WATER ON TAP

Researchers are exploring unconventional sources of fresh water to quench the globe's growing thirst.

BY QUIRIN SCHIERMEIER

In an effort to combat his country's long-standing water crisis, Iran's president took to Twitter last year. "We need plan to save water in agriculture, prevent excessive tap water use, protect underground sources of water and prevent illegal drilling," Hassan Rouhani tweeted in November.

Iran is far from alone. From the southwest United States to southern Spain and northern China, water shortages threaten many parts of the world. Nearly 800 million people lack access to safe drinking water and 2.5 billion have no proper sanitation.

The situation will probably get worse in coming decades. The world's population is expected to swell from 7 billion today to more than 9 billion by 2050, even as climate change robs precipitation from many parched parts of the planet. If the world warms by just 2 °C above the present level by the end of the century, which scientists believe is exceedingly likely, up to one-fifth of the global population could suffer severe shortages of fresh water.

"Even without global environmental change, feeding 9 billion people by 2050 will require an additional 2,000–3,000 cubic kilometres of fresh water in agriculture — more than the total global use of water in irrigation," says Johan Rockström, a specialist on water resources at Stockholm University and director of the Stockholm Resilience Centre. "This equates to nothing less than a new agricultural revolution. Novel approaches, such as water-harvesting practices, are absolutely critical in the future."

Most countries are seeking to expand access by tapping the underground aquifers that already supply the bulk of the fresh water for the global population. At the same time, some are experimenting with recycling waste water for agriculture and other uses. But many nations hope to tap unconventional sources — ranging from fog to the ocean — to quench their thirst. Some approaches involve billion-dollar deals; others are local efforts that require little in the way of costly technology. Here *Nature* looks at five ways to produce fresh water from unusual sources.

DESALINATION AT A COST

Like all Mediterranean countries, Israel receives most of its precipitation during the winter months. But last winter, almost no rain fell. In the past, such a drought would have caused severe problems for Israel's 8.2 million people. But thanks to the seawater desalination plants that Israel has built over the past decade, the country's taps did not run dry.

Israel's four large 'reverse osmosis' plants rank among the biggest and most efficient desalination facilities in the world. By next year, they are expected to provide more than 500 million cubic metres of fresh water per year — about half of Israel's needs. In 2012, IDE Technologies in Kadima, the company behind three of the existing Israeli plants, signed a deal to design a US$1-billion desalination facility near Carlsbad, California. When completed by 2016, it will supply fresh water to about one-tenth of the 3.2 million people living in San Diego county.

A rapidly growing global industry, desalination has become in the past 20 years an essential source of fresh water for the Middle East, Australia, the United States, South Africa, Spain and, increasingly, India and China. In 2012, the total amount of installed desalination capacity exceeded 80 million cubic metres per day, enough to supply some 200 million people.

"With nearly half of the global population living within 100 kilometres of the ocean coast, you just can't avoid desalination," says Gary Amy, director of the Water Desalination and Reuse Center at the King Abdullah University of Science and Technology (KAUST) in Thuwal, Saudi Arabia. "Desalination is here to stay and it will inevitably become bigger."

But by any method, desalination consumes much more energy than conventional water sources. It takes just over 3 kilowatt hours (kWh) of energy to produce 1 cubic metre of potable water at the most efficient commercial reverse osmosis desalination plants — where pre-filtered sea water is forced under pressure through a series of semi-permeable membranes. A process that evaporates ocean water in thermal plants requires about 10 kWh to produce the same amount of potable water. Some oil-rich countries do not mind the high price: Saudi Arabia's desalination industry, for example, currently burns some 300,000 barrels of oil per day.

Engineers are trying to improve reverse-osmosis technology using components such as low-energy pumps and advanced membranes. Some are experimenting with membranes made of graphene to replace the polymers currently used. And efforts are under way globally to shift from fossil fuels to renewable energies in the desalination process.

Even with those advances, desalination will remain costly, says Maria Kennedy, a water-treatment specialist at the United Nations' Institute for Water Education in Delft, the Netherlands. "Nobody decides to do desalination unless they're out of other options."

RIVERBANK FILTRATION

Every July and August, millions of Hindu pilgrims flock to the holy city of Haridwar in India, to visit its temples and fetch water from the Ganges river. The aquifers that supply fresh water to the city cannot keep up with the annual influx of people, so another source is needed. The banks of the Ganges offer a solution.

Germans along the Rhine have been using riverbanks to filter water since the 1870s. The method is straightforward: when wells are dug next to a river in regions with suitable geology, the river water filters through sand and gravel that strips out most of the chemical and biological pollutants, and so emerges relatively clean.

"The treated water may not always meet the water-quality requirements," says Saroj Sharma, an environmental engineer at the UN's water institute. But when the river is relatively clean and the geological conditions are favourable, as in Haridwar, it may need only a minor amount of disinfection, says Sharma.

Hindu pilgrims gather to bathe in the Ganges.

DANIEL BEREHULAK/GETTY

India will have to increase its use of natural water-treatment systems. Groundwater currently provides 85% of the country's domestic water, but supplies are rapidly declining: in 20 years, about 60% of all of India's aquifers will be critically degraded, according to the World Bank.

Researchers are now looking to improve the efficiency of technologies for natural water filtration and reuse in India as part of the Saph Pani project, a $6.5-million collaboration at nine sites in the country, funded by the European Union. The studies range from riverbank filtration in Haridwar to wastewater treatment in artificial wetlands in Hyderabad.

ANCIENT TECHNOLOGY

The Tigray region of northern Ethiopia is notoriously dry, and as a result has experienced repeated famines. But the villagers of Koraro no longer face water shortages, thanks to an imported ancient technology.

Upmanu Lall, director of Columbia University's water centre in New York City, brought the method to Koraro as part of the university's Millennium Villages Project, which seeks to fight poverty and hunger in Africa through community-led efforts. While searching for a way to supply the community with water, Lall sought inspiration from waterworks known as qanats, invented by Persian engineers more than 2,000 years ago. These elaborate tunnels carry groundwater from high elevations down to dry valleys and plains; some ancient systems are still in use in Iran and parts of the Arabian Peninsula. In 2009, with $250,000 funding from the Ceil and Michael E. Pulitzer Foundation, Lall's engineering students began to design a modern version of a qanat in Koraro.

The village and surrounding fields are on a sandy slope, just a few kilometres away from the steep cliffs of a mountain. The region receives scant rainfall, except in July and August, when flash floods badly erode soil. In the past, villagers have stored rainwater in tanks, but much of that water evaporated quickly and the rest often became polluted.

To get around these problems, the Columbia students, aided by Ethiopian engineers and local villagers, designed a system of small rock dams at the top of the mountain to control surface run-off and allow the rainwater to seep into the subsurface.

The water then flows down through the mountain into a trench measuring 3 metres wide by 3 metres deep, which stretches from the foot of the mountain down the slope to the village 4 kilometres away. The system, which can hold 36,000 cubic metres of water, has been working for three years. The trench recharges the groundwater around Koraro, thus supplying villagers with water for drinking and agriculture. The water has enabled villagers to add an extra planting season, and it supplements irrigation during breaks in the rainy season.

"Just like the master-builders of ancient Persian qanats, we have created an aquifer where actually there wasn't one," says Lall. "And, filtered by the sand, the water we produce is of pure drinking quality."

"Water scarcity is often caused by sporadic rainfall rather than actual lack of water," says Alberto Montanari, a hydrologist at the University of Bologna in Italy. "The challenge then is to devise sustainable solutions for storing water to make a reserve for the dry season. The Koraro project is an excellent example how this can be done."

As word spreads about the success of the scheme, other communities in Tigray are planning to adopt similar techniques. The method, says Lall, could be applied in many locations with appropriate topography and hydrology, including most of Africa's semi-arid highlands. And Lall is already looking beyond Africa: he is in talks with the state of Jharkhand in northeast India to develop a qanat there.

NEWS FEATURE

GREENING THE DESERT

Agriculture uses more than two-thirds of Earth's fresh water, so the idea of a farming practice that produces more water and energy than it consumes seems too good to be true. But in the desert of Qatar, scientists are showing that salt water and sunlight can yield food and clean water in a self-sustaining cycle.

The Sahara Forest Project (SFP), a Norwegian company launched in 2009 and supported by the Oslo-based fertilizer company Yara and the Qatar Fertilizer Company of Mesaieed, operates an $8.5-million pilot facility outside Doha. Last year, the 700-square-metre greenhouse produced a crop of vegetables comparable to that of commercial greenhouses in Europe, according to SFP.

Greenhouses normally trap heat, but the reverse is required in hot places such as Qatar. At the SFP facility, sea water does the trick. The water, piped from the ocean just 100 metres away, trickles over a lattice at the windward side of the greenhouse. As the water evaporates, it humidifies the air entering the greenhouse and cools it by some 10 °C, creating an indoor climate suitable for growing vegetables such as cucumbers and tomatoes. Other crops, such as barley, salad rocket and useful desert plants, grow between hedges downwind of the greenhouse.

When the desert cools at night, water condenses on surfaces inside the greenhouse and is collected for irrigation and drinking. A desalination facility at the site produces further fresh water. And the electricity needed to run the entire installation comes from solar power.

Joakim Hauge, chief executive of the SFP in Oslo, believes that the concept can be scaled up to create green oases in desert climates that are otherwise hostile to farming. "With 60 hectares of greenhouse production we could match the yearly import of cucumbers, tomatoes, peppers and aubergines to Qatar," he says.

Agriculture uses more than two-thirds of Earth's fresh water.

The company is working with the government of Jordan to set up a 20-hectare pilot facility, including a commercial greenhouse unit and a research and innovation centre, in Aqaba. A larger commercial facility, says Hauge, would be able to produce excess electricity that could be exported to the grid.

The concept might work in any dry and sunny location that is near sea level, and therefore has low pumping costs. Even so, saltwater greenhouses remain an experiment for now, says Nina Fedoroff, director of the Center for Desert Agriculture at KAUST. "The concept is intriguing," she says. "But it is still a rather pricey way of producing food that might not gain huge commercial traction."

A fog collector in the hills above Lima, Peru.

MARIANA BAZO/REUTERS/CORBIS

FOG HARVESTING

For as long as people can remember, women in the small mountain village of Tojquia, Guatemala, have had to trek down to the valley bottom during the dry winter months and haul fresh water back uphill to their families. But now they can get their water by wringing moisture from the fog that often envelops their community.

One cubic metre of fog can contain up to 0.5 grams of liquid water, and harvesting it is relatively easy. A large vertical mesh panel can collect water droplets as the wind pushes clouds of moisture through its fibres. Tiny at first, the droplets coalesce and grow, then run into a gutter at the bottom and into a storage tank.

At 3,300 metres above sea level, where winters are windy and dry but often foggy, Tojquia is an ideal site for this technique. With the help of researchers from the non-profit FogQuest project in Kamloops, Canada, the residents of Tojquia have installed 35 collectors since 2006. These produce an average of 6,300 litres of potable water per day — enough for about 30 families during the dry season — and considerably more in the wet season when rainwater, too, is collected in the storage tanks.

Fog collection is catching on in seasonally dry regions that lack other sources of fresh water. The first simple mesh panels were built in the 1960s in the port town of Antofagasta in northern Chile. Today, 35 countries are using the technique, particularly along the Pacific coast of South and Central America, in the Atlas Mountains in Morocco and on the high plateaux of Eritrea and Nepal.

Improvements could come from advanced mesh materials, such as the permeable fibres developed by scientists at the Massachusetts Institute of Technology in Cambridge; when tested in Chile, these collected fog at a rate five times that of conventional mesh. And in the Namib Desert in Namibia, three-dimensional meshes developed at the Institute of Textile Technology and Process Engineering in Denkendorf, Germany, have achieved up to three times higher water yields than normal meshes.

Even with those kinds of gains, fog harvesting will not solve Chile's — or any other country's — water shortages. But it can provide a simple and sustainable method of producing fresh water in semi-arid regions that are short of other options, says Otto Klemm, a climatologist at the University of Münster in Germany.

"If the climatic conditions are right — and, importantly, if local people are trained to independently maintain the facilities," he says, "it does have the potential of supplying rural communities with precious fresh water year-round." ■

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