BRIEF COMMUNICATION OPEN

Learning from Hanoi to imagine the future of water distribution

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In many countries, water distribution systems consist of large, highly pressurized pipe networks that require an excessive amount of energy and that are vulnerable to large-scale contamination. To imagine the future of water distribution, we can learn from Hanoi, Vietnam, where water is distributed at low pressures and most buildings are equipped with a basement tank, a rooftop tank, and separate water treatment processes, resulting in a system that consumes less energy and that is more resilient.

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Collect, treat, distribute, consume. This is more or less what water distribution consists of in many countries. Water is first collected from a natural source and pumped into a water treatment plant, and it is then treated. Subsequently, it is propelled into large networks of pipes that systematically need to be pressurized so that drinkable water flows out whenever we open a tap; see Fig. 1a. Throughout the world, this is often seen as the preferred solution to operate water distribution systems; i.e., the “golden standard”. The problem is that this model is not adapted to tackle the challenges of the twenty-first century and it possesses at least two major problems.

First, ensuring that water pipes are systematically pressurized requires an excessive amount of energy (~80% of all the energy used by water utilities in the United States¹). This represents so much energy that water utilities are often the largest clients of electric utilities. Chini and Stillwell² found that, on average, the treatment and distribution of water in the US requires 340 Wh m⁻³. Second, water distribution systems are not resilient. Again, because water pipes are constantly under high pressure, enormous forces are exerted on pipe walls, and as water distribution systems get older, the occurrence of pipe breaks is inevitable. Consequently, many water utilities go to great lengths to minimize any subtle change in water pressure to avoid water hammers that can result in pipe breaks and that can lead to large-scale contamination. As water distribution systems are getting older in many cities around the world, it may be time to revisit the golden standard of water distribution.

In the search for a different model, we can learn from Hanoi, the Vietnamese capital; see Fig. 1b. The initial process in Hanoi is similar to the golden standard. Water is collected from a natural source (i.e., surface water bodies or groundwater wells) and it is treated. Water is then pumped into an extensive pipe network. The difference is that until 2008, not enough water could be treated and pumped to supply the entire city, and therefore, one by one, certain sections of cities were shut off from the water distribution systems during the day—these systems are called intermittent water supply (IWS) systems, in contrast to continuous water supply (CWS) systems, and are common in low and middle income countries. As a result, nearly every building had a water tank in the basement to store water when the system was not running—these secondary, in-building systems are called secondary water supply (SWS) systems. While Hanoi is now continuously supplied with water, the practice remains. Consequently, buildings

are generally self-sufficient for several days when the water supply is interrupted. As an example, in October 2019, one water treatment plant in Hanoi was contaminated, which in turn contaminated a portion of the water network, but most buildings were not disrupted because they had isolated themselves from the network in a timely manner and they had stored sufficient water for several days. Moreover, because buildings are equipped with basement tanks, water pressure in the system can be lower. In Hanoi, low-pressure zones have pressures around 10 meters (the minimum acceptable for fire safety), thus requiring less energy than the golden standard—as an example, in the US, average water pressure tends to be ~30 meters (roughly to supply a five-story building). More generally, beyond the context of Hanoi, water pressure management is well studied and has been recognized to help reduce leakage and energy consumption³.

In addition, most buildings in Hanoi have another smaller water tank placed on roofs. Water from the basement tank is first pumped to the roof tank—the process is usually automatic but it could be programmed to only run when electricity demand is low. For a typical house, the basement tank has a volume of 3–5 cubic meters while the rooftop tank contains about 1–2 cubic meters of water; see a picture with typical rooftop tanks, Fig. 2. Because the tank is on the roof, gravity alone is used to supply water throughout a building, and water can therefore be supplied during power outages (until the rooftop tank is empty).

Overall, in Hanoi, water distribution consumes about 100 Wh m⁻³ for treatment and distribution (data from the Hanoi Water Limited Company) and about 130 Wh m⁻³ to pump water from the basement tank to the roof tank (for a four-story building; see Methods), for a total of 230 Wh m⁻³ (about two-thirds the US average).

Naturally, the Hanoi model is not without flaws. Large pressure differentials in water distribution systems can degrade water pipes more quickly as is common in IWS systems. Moreover, as a result of allowing lower water pressures or even shutting off the water distribution systems to part of the city (as it used to be), contaminated groundwater may enter the pipe network and contaminate the entire system. To partly tackle water quality issues, in Hanoi, many buildings are further equipped with separate treatment processes, located after the rooftop water tank (i.e., after the SWS system) to treat potable water on demand (often in the form of water filters). This strategy further ensures that water quality is controlled by the user. In fact, once it passes

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a) Conventional Water Distribution System (Golden Standard)

b) Hanoi Water Distribution System

Fig. 1 Conventional versus Hanoi Model for water distribution. **a** Conventional water distribution model of collect, treat, distribute at high pressures, and consume. **b** Hanoi water distribution model of collect, treat, distribute at low pressures, store, treat, and consume.

Fig. 2 Typical rooftop water tanks in Hanoi. The picture shows four rooftop tanks. The smaller horizontal drum with a series of tubes on the left-hand side in front of a rooftop tank is a solar water heater.

the water meter, water is owned by the property owner. As a result, the owner is responsible for the quality of water once it reaches the SWS system; and, if not maintained well, water quality can be affected in SWS systems due to longer water stagnation times, higher temperatures, and loss of disinfectant residuals⁴. One consequence of transferring some of the responsibility to building owners is that some financial burden is placed onto building owners themselves.

Overall, Hanoi has achieved a hybrid system that is both centralized and decentralized. The distribution of clear, low-pressurized water is centralized, similar to the golden standard, except that the process tends to consume less energy. Once water enters a building, it is generally stored in a basement tank, then pumped to a smaller rooftop tank, and finally treated one last time into potable water. In contrast to the collect, treat, distribute, consume model, Hanoi follows a collect, treat, distribute, store, treat, consume model. In the end, the Hanoi model is both more resilient while potentially requiring less energy to operate.

Ultimately, the legacy from the end of the nineteenth century of keeping enormous pipe networks pressurized with potable water is simply neither sustainable nor resilient. Water distribution as a whole should be revisited and better integrated with other infrastructure systems^{5–7}. Any effort to transform the golden standard will require substantial learning and a dramatic socio-technical transition, and while the Hanoi model is not perfect, it offers valuable insights and ideas to set us on the path toward the future of water distribution.

METHODS

Equation (1) is used to estimate the energy consumption E_{pump} to pump water from a basement to a rooftop tank.

$$E_{\text{pump}} = \frac{\rho \cdot g \cdot V \cdot (H + h_f)}{\eta_{\text{pump}} \cdot \eta_{\text{motor}}}, \quad (1)$$

where ρ is the water density (i.e., 1000 kg m^{-3}); g is the gravity acceleration (i.e., 9.81 m s^{-2}); V is the pumped water volume; H is the geodetic lift; h_f is

the total friction loss (i.e., for indoor pipe network, friction losses are estimated to make up 30% of the geodetic lift); η_{pump} is the pump's efficiency (for indoor systems η_{pump} is ~30–60% depending on pump's age⁸); η_{motor} is the pump motor's efficiency (for small motors, with rated power under 2.2 kW, η_{motor} is ~75%).

For a typical four-story residential house ($H = 14$ m), assuming a pump efficiency of 50%, the energy consumption to pump 1 m^3 of water from the basement to the roof is $E_{\text{pump}} = \frac{1,000 \times 9.81 \times 1 \times 1.3 \times 14}{0.5 \times 0.75 \times 3600} = 132.25 \text{ Wh}$, thus ~130 Wh.

Reporting summary

Further information on research design is available in the Nature Research Reporting Summary linked to this article.

DATA AVAILABILITY

No datasets were generated or analyzed during the current study. One data point was collected from the Hanoi Water Limited Company (<http://hawacom.vn/home/>), as described in the following figshare metadata record⁹: <https://doi.org/10.6084/m9.figshare.13160015>.

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AUTHOR CONTRIBUTIONS

S.D. conceived the idea for the work. T.T.M.T. collected information and data from the Hanoi Water Limited Company. P.T.H. performed the analysis and analyzed the results. N.H.Q. interpreted the results and contributed to the idea and discussion. S.D. led the writing of the manuscript with major inputs from all authors.

COMPETING INTERESTS

The authors declare no competing interests.

ADDITIONAL INFORMATION

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