Developing decentralized, closed-loop modular systems for wastewater management

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Beneath the Bahnhofstrasse in Zurich, a sewer conveys wastewater to the treatment plant. Rainwater is channelled through a separate pipe. Credit: Max Maurer / ETH Zurich

Out of sight, out of mind: we've been flushing away human waste ever since sewers were invented, using copious amounts of fresh water to expel it from our homes and cities as fast as the pipes can carry it. Modern urban water systems are widely regarded as one of the greatest achievements of the past century. They provide us with clean drinking

water, channel our wastewater to treatment plants and divert rainwater away from built-up areas.

"As a result, we enjoy dry and hygienic living conditions, two of the mainstays of public health in densely populated urban areas," says Max Maurer, Professor of Urban Water Systems at ETH Zurich and Eawag, the Swiss Federal Institute of Aquatic Science and Technology, which is part of the ETH Domain.

To achieve this, industrialized countries have built a vast amount of infrastructure—some 230 billion Swiss francs' worth in Switzerland alone. Laid end to end, Switzerland's 200,000-odd kilometers of water and sewerage pipes would encircle the globe five times. The extensive network of underground sewers carries wastewater to nearly 800 centralized treatment plants.

This approach to water infrastructure has proved its worth in industrialized countries—and for decades, it was also regarded as a benchmark for the rest of the world. "But the truth is that conventional urban water systems are no longer sustainable," says Maurer.

From waste to resource

Kai Udert, professor at the Institute of Environmental Engineering at ETH Zurich and Senior Scientist at Eawag, is equally skeptical about conventional water infrastructure. "We use drinking water to dilute feces, urine and slightly dirty water from bathrooms and kitchens and move them through the sewerage system—that's patently absurd." he says.

Udert, an expert in process engineering, sees sewage not as foul-smelling waste that needs to be disposed of, but rather as a valuable resource that should be properly exploited. His explanation of why we need to take a

new approach is simple. "Wastewater is one of the last linear waste streams," he says. "We dispose of everything in the same way, regardless of whether it's clean or dirty. That's inefficient, and it creates all sorts of problems that people have been trying to fix for years." For example, conventional systems squander not only huge amounts of water and energy but also valuable nutrients which, if not fed back into the cycle, end up damaging the environment.

Meanwhile, the challenges are growing: the wastewater industry is struggling to deal with climate change, rapidly aging infrastructure, a booming population and increasing urbanization, as well as new pressure on treatment plants to remove micropollutants.

Maurer and Udert argue that it's time for a rethink. They are calling for a paradigm shift, moving away from a handful of centralized plants towards a decentralized system of wastewater treatment based on modular water infrastructure. This would give us a more efficient and effective means of managing urban water resources.

Recycling at source

"Think compact, highly efficient, decentralized systems that offer flexible wastewater treatment on a local level—that's the alternative we're proposing," says Maurer. At Eawag, Udert and Maurer have spent years developing suitable processes for small-scale treatment facilities. Their work is based on the three key principles that underpin a closed-loop sanitation system designed to conserve and recover resources.

Separation at source—also known as NoMix sanitation—seeks to segregate wastewater into its different fractions, because human waste and water are much easier to treat and recycle if they are not mixed together in the first place.

Resource recovery takes various forms: nutrients such as nitrogen and phosphorus can be obtained from urine and feces, while greywater—slightly dirty wastewater from kitchens, bathrooms and washing machines—can be treated and reused multiple times. Thermal energy is also recovered. Similarly, applying recovered nutrients to the fields as fertilizer closes the nutrient cycle, thereby benefiting the environment and reducing dependence on imports of mineral phosphorus fertilizers.

The third principle, decentralization, seeks to eliminate the costly transport of water through centrally managed pipe systems by ensuring that wastewater and waste can be treated as close to source as possible.

The researchers develop and test new wastewater technologies in the basement of NEST, the research and innovation building run by Eawag and Empa, the Swiss Federal Laboratories for Materials Science and Technology. Some of the processes they use stem from research projects launched over 15 years ago to develop off-grid sanitation solutions for countries in the Global South.

Well-known examples include Vuna and Blue Diversion Autarky, which provide a safe and affordable way to dispose of wastewater without requiring a combined sewerage system and centralized treatment plants.

Vuna stands for "Valorisation of Urine Nutrients in Africa." In this approach, co-developed with ETH Zurich, separately collected urine is converted into fertilizer in a treatment plant located at a distance. The second project gave rise to the Blue Diversion Autarky toilet, a system that collects and treats urine and feces and collects and recycles flush water in separate modules housed within a single structure.

Biogas reactor and pasteurizer

Elizabeth Tilley understands all too well the importance of decentralized sanitation systems that do not require a water supply. Yet, in many regions of the world, fundamentally new concepts are required to make these work. Tilley began her research career at Eawag and completed her doctorate as part of the Vuna nutrient recycling project in South Africa, which was led by Udert. Today, she is Professor of Global Health Engineering at ETH Zurich, where she and her research group work to devise affordable and socially acceptable solutions for the protection of human health and the environment.

Some 2.3 billion people around the world use on-site sanitation systems such as pit latrines. These serve as an initial barrier to excreta-related pathogens, but regular emptying of the latrine creates its own set of problems. If the sludge is simply dumped into the environment or left untreated, the risk of pathogens spreading—and the potential for outbreaks of diseases such as cholera—is high.

There is an urgent need for decentralized technologies that are robust, affordable and easy to operate. One promising technology is an anaerobic biogas reactor that is essentially a large, rubber balloon. This treats the fecal sludge to a certain degree, although not enough to make it safe for disposal. On the plus side, however, the process does yield a useful by-product in the form of a methane-rich gas (biogas), which can be used for cooking—just like propane or natural gas.

Together with Kenyan engineering firm Opero and a Mexican supplier of biogas reactors, Tilley and her team set out to discover if they could use biogas derived from the sludge to fuel a pasteurizer that would then heat the effluent to a temperature sufficiently high to kill all the pathogens.

Julia Jäggi, a Master's degree student in the Department of Mechanical and Process Engineering, spent three months in the Kenyan city of

Kisumu, on the shores of Lake Victoria, designing and testing a pasteurizer with the capacity to treat the waste of about 500 people a day. "Engineering in the lab is one thing, but this really put our flexibility and creativity to the test! Every day was about solving problems on the fly and making the most of the resources we had," says Jäggi. Tilley is confident that their system will soon be ready to deploy and will help prevent infectious diseases.

Tapping into existing expertise

There's no doubt that water poses one of the biggest challenges of the future. Using this resource intelligently and sparingly is essential, both in Switzerland and abroad. "The concepts we developed for poorer countries 15 years ago are becoming increasingly relevant to Switzerland. We're now reaping the rewards of this knowledge," says Udert.

Maurer and Udert believe we will soon be seeing modular treatment plants in urban areas and compact reactors to treat wastewater in homes. The COMIX research project, which was co-led by Maurer, recently examined the potential use of modular technologies in the Swiss water management sector. Its results suggest that the proportion of decentralized wastewater treatment plants could rise from 2.5% to 50% in the long term.

The researchers also see an opportunity for Switzerland to fast-track efforts to make its water infrastructure climate-friendly. This would give it the head start it needs to position itself as a lead market for the development and testing of modular water systems. Over the years, Switzerland has accumulated a wealth of expertise in all aspects of water resources management, thanks not least to its universities of applied science, industry and the institutions of the ETH Domain. "Yet this expertise has remained largely untapped," says Maurer.

It would take a concerted effort by research, industry and the public sector to conduct the pilot projects required to demonstrate the feasibility of this applied knowledge and to then create an initial market. "But when it comes to the processes, the know-how and the financial resources—it's all there already," says Udert.

Provided by ETH Zurich

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