The Clean Water Crisis

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1. ***Clean water is precious.*** We use it to drink, to wash ourselves and everything else, for sport, leisure and water "features" in gardens, parks and public spaces, to irrigate our crops, to water (and feed) our livestock and pets, to turn turbines that make our electricity, to drill mines, to cool industrial machines, and to keep our ecosystems healthy which keeps our planet alive.

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Global population tripled in the 20th century. During that time our water use *per capita* doubled, which means our global water use increased by six-fold. It also means our fresh water is becoming "tapped out." Fresh water resources no longer suffice for our needs: there is a fresh water crisis.

In addition to a physical insufficiency of fresh water in many low-income communities, logistical problems of water distribution compound the scarcity problem. Communities struggle share limited water resources and/or travel significant distances to access it. In both cases, water has to be physically carried from the source to where it is needed. This heavy work falls mostly to women and children. It takes up time that could otherwise be spent in school, caring for family members, or in work that could provide food or income to the family.

Another crucial issue is the inadequate treatment of waste and wastewater in many places which pollute many fresh water sources. Since wastewater contains human pathogens, contaminated water supplies are sources of infections. About 80% of wastewater returns to the environment without adequate treatment, and about two million tons of human waste are disposed of in water courses every day. As a consequence, one-third of all rivers are polluted with pathogens. The United Nations University Institute for Water, Environment, and Health (Guppy and Anderson, 2017) estimates that 1.8 billion people, almost 25% of humans, drink water from a source contaminated with feces. The World Health Organization estimates that 485,000 people – mostly children – die each year because of drinking water that contained diarrhea-causing pathogens.

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2. ***The Role of Microbes in Water We Drink***. Common thought tells us that combining drinking water and microorganisms is always unthinkable, but modern research has forced us to rethink that assumption. Fresh water and microbes have many wide-ranging relationships that are neither simple nor fixed. Today and in the future, our elected officials, business leaders, and general populace must become microbiologically literate to make informed decisions and establish goals that will protect our planet's water so that it is safe and available to all of earth's human inhabitants and its ecosystems. A good place to start looking at the complicated relationships between microbes and fresh water is in the water we drink.

Of course, we do not want water-borne pathogens like diarrhea, cholera, dysentery, typhoid, or polio in our drinking water. A child dies every two minutes because of a water-related disease, and many more children become stricken with water-borne diseases that keeps them out of school. Childhood illnesses can inhibit a child's ability to get adequate nutrition from the food they eat. They become undernourished; their ability to grow and learn is impaired.

But most microorganisms in water are not pathogenic. Beneficial microorganisms in the soil clean water as it travels down into the aquifer where it can be tapped by wells and become drinking water. The microbes can work independently or in biofilms to break apart and digest organic materials, *including harmful microbes*. Soil microbes carry out beneficial processes: decomposition, nutrient recycling and cleaning the water that is infiltrating into the aquifer.

As our understanding of the microbial world increases, we find more instances of water-borne microbes that could protect us. For example, when parasitic roundworms are ingested from unsafe food or water, they can cause abdominal pain and diarrhea in humans and other animals, especially our livestock. But recently, a bacterial species was discovered that eats roundworms, from the inside out, killing them in hours. As roundworms becoming increasingly drug-resistant, these *Chryseobacterium nematophagum* or "golden death" bacteria might be used in the future to treat roundworm

3. ***The Role of Microbes in Chemical Pollution of Water.*** Water scarcity can also be caused or worsened by chemical pollution of freshwater sources like rivers lakes, or underground aquifers, by industrial chemicals, like agrochemicals, or natural pollutants, like arsenic and heavy metals. Scientists are actively researching beneficial bacteria to help cleanup many types of industrial and agricultural pollutants (Kovner, 2019). Bacteria have been discovered that break down agricultural pesticides and herbicides that find their way into our fresh water sources, by way of runoff from contaminated soil (Javaid, 2016). Microbes have also been isolated that can break down many pollutants from industries as well, including some that can clean oil spills ~~(Thomasy, 2019).~~ And, although heavy metals and metalloids cannot be eliminated by degradation, they can be modified and rendered less soluble in water, and thus less available (bioavailable) and thereby less toxic to life.

Fracking is the controversial process of drilling into shale to retrieve natural gas that is held in the rock. To drill a fracking well, 1.5 to 16 million gallons of water mixed with harsh salts and industrial chemicals are injected into the rock, causing fractures that release the gas to flow and be collected. Once the well is flowing, the water is brought back up. The water contains a mixture of hydrocarbons and chemicals. Currently, less than 1% of the billions of gallons used in the fracking process can be reused. However, scientists are now finding bacteria that can break down these chemicals and may ultimately be used to develop processes to reclaim this toxic water.

Today, when 40% of our global population experiences water scarcity, we can ill afford to pollute our precious water resources. However, by understanding how microbes can be used to reclaim polluted waters, we will be able to recover some of it.

4. ***The Role of Microbes as Biosensors.*** Water pollution can be difficult to spot. Bad smells, dirt, or feces are obvious. But we cannot easily detect the existence of pathogens, pesticides, hydrocarbons, heavy metals like lead or mercury, hormones, PCBs, dioxins, or antibiotics in water. In many cases, water should be tested to see if expected pollutants exist in the water. Sometimes, as in the case of waste water from fracking wells, the water must be first analyzed to determine exactly what is polluting it.

Pollutants are chemicals, so are traditionally measured by chemical analysis. However, as mentioned above, sometimes the total amount of a pollutant is not a measure of its hazard, because some pollutants are poorly soluble in water and hence have a low bioavailability. So the hazard level of a pollutant is determined by its bioavailability.

How to measure the bioavailable amount of a pollutant in a sample? Obviously using a biological test system: a biosensor. Many types of biosensor have been developed , and the least expensive and most robust is usually a whole-cell biosensor, consisting of bacteria or fungi that recognize and bind the pollutant, and as a consequence, produce a signal – a visible effect like bioluminescence or a chemical or electrical response that can be amplified and displayed – whose strength is proportional to the concentration of the bioavailable fraction of the pollutant. This is similar to the cell receptors in your nose that react to scents and then create a chemical response that triggers an electrical response along nerves to the brain.

Of course, chemical analysis is also very important in the measurement of pollutants in water samples to determine the scope of pollution and/or if remediation has been successful. But these lab technologies often require expensive equipment, pre-treatment of samples, trained personnel and time. These resources are generally not available in developing nations, rural locations, or when time-sensitive pollution events occur. However, biosensors that rely on microbes are being developed that can quickly and inexpensively identify and/or measure pollutants.

5. *The Role of Microbes in Water Scarcity due to Drought or Desertification.* Drylands, which cover approximately 38% of earth's land area, are home to approximately 2.7 billion people (Harrison, 2020) These areas can potentially lose more water to evaporation and transpiration than they receive in precipitation, and therefore are particularly susceptible to land degradation which results in the loss of soil quality, vegetation, water resources or wildlife. Human activities such as deforestation, overgrazing and poor irrigation contribute significantly to land degradation and can lead to desertification. The land becomes unreliable for subsistence or commercial farming. Approximately 12 million hectares (30 million acres) of productive land is lost to desertification and drought each year.

As climate changes and land becomes degraded, humans are driven to overexploit the land. One example of this is deforestation. Removing trees upsets the microbial ecosystems in the soil that provide nutrients and hold the soil together. Top soil can be blown or washed away leaving infertile lands. Rainfall patterns destabilize in the deforested lands and the lands surrounding them. Invasive plant species that are not suitable to grazing livestock can move in. Humans are displaced. Ecosystems and biodiversity suffer.

Re-planting trees in these degraded lands may contribute to the solution for cooling off a hot planet, increasing rainfall, reducing flooding, and making more water available (Evans, 2017) (Vidal, 2018). The tree-planting business is booming (Faruqi, 2019). But trees will not grow in dead soil. One teaspoon of *healthy* soil contains more microorganisms than there are people on earth. In order to reclaim degraded ecosystems, soils need microorganisms.

Mycorrhizal fungi in the soil extend the capabilities of plant roots to access water and nutrients from the soil. But mycorrhizal fungi are not one-size-fits-all. They are plant- and site-specific. The fungi must interact with bacteria in the soil to create a plant root microbiome which provides a range of services to the plant. Fungi and bacteria also colonize the above-ground parts of plants – stems, leavers, flowers, etc. – and contribute to plant health. Communities that invest in any tree-planting activities must become microbiologically literate so that they understand the microbial world's essential and complex contribution to tree health and healthy communities. Entrepreneurs who want to remediate the land degradation must incorporate microbes. Community members must be careful to choose businesses that understand how the microbial is interwoven with plants, minerals, and water. Buyer beware. Be microbe aware.

6. *Conclusion.* Everyone deserves to drink water that is not polluted and easily accessed. But today children and families in developing nations die every day from illnesses caused by pathogenic, water-borne microbes. Many more children are disadvantaged by water-borne pathogens in their drinking water that cause illnesses resulting in missed school days or diminished mental or physical growth due to malnourishment. Scientists, governments, and community members working together can find solutions that can provide simple sanitation and easily accessible, safe drinking water for all. In order to understand and implement new technologies, officials and community members must understand basic microbiology principals.

One of these important microbiology principals is that most microorganisms are beneficial and can help us solve many of our fresh water problems. Working together, communities, research facilities, businesses, and governments, we must determine if or how we can use microbes to help us exploit technologies that use microbes to

- provide sanitation facilities to the billions of people who need them.
- clean feces and remove fertilizer from fresh water sources to make it clean enough to drink.
- kill parasites like roundworms.
- create bioreactors that identify and remove toxins from waters polluted by industries, including fracking.
- reclaim lands that have succumbed to drought and desertification by bringing the soil back with microbial life.

Scientists cannot create technologies, market them, and administer them alone. Technologies developed in laboratories must interface with the public. Top-down solutions rarely solve problems. The people who use new technology must be brought in during the earliest stages of design and implementation, in order for a community to accept and use innovations. These community members cannot make wise choices unless they are microbiologically literate. We cannot afford to have business leaders, politicians, and users who do not understand the implications and ramifications of possible solutions presented by scientists. We need a world that is microbiologically literate.

The Evidence Base, Further Reading and Teaching Aids

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