we convert waste (including solid waste) into a resource? All water is potentially good water if treated "fit for purpose." A global concerted effort in urban planning, infrastructure, and innovation could be the only hope to achieve the UN's Sustainable Development Goals.

Avoiding Water Apartheid

Pay Drechsel
International Water Management Institute

It was alarming to read that about 100 million people across India are on the front lines of a nationwide water crisis and that more than 20 major Indian cities will soon run out of groundwater. At the same time, surface water reservoirs in urban vicinities struggle with their support of agricultural, domestic, and environmental needs. The UN postulated a fast-approaching "climate apartheid," which will be at its core a "water apartheid," where private water supply will continue to boom and only the wealthy parts of urban society will be able to afford sufficient water.

To sustain urban demands, inter-basin (long-distance) water transfer and seawater desalination, and increasingly the production of potable water from wastewater, are common investments. Less explored is inter-sectoral water exchange (Otoo and Drechsel [2018]. *Resource Recovery from Waste* [Earthscan]), where freshwater originally allocated to agriculture is being moved to a higher economic value for domestic use and treated wastewater is made available to farmers, directly or via aquifer recharge. The related research and water-management challenges concern the complexity of the contractual setup of water swaps, including the incentive systems for farmers, the timing, and the monitoring of social and environmental benefits or costs. Earlier this year, a review of water reallocation from rural to urban areas (Garrick et al. [2019]. Environ. Res. Lett. *14*, 043003) found few data to assess the effectiveness, equitability, and sustainability of water transfers. The authors identified frameworks and metrics for assessing reallocation projects, which can also be applied for the business of fresh- versus wastewater swaps.

New Tools and Collaborations

Robert McDonald
The Nature Conservancy

The world's future cities face two massive challenges in the coming decades to their goal of ensuring clean water to all. More than 2 billion additional people are expected in cities by 2050, and cities will struggle to meet this growth in demand for clean water while also extending delivery lines to those in the informal sector without access to municipal water. At the same time, climate change has begun to make water supplies irregular, increasing the risks of droughts that can disrupt municipal water supplies, as has happened recently in Chennai and Cape Town.

I see two major solutions that can help cities meet these twin challenges. A clear research priority is how climate change will affect the world's urban drinking-water systems. Although much has been written about the potential impacts of climate change, still relatively few tools enable water and wastewater utilities to easily begin planning for climate change. Climate change has arrived, and these utilities will be significantly affected by climate change, but many of them (particularly in cities with fewer resources) have not yet begun planning for how they will cope. A clear management priority is for cities to begin to make more efficient use of the water they have access to. This will often mean collaboration across sectors and institutions, which are currently often not working in an integrated way. In a crowded, climate-altered world, breaking down these silos will be crucial to achieve drinking water for all.

An Integrated Vision for SDG 6

Charles J. Vörösmarty
The City College of New York

The question concerns reliable drinking water, sanitation, and hygiene—what water experts call WASH, an absolute necessity for healthy and vibrant cities but a huge problem for fast-growing and poorly managed urbanization across much of the world. *What happens when there is insufficient or unusable water when and where it is needed?* As we have for millennia, we turn to water engineering, which without question brings enormous health and economic benefits. Yet, when viewed monolithically, engineered solutions can be over-designed and over-priced and impair the very waterways we use for water supply. Despite a strikingly pointed debate in the design of Sustainable Development Goal (SDG) 6 on water—wherein developing-world representatives argue nearly exclusively for WASH and richer countries propose added environmental protection for long-term water-system sustainability—a broader vision has emerged. The vision recognizes that WASH needs not only innovative technologies but also sound water management, pollution control, and watershed and waterway protection. Achieving this blueprint will be no easy task given that scientists continue to uncover persistent signs of management failures and pandemic water degradation. Choosing my words carefully, I consider myself *cautiously pessimistic* because history has not been on our side, and a new way of doing business has yet to take root. An extended WASH concept will include protecting, rehabilitating, and putting to work natural capital; comprehensive monitoring; training next-generation practitioners; and engaging stakeholders from academia, government, business, and the public.

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Urban Water Challenges

Michelle T.H. van Vliet
Utrecht University

Accessibility of clean water is fundamental for a wide range of human uses, such as irrigation, livestock, household uses, and energy and manufacturing uses. Over the past decades, water use has increased rapidly under a growing world population, particularly in megacities. However, both the availability and the quality of water resources are affected by socio-economic and technological developments. Urbanization and increasing volumes of untreated wastewater from households, industry, and agriculture contribute to the deterioration of water quality, particularly in developing countries. Also, climate change and increasing climate extremes, such as floods and droughts, challenge urban water management by affecting both the availability and the quality of water resources. In many megacities, the gap between the demand and supply of available clean water resources is increasing. Hydrological and water-resource model systems have been developed to improve our understanding of changes in water-resource availability and quality for water-management decision making. However, further developments could still be made in tailoring these model systems to improve the representation of impacts of hydro-climate extremes and to better capture the complexity of urban areas in these model systems. From a water-management perspective, a stronger integration of sustainable urban water management into river-basin water management would also be a priority to better address future water challenges and to achieve sustainable management of clean accessible water for all in line with the UN Sustainable Development Goals.

Innovation in Water Governance

Anik Bhaduri
Sustainable Water Future Programme,
Future Earth

Cities in many countries worldwide, for instance, in India, Mexico, Japan, South Africa, Brazil, China, and Indonesia, are facing unprecedented water risk in terms of quantity and quality.

Accelerated changes in the use of water, land, and energy as well as unplanned and uncoordinated infrastructure development driven by rapid urbanization and climate change lead to abrupt changes and disruptions in urban water-provisioning services. Innovative combinations of science and digital technology can provide an opportunity to address the challenges of urban water governance.

A real-time tracking system is needed to specify spatially where investments can have maximum impact in containing urban water-security threats. Machine-learning algorithms and artificial intelligence can help in risk analysis under different scenarios that define the development path of the cities in the future. These systems should be supported by evidence-based decision making through the use of big-data analytics.

Blockchain-based solutions, for instance, can be used as a governing tool that can replace intermediaries, modernize the regulatory processes, and act as an accounting, auditing, interlinking, and trading platform that enables water-quantity and water-quality markets to function effectively where the buyers face *ex ante* water-quality uncertainty.

Such innovation has the potential to increase the efficiency of water and energy usage, reduce wastage, pinpoint infrastructure opportunities, extend the life of existing assets, and increase access to better information for better governance.