WATER WELL

A RESOURCE ON CLEAN WATER FOR LOCAL COMMUNITIES

EDEN CHUNG

Water Well :
a resource on clean drinking water
for local communities

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Acknowledgements

This resource book developed from an initial curiosity of why a school community in Sierra Leone kept facing chronic diarrhea each year, season after season. Figuring out an answer to one question led me to ask another and before long I had an extensive body of research about clean drinking water. I hope that presenting this knowledge in a guide will allow local communities to understand water issues better and to know that solutions exist which could be self- implemented to improve and accelerate access to clean drinking water, while also suggesting actions that everyone can take to make a contribution to the issue of water scarcity.

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- Arthur Vincent, headmaster of Global Outreach School, Masantigie, Sierra Leone

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Introduction

This publication is intended to be an educational research guide for households and communities to learn about drinking water and how to improve access to clean water locally. Globally, one in three people do not have access to safe drinking water, with 2.2 billion lacking safely managed drinking water services, according to UNICEF/ WHO, and this situation is widespread. Accessible safe drinking water is a problem on every continent, in both developed and developing countries.

The water crisis is often talked about in general and global terms, but the aspects of accessing clean water are location specific. Depending on the location, different places have different water situations: how close they are to a source of freshwater, how clean their source of water is, what contaminants are in their waters, how they treat and transport their water, and so on. Lack of clean water may have varying consequences in health, economics, or even gender equality from one city to another. The current model of a centralized system with piped infrastructure might not be the best solution for the whole planet. In fact, projections show that if developing countries need to rely solely on government projects providing boreholes, pumps, and piped networks, it could take more than 100 years to provide clean water for their citizens.

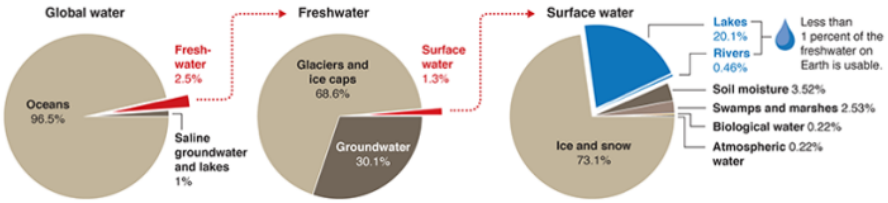
Small communities and households can act faster than governments, knowing best what their specific needs. According to the August 2021 report from the Intergovernmental Panel on Climate, we can still act to negate climate change, but it must happen immediately. Rather than depending on and waiting for governments to help, communities can find their own decentralized solutions at a human scale, tailored for a village cluster, a household, or even to a single water appliance, giving them clean drinking water, sanitation, better health, and empowerment to have a say in their own futures, sooner.

This guide aims to introduce the current global drinking water situation, what causes unclean drinking water, methods of treatment or filtration, new technologies, and other concrete actions one can take. We hope that by adding up many small gestures, made by individuals and communities, we may start to make some big collective impacts.

Chapter 1

Current Water Situation

Water is vital to life and connects every part of our existence. Water is the most abundant molecule in cells, making up around 70% of total cell mass. About 60% of our bodies are water. 71% of our planet's surface is covered by water. Since water is everywhere, many often assume there is a large supply of it, so drinking water is not at the top of everyone's list of priorities. Water is not an unlimited resource, however. Although 72% of the Earth is covered in water, 97% of this is salt water in oceans and seas, 2% of the remaining freshwater is frozen, leaving about 1% for everyone to drink.



Infographic from http://www.kidsdiscover.com/infographics/infographic-water-cycle-for-kids/

Water impacts our well-being, our economic situations, health, hunger, energy and our environment. For example, many processes making up life on Earth require liquid water to function. Water also provides a natural environment for life due to its properties such as heat conduction, dissolution properties, surface tension, transparency, and high boiling and melting points. When scientists look for signs of life on other planets or elsewhere in the solar system, they look for evidence of water.

Some may think that we are only on the edge of reaching a water crisis, or that it may affect only some less developed countries, but in fact the available clean water supply has been decreasing; shortages exist on all continents. A water crisis is already happening.

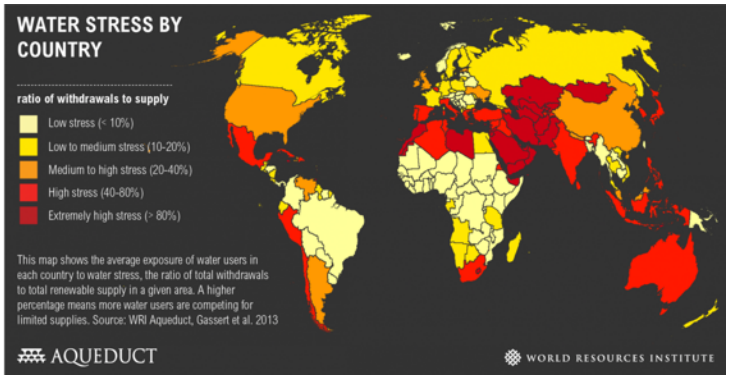
It's not true anymore that the developing world is not affected by water shortage or water quality concerns at the tap. Take California, for example, one of the most developed and wealthy states in the world, is facing a water

crisis. Even Switzerland is facing droughts or water contamination of aquifers due to agricultural / industrial activities in some regions. "We cannot split the world in two anymore when it comes to water challenges that are occurring now or tomorrow," says Ramzi Bouzerda, CEO of Droople.

In the 1970's it was estimated that more than 70 percent of the global rural population lacked access to safe water. 10 years later, in the 1980's, the United Nations initiated the UN International Drinking Water Supply and Sanitation Decade as the first real global effort to serve the world's population in accessing local water services.

Since then, a lot of progress has been made, however, major challenges still stand in the way. Each day about 1,500 children under the age of 5 die from diarrheal disease, mainly related to their access to clean water, hygiene and sanitation. Nearly two-thirds of a billion people do not have access to any improved or engineered water point within a 30-minute round-trip from their home. The model of large, complicated infrastructure water projects cannot just be scaled down for rural communities in developing countries. There are many differences between regions in terms of their water sources, needs and ability to adopt advances in technologies.

One of the most important issues today is how to sustainably use and share clean water equally.



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Water Scarcity: What is It and What Causes It?

Water security, the ability of a population to access enough acceptable water, is a risk for people already, affecting more than 40% of the world's population, and will continue to worsen in the coming decades. It has been estimated that by 2040, the global demand for freshwater will exceed the available supply and by 2050, one in four people will be suffering from water shortages.

Water scarcity is caused not only by the diminishing quantity of water available, but also by the continual decline of water quality. There are several main factors contributors to water scarcity:

Population growth: the global population is growing at a fast rate and estimated to grow to around 10 billion by 2050. This increase in population means more and more people are drawing from the same limited water resources. The rate of population growth differs depending on the area, but those with high rates of population growth will suffer the most stress on water sources. Developing countries like Africa and Asia are expected to have the highest rates of growth, where clean water access is already a significant issue.

Urban development: people are increasingly moving from rural areas to urban centers, increasing the strain on the limited capacity of existing water systems in those cities.

As an example, in China from 1978 to 2010, the urban population in cities increased from 18% to 50% of the total population, causing serious stresses on the major urban areas. Two-thirds of China's 661 cities suffer from shortage of water supply, with 110 of them suffering from extreme shortages. The water allocation per person in the North China Plain, where many of the major cities lie, is one-fifteenth of the world average, well below measures of water-scarcity. Annual precipitation has also declined there, while the increase in urban construction is taking over natural land, destroying ecosystems and freshwater contributors, so limited water resources are stressed to extremes.

Migration into cities also means that rural areas end up left behind, as essential water services will likely focus on urban areas which are easier to access and serve.

Water Pollution: as more humans use water and go about their daily lives, our water sources are becoming increasingly polluted. Multiple human-made substances can contaminate our waters, such as manufacturing waste, chemicals, personal care products and drugs, pesticides, fertilizers, dyes and paints, and human waste. Every day, 2 million tons of sewage drain into our water supplies, 300 megatons of waste from industry are discharged into water bodies each year, and 13 million tons of plastic end up in our oceans each year.

Agriculture: Agriculture makes use of an incredible 70% of the world's available freshwater, in some countries using up to 95% of their water resources. While water is a necessity for agricultural production and securing enough food to feed the growing population, requiring more food puts additional pressure on water supply and quality, reducing the amount of clean drinking water available. Although an individual only needs to drink about 2 litres of water a day to stay healthy, the food an individual consumes per day requires up to 5,000 litres of water to produce.

At the same time, agriculture is one of the areas most affected by water scarcity, where climatic weather extremes like droughts, floods and rising temperatures can significantly decrease the amount of crops grown and thereby impact our ecosystems, forests, lakes and wetlands, on which agriculture depends.

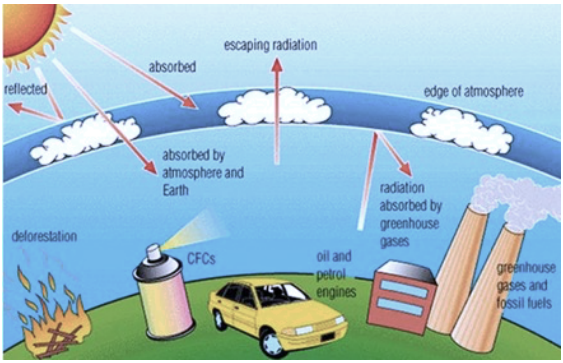
Infrastructure: much of developed countries' water infrastructure is aging and failing, with some countries still using pipes from the 1800's. Burst pipes, leaks, and lead content in old pipes are several problems arising from the aging infrastructure. The systems are also highly complicated, having to transport and treat the water for consumption beforehand, and then transport and treat the sewage water afterwards in large, centralized engineering projects. High costs and lack of funding are barriers to replacement. In the United States, an estimated $300 billion will need to be

spent by local governments to upgrade water and sewage pipes in the coming decade.

Climate Change is a Water Story

Climate change is closely linked to water issues. For example, many impacts of climate change are related to water. As global warming increases, changes in the water cycle cause droughts, melting glaciers, sea-level rise, storms and floods, becoming more extreme and posing serious risks to the environment and to human life. Climate change also has direct impacts on water scarcity.

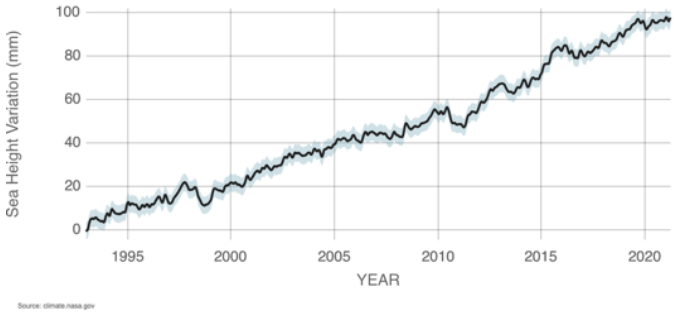
Climate change is a change in regular weather patterns of a location over an extended period, usually regarding temperature and precipitation. These changes are mainly caused by human activities which release greenhouse gases such as carbon dioxide, methane or chlorofluorocarbons, nitrous oxide, and ozone, increasing the greenhouse effect. When the sun's rays enter the Earth's atmosphere, the rays are reflected off Earth's surface; some rays reflect into space, whereas others are trapped by the atmosphere, caused by the greenhouse effect. The increase in greenhouse gases causes more rays to be trapped in the atmosphere rather than reflected into space, heating up our Earth.



The Greenhouse Effect
Source: UN IPCC

Temperature increases have direct impacts on water

Glaciers and snow caps are melting, and seawater expands as it warms. Both contribute to the rise of the global sea level, which has increased 24 cm since 1880, with an accelerated rate of increase particularly in the last 25 years, and is predicted to rise another 50 cm by 2100. This will cause the salinization of coastal aquifers, further decreasing the Earth's supply of drinking water. Freshwater from glaciers and snow will decline over the next 100 years, which will decrease the amount of water available during dry seasons in regions where water is supplied by melting water from mountain ranges, affecting 1/6 of the world's population. This has been observed in some cities along the Andies in South America for example.



Satellite sea level observations

The rise in water temperatures also affects water pollution, with increased sediments, nutrients, dissolved organic carbon, pathogens, and pesticides entering or surviving better in the warmer water. Oxygen concentrations in the water decrease and phosphorus release increase. This will impact ecosystems, human health and water networks. Higher water temperatures promote algal blooms which will affect both ecosystems and human health. A recent study by the Swiss Federal Institute of Aquatic Science and Technology (EAWAG) and the Swiss Federal Institute of Technology in Lausanne (EPFL) shows that viruses in warmer conditions could be less resistant to disinfection, increasing the spread of viruses and making them harder to treat.

Droughts impact around 55 million people each year, and are expected to be more prevalent, especially in the US and southern Canada, Africa, and the Middle East. Drinking water will become ever scarcer while water quality will also be negatively affected. In addition, high population centers will be stretched and stressed from migration of people seeking to escape habitually drought-stricken areas while agricultural areas will require increased supply of pumped ground water for irrigation. Finally, droughts and heatwaves will continue to increase the risk of wildfires.

Floods and heavy downpours have also been increasing and cause the spreading of fecal matter, pathogens and viruses (such as E. coli, Salmonella, and Shigella) when sewers and wastewater facilities become overloaded and flood. Mr. Arthur Vincent, headmaster of the Global Outreach School in Sierra Leone, recounts that about half of the 450 students at his school are affected by diarrhea during the year, particularly during dry season, when low water levels result in higher concentrations of pollutants in drinking water, and at the beginning of rainy season when pathogens are washed into the drinking water source.

The WHO predicts that between 2030 and 2050, climate change will cause 250,000 more deaths per year from malaria, diarrhea, malnutrition, and heatwaves, which are all directly linked with the supply of clean water.

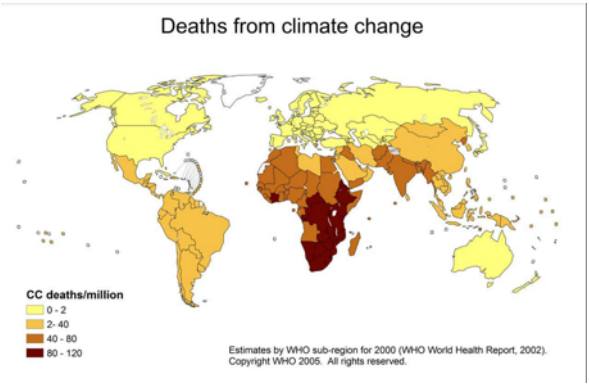


Table reprinted with permission World Health Organization
https://www.who.int/heli/risks/climate/climatechange/en/

Access to Water: A Fundamental Human Right

Access to water is recognized as a fundamental human right by the United Nations. While people are the rights-holders, states are the duty-bearers to provide this right. Essentially, everyone has the right to have access to sufficient, safe, acceptable, physically accessible, and affordable water for personal and domestic use, as defined by the UN.

In 2015, the United Nations created the 17 Sustainable Development Goals (SDGs) as a shared action plan aiming to end poverty, protect the planet and provide peace and prosperity for all by 2030. Part of this plan to achieve a better future is the call for universal access to clean water: SDG 6 aims to attain safe and affordable drinking water for all. While the 17 SDGs are very interlinked, there are several that are particularly related to, or affected by, drinking water issues.

- No poverty: Goal 1
- Good health and well-being: Goal 3
- Quality education: Goal 4
- Gender equality: Goal 5
- Access to water and sanitation for all: Goal 6
- Climate action: Goal 13
- Life Below Water: Goal 14

To reach the UN goals for 2030, the UN has created more specific global targets for Goal 6 - Clean Water and Sanitation including:

- Achieve universal and equitable access to safe and affordable drinking water for all.

- Achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations.

- Improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally

- Substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity.

- Protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes

- Expand international cooperation and capacity-building support to developing countries in water- and sanitation-related activities and programs, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies

- support and strengthen the participation of local communities in improving water and sanitation management

The UN defines safely managed drinking water as having an improved water source located on premises, available when needed, and without fecal contamination. Improved sources include piped water, boreholes, protected dug wells, protected springs, rainwater and packaged or delivered treated water.

Although some progress has been made in reaching the SDGs, we are still not on track to reach the targets by the deadline. For SDG number 6, we must quadruple our current rates of progress to reach the targets for 2030. Still, billions of people lack basic clean drinking water and sanitation. Globally, a third of people do not have access to safe drinking water, almost half lack safely managed sanitation, two fifths of people do not have basic hand-washing facilities and more than 673 million people still practice open defecation. In addition, those living in rural areas have worse levels of water, sanitation and hygiene (altogether known as WASH).

According to Daniella Bostrom, Communications Manager at UN Water, the agency coordinating the UN's work on water and sanitation, the main barrier to progress is coordination. Around the world, government ministries work on water and sanitation issues in different ways. Some countries see water issues as more a matter of environment, some more a matter of health. Coordination makes it difficult to accelerate progress on a global scale.

Ryan Blyth, Global Learning Advisor at the Centre for Affordable Water and Sanitation Technology (CAWST) also agrees coordination across the planet is difficult and has a strong impact on progress, particularly concerning WASH in schools. However, he highlights the example of the Three Star Approach for WASH, designed by UNICEF, as an effective approach to facilitate coordination at a global scale, while allowing local schools to do what they can depending on their situation, to meet three simple criteria: to ensure all students are washing their hands with soap, have access to drinking water and have gender segregated toilets at school each day. These three main actions are prioritized, but the approach also encourages local action without depending on costly equipment or

infrastructure to meet the health goals, keeping actions 'simple, scalable and sustainable.'

There is indeed a long way to go to meet the 2030 SDG goals, but Ms. Bostrom is still optimistic about getting there. She explains there has been a structure produced, called the UN Cooperation Framework, that aims to improve coordination at a country, regional and global level in 162 countries to reach the 2030 goals. Under this framework, many new initiatives have been launched to address key challenges, allowing for contributions to be shaped to a configuration as required inside, and outside of each country. Ms. Bostrom adds that water has gained increased attention on the international agenda, which she hopes will help meet the 2030 goals.

Chapter 2

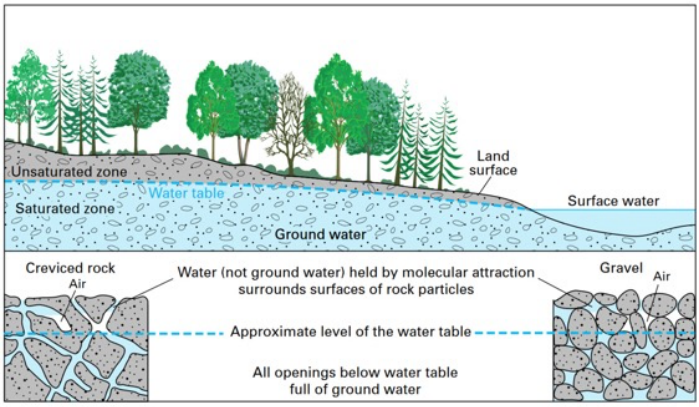
Drinking Water

Drinking Water Sources: Surface and Ground Water

Our drinking water comes from two sources: surface water or groundwater.

Surface water refers to any flowing bodies of water, including lakes, rivers, streams, reservoirs, or ocean and is generally refilled via precipitation. Surface water is more easily accessible than groundwater, but is mostly used for non-drinking water purposes, due to the high levels of contaminants, often accumulated through runoff. Therefore, surface water must go through many stages of treatment and filtration before it is safe to drink.

Groundwater, on the other hand, is a part of the natural water cycle, where water continuously moves within the Earth and the atmosphere. Liquid water flows across land, enters the ground, is absorbed by plants, then evaporated from plants into the atmosphere, starting the cycle again with precipitation. Groundwater is water stored in spaces deep underground in between rock particles, mostly within 0.8 km or less from Earth's surface. We access this water by drilling or digging wells. Groundwater provides most of the drinking water in the US.



How ground water occurs in rocks.
Source: US Geological Survey

Consequences of Drinking Water Scarcity

Health Impact

The human body is made up of 60% water, making it an essential part to our health, helping to regulate our body temperatures, carrying nutrients and oxygen to cells, cushioning the joints, flushing toxins out of organs, and eliminating waste, hydrating skin, among many other jobs. Lack of water can cause dehydration and affect many body functions.

However, not just any water is suitable for the body, as dirty water can lead to life-threatening diseases. Every day, about 1000 children die due to unsafe water, inadequate sanitation or poor hygiene. Water related diseases, caused by unsafe drinking water contaminated with pathogens, bacteria, and viruses are one of the biggest causes of death in children. These diseases include cholera, diarrhea, dysentery, hepatitis, typhoid and polio.

In countries where children and women travel significant distances from their homes in order to collect water, injuries from lifting and carrying the heavy loads of water are sustained. As well, having to walk to access the water means that even if the water was safe at the source, there are greater chances of contaminating the water with fecal residue in the handling, transporting and carrying of the containers.

Environmental Impact

Water scarcity doesn't only affect humans, but also the environment. In order to secure, replenish and purify water, water ecosystems suffer.

First, wetlands have been disappearing at a rapid pace, reducing wildlife habitat and causing the loss of natural water filtration, storm protection and flood control that wetlands usually provide. Throughout the world, wetlands have decreased by 50% since 1900.

Natural bodies of water are contaminated by industry, transport, household use and human waste. The flora and fauna depending on those water sources will also be negatively impacted, disrupting the delicate balances of ecosystems.

The decrease in water resources can also degrade land, making them unusable for certain activities, such as farming.

Economic Impact

In areas where water is not easily accessible, the time and effort spent on collection wastes valuable time which could be used for education or economic opportunities. The drinking of unsafe water also exposes people to illnesses and higher health care costs. Hundreds of millions of people are stuck in a cycle of poverty due to lack of safe drinking water and basic sanitation.

Furthermore, difficulties in sourcing fresh water will increase costs of securing adequate water supply for individuals, farmers and companies or, alternatively, inadequate water supply will cause production and livestock losses in agricultural, threaten farmland, and inflating food costs.

Gender Inequality

In 71% of households in the world, women and girls are responsible for collecting water, and they are usually the most negatively impacted when there is none available. When water is not available near to their homes, they often need to make long journeys to carry water by hand from the closest course. In sub-Saharan Africa, the UN estimates that up to 37% of the population need to walk an average of 5km each day in order to access improved water sources. UNICEF reports that 200 million hours are spent each day by women and girls to collect water, The long journeys to collect water can also be dangerous for females, from a personal safety point of view.

If water becomes more accessible and safe, women will have more time to work and be productive, allowing them to generate income too. Women will also have more time to spend with their families or on childcare or improving their households. Conversely, women who are no longer required to fetch water can become more active in their communities. Evidence shows that with access to clean water, girls have more time for education, allowing them to become equal in knowledge to their male peers. Other evidence has shown that access to clean water can improve agricultural yields, ensuring that women and girls are not forced to forgo meals for the male members of their

households. In general, a household's health improves when there is a safe water source.

Another issue related to water and gender inequality focuses on stigmatized menstruation, as many girls do not have the access to water to properly manage menstruation. Often, schools do not have well designed toilets or facilities to offer privacy and appropriate measures for washing in school, causing many girls to drop out of school when menstruation starts. Clearly, dropping out of school impacts a woman's economic prospects and her future in general. In some areas of the world, women are considered adults once they have their first menstruation and are encouraged to drop out of school in order to marry and start families.

Compacted across a population, this has a large impact on the country as a whole. For example, in India, if water and toilets were more accessible to 1% of girls, the country's GDP would increase more than $5 billion. Individually, every year that a girl stays in school, her income increases by 15-25%. Without the ability to earn their own income, women are left financially dependent on men, extending and reinforcing gender stereotypes. Water plays a key role in lifting girls and women out of the poverty cycle.

Women, an untapped resource, are also often left out of decision-making processes when it comes to water infrastructure, even though they are the ones responsible for the day to day collection and use of water. In an example from Nepal, women were not consulted in the placement of water services, which men had located by the roadside. Women could not bathe or wash their clothes used for menstruation comfortably out of public view, so they ended up carrying water back to their homes several times each day, wasting time and energy.

Studies have shown that when women are involved in the planning of water resources, the projects tend to be maintained better and last longer.

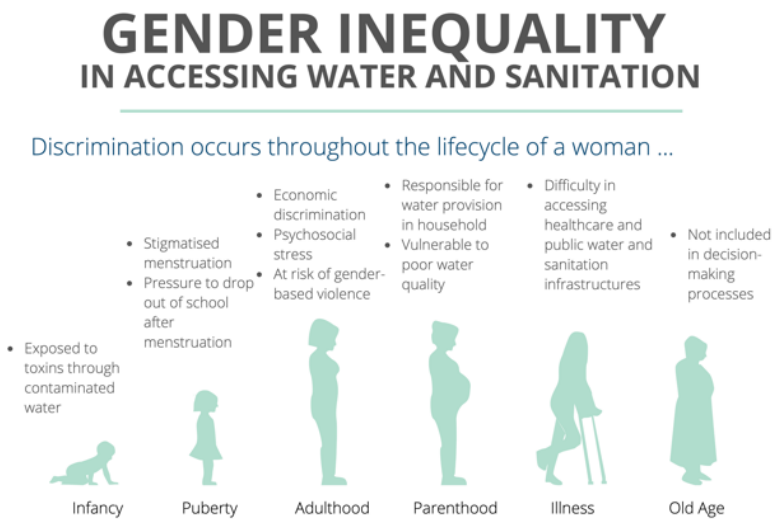


Figure reproduced from Gender Equality and the Human Rights to Water and Sanitation, A report by the special rapporteur on the human rights to water and sanitation, Leo Heller, United Nations Human Rights Office of the High Commissioner.

Water access and the empowerment of women are very closely tied. Equity improves with the improvement of access to water, as well as related fields like agriculture, health, education, and computer technology.

Gender equality relating to the basic survival need for clean water seems should be an urgent aim to enable other equal opportunites for women. For example, equal remuneration for both genders can only apply if women make it to the workforce. Working on keeping girls in school so that they can one day hold jobs needs to be addressed first.

Impact on Children and Education

After women, children are the next in line to collect water for the household. Around the world, children spend 200 million hours a day collecting water, taking time away from their education. In some cases, children miss schooling altogether, having to prioritize water collection for their families. In other cases, they become so sick from water related illnesses that they require hospitalization. Without enough clean drinking water, children can become dehydrated, causing lack of concentration as well as a host of other health problems.

Household WASH has a huge impact on young children; providing handwashing stations and sanitation facilities in primary schools can reduce the amount of days students miss school by reducing cases of diarrhea and other diseases. The provision of sufficient clean drinking water also has been shown to improve children's memories, attention, and cognitive performance.

Chapter 3

Drinking Water and Health

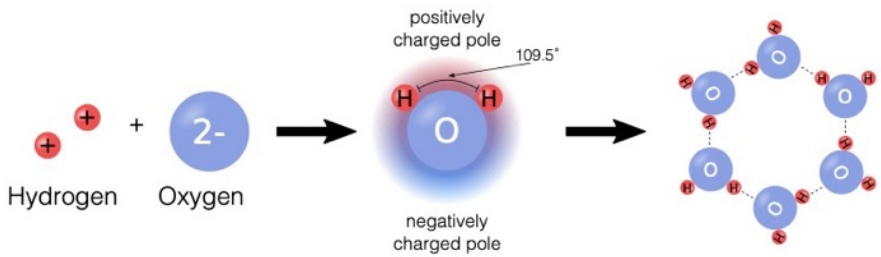
Why is Water Necessary for Life?

Water is the essential ingredient for all life on our planet. At the biological and cellular level, water has unique properties which make it vital to life.

Water at the Molecular Level

A water molecule is made up of two hydrogen atoms, each one linked to a single atom of oxygen, making the chemical formula for water is H_2O. Water is at the liquid state at specific temperature and pressure conditions. Because the hydrogens bind to the oxygen on one side, the water molecule which is asymmetrically charged, positive on one side and negative on the other.

This polar charge allows water to form strong bonds with other polar molecules including itself, which in turn, creates the capability for water to dissolve more substances than any other liquid. Therefore, water is considered a "Universal Solvent". In this role, water can support life by helping cells to move and aiding the intake of substances, such as oxygen, nutrients, or medicines into the body.



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Why Do Our Bodies Need Water?

Growth and Development

Not having access to safe drinking water can create an endless cycle of poor health, stunting growth and development of children especially. Proportionately to their body weight, children have much higher requirements for water than adults. If the daily intake of water is not achieved, it can cause dehydration, which may lead to permanent physical or mental damage. A loss of 15% of total body water can cause death.

Repeated infections from unsafe water, or poor sanitation and hygiene, could lead to intestinal damage, and nutrients absorbed less effectively by the body. Less nutrients could also mean malnutrition, stunting physical growth and brain development. A body weak from lack of water is also more susceptible to other infections, repeating the cycle and leaving long-term effects on child health and development.

Removing Waste from our Blood

Water is essential for our kidneys to function, as they remove waste that enters the body from foods and drink, then pass it through to our blood, then finally dispose of it as urine. The kidneys regulate total body water and its concentration. Water will also help to keep the blood vessels open for easy traveling of blood to the kidneys.

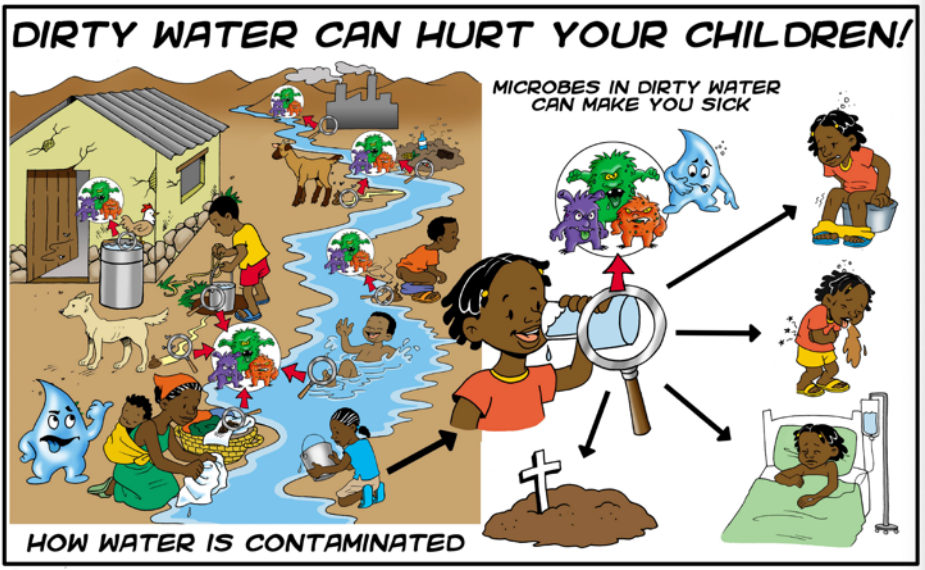
Dehydration from lack of water will impact the kidney's ability to dispose of waste from our bodies.

Other Functions of Water in the Body

- Your blood, muscles, lungs, heart and brain are composed mainly of water.
- Water helps to regulate your body temperature through sweating and respiration, particularly in hot environments and when doing sport.
- Water helps create saliva, which is necessary to break down the foods you eat. Drinking water regularly is essential to producing enough saliva, and also to helping you to digest food easier.

Water contaminants

Water contaminants refer to any substances present in water that are not water molecules (H_2O). They can either be naturally occurring or man-made. Water almost always contains a degree of contaminants, although some may be harmless to the body, unless present at higher concentrations, and some which can cause disease. Harmful contaminants cause either acute effects or chronic effects; acute effects are harmful effects that occur within a short time of exposure, so within a few hours or days, whereas chronic effects are harmful effects that occur after long term exposure, which could be several years. Some examples of chronic effects are kidney or liver problems, cancers, or reproductive issues.



Source: Center for Affordable Water and Sanitation Technology (CAWST), 2006
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Generally, water contaminants can be categorized into 5 categories:

1. Pathogens
2. Toxic minerals and metals
3. Organic chemicals
4. Radioactive substances
5. Additives

Pathogens

There are 4 general categories of pathogens: protozoa, bacteria, viruses, and helminths (parasitic worms).

Protozoa are single cell organisms usually measuring between 1-15 microns. One single protozoa cell can cause an infection.

Bacteria are single cell organisms, between 0.2 and 5 microns. They reproduce quickly in warm environments and water.

Viruses are extremely small at 0.02-2 microns in size. They must exist in a host body because they do not have their own metabolism; therefore, propagation must occur in living cells.

Finally, **helminths** are invertebrates with either long, flat, or round bodies, measuring between less than 1 mm to over 1 m. They survive by feeding on a host, which may cause the host to become ill. In contrast to the other 3 pathogens, helminths develop through egg, larvae and adult stages.

Within each of these categories of pathogens, there are many water-related diseases, with many causing diarrhea, which is the 2nd leading cause of death in children under 5 years old, with almost 2200 children dying everyday of diarrhea. Diarrhea causes death by leaving the patient extremely dehydrated. In addition, diarrhea can affect childhood growth and cognitive development.

Often, these diseases are spread through fecal matter. In a model developed by Stanford, NC University, and Tufts professors, the seven pathways to fecal ingestion are:

1. Hand-to-mouth contact with the individual's hands
2. Hand-to-mouth contact with others' hands (such as caregivers)
3. Object-to-mouth contact
4. Food
5. Water
6. Soil ingestion
7. Direct feces ingestion

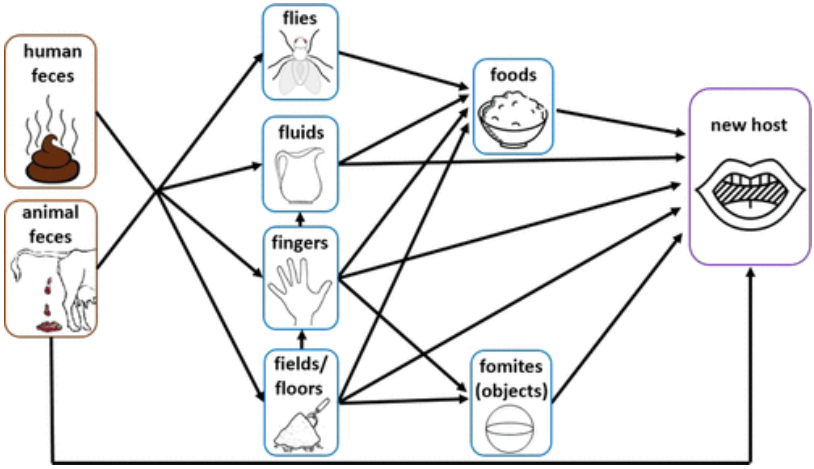


Image reprinted with permission "Figure Pathways of exposure to fecal contamination (from Wagner, E. G.; Lanoix, J. N. Excreta Disposal for Rural Areas and Small Communities; Monograph Series 39; World Health Organization: Geneva, Switzerland, 1958 https://pubs.acs.org/doi/10.1021/acs.est.0c02606."

Salmonella

Salmonella is a bacteria found throughout the world for over 100 years, and can be found in both hot and cold climates. Salmonella occurs when water has been contaminated with feces of infected humans or animals, which usually occurs through sewage overflows, sewage systems not working properly, storm water runoff or agricultural runoff. It can also enter the body by eating undercooked eggs or poultry. In water, it is odorless and colorless, so water supplies should be regularly tested.

Chapter 4

Actions for the Global Problem

Chapter 5

Local Solutions: Sourcing Drinking Water

For significant progress to be made to solve the water crisis, along with gender inequality and social and economic consequences, other approaches need to be developed, which includes promoting natural infrastructure and developing new technologies. Rather than solely depending on governments to help with infrastructure, the global community can also become engaged.

In academia, there has been discussion on a more human-centric model for water, which can leapfrog expensive and complicated infrastructure projects. Different areas can have different water situations, depending on how close they are to a source of freshwater, how clean their source of water is, what particular contaminants are in their waters, or how they transport their water. Solutions could be tailored to the scale of a city, a village cluster, and even to a single household, while enhancing naturally occurring infrastructures to create great efficiencies.

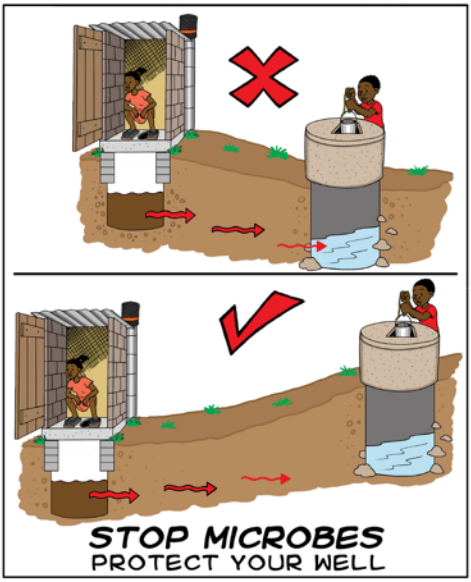
While the solutions governments are looking at are beyond what a small community or family might be able to do for themselves, there are other ways communities can improve both their water situation and sanitation at a local scale giving them better health and ultimately brighter futures sooner.

This chapter addresses ways to source water locally if a municipally provided source of drinking water (within a reasonable distance) is unavailable.

Drilled wells, or boreholes, are the last type of well and require specific equipment to drill deep into the ground, even through rock. These are made by rotary-drilling machines and can reach 300 meters in depth. A pump is often used in conjunction with boreholes to bring the water up to the surface. Drilling and finishing a borehole should be done by well trained, and experienced professionals.

Wells should be carefully located away from possible sources of contamination. The Centers for Disease Control and Prevention recommend keeping the following minimum distances:

- Septic Tanks, 50 feet (15.24 meters) from well
- Livestock yards, Silos, Septic Leach Fields, 50 feet (15.24 meters) from well
- Petroleum Tanks, Liquid-Tight Manure Storage and Fertilizer Storage and Handling, 100 feet (30.48 meters) from well
- Manure Stacks, 250 feet (76.2 meters) from well

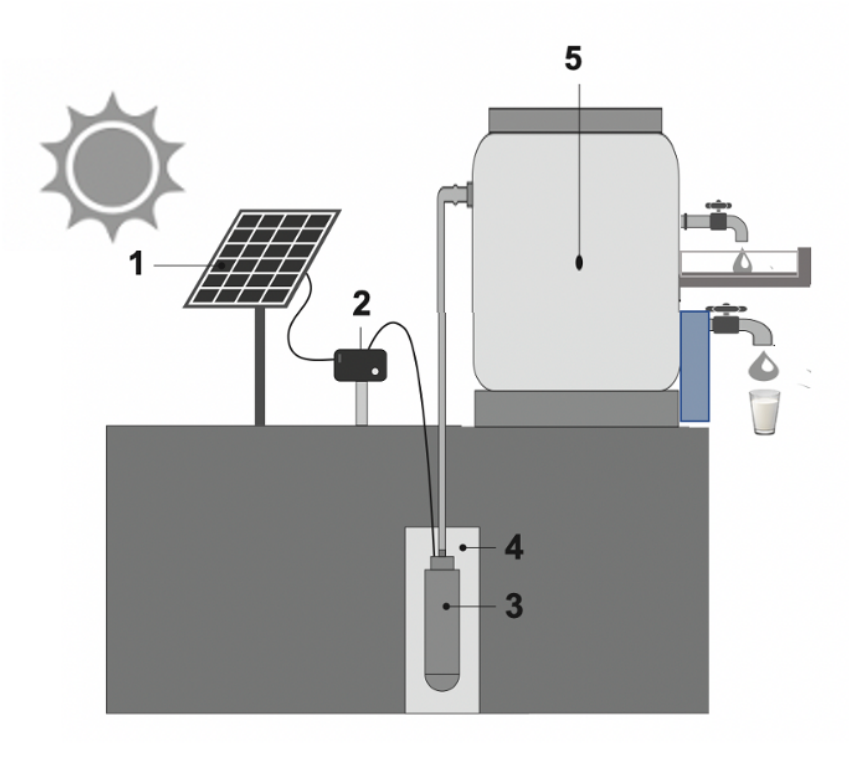


Source: Center for Affordable Water and Sanitation Technology (CAWST), 2011, licensed under CC BY-SA 4.0

Pumps

Water can be lifted from hand-dug wells by a rope attached to vessels such as buckets or modified jerrycans, but this can often contaminate the water (dirty vessels), and by design, for a bucket to be able to enter the well, the hole must be open to a certain extent, allowing debris, insects, rodents or other animals to also get into the well. In addition, with wells more than 25-35 meters in depth, hand lifting water up to the surface is quite difficult.

A hand pump is a pump that uses human strength to draw water to the surface. Hand pumps can be used in all three types of wells above using different mechanisms appropriate to varying depths from 7 meters to 45 meters or more. They are easy to install, simple to use, and can lift good amounts of water reliably up to about 80 meters of depth. They are also one of the cheaper pump types, with many low-cost models available. In addition, they are safer than bucket lifting as the well is sealed. Across the world they are widely used, particularly in rural areas; it is estimated that around a million hand pumps are in operation and about 100,000 new ones installed each year. They are considered the minimum infrastructure needed to provide basic water supply services.



1. Solar Photo voltaic panels
2. Controller
3. Submerged Pump
4. Well Borehole
5. Water storage tank

Example of a Solar Pump Water Installation

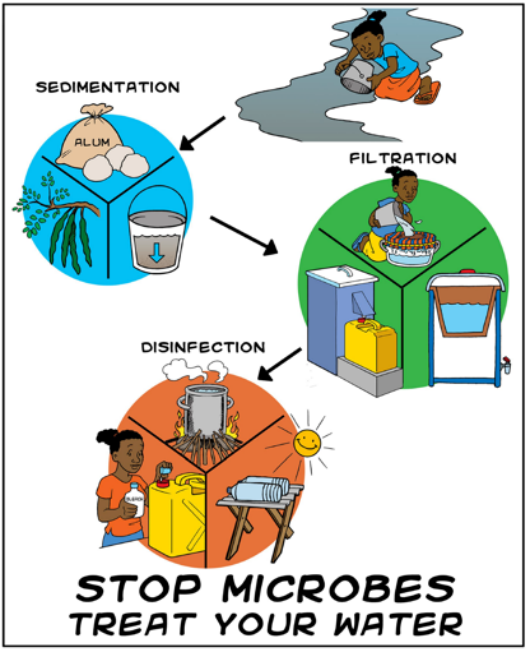
Chapter 6

Local Solutions: Treatment of Drinking Water

Household Solutions for Water Filtration and Treatment

In this section, some **household** treatment of drinking water solutions will be outlined. Using these household treatment methods will have direct and immediate effects on the health of the users and allow greater productivity due to better health.

Ideally, two or more treatment methods should be combined, to increase the efficacy. This should include a prevention system, reducing the contaminants entering water, followed by a treatment system, removing the contaminants present in water.



Source: Center for Affordable Water and Sanitation Technology (CAWST), licensed under CC BY-SA 4.0

Chapter 7

New Technologies

Technology will have a critical impact on freshwater supply and demand in the coming years. There are two ways technology can be used: technology in the physical infrastructure of accessing water, and technology to monitor the use of the infrastructure (using computer science and information technology).

UV LED filtration

Natural ultraviolet (UV) light, as discussed in the previous chapter, is a method of purifying water that has been used for centuries. However, a new product, called the UV LED light, uses UV's capability for purification in a new way. UV LED uses UV water disinfection systems through light-emitting diodes. These systems are extremely efficient at killing pathogens and microorganisms found in water.

Chemical treatment, in general, is the most used method of disinfecting water. Although there are many benefits of these treatments, some chemicals can harm the environment and the body with repeated and long-term exposure. Conventional UV lamps offer a good alternative to chemical -free treatment, however, they normally contain mercury, which itself is highly toxic. The new UV LED technology does not contain mercury, therefore considered one of the most eco-friendly, convenient, and effective solutions for water filtration.

Currently, UV LED lamps are mainly installed at the point of use (for household treatment), which can serve one or two taps. The devices are small so they can be installed in many locations, without the need for storage tanks. Their low energy consumption allows them to be powered with a small solar panel or battery, and means the lamps will not transfer heat to the water. Some point of entry models are already on the market which can be used to serve multiple outlets, but UV LED for more commercial or larger installations is still in development.

Two main producers of UV LED lamps are Pelican Water and Aquisense.

Harvesting atmospheric water

As seen in previous sections, there are many methods to harvest water such as ground water harvesting, rainwater collection and storage, and water desalination. However, these systems require liquid water sources to be available. Water scarcity, exacerbated by climate change and extreme changes in rainfall patterns, are creating periods of prolonged droughts in certain areas. Therefore, treatment devices will not help when there is no available water to filter. Currently, around 4 billion people experience water scarcity at least one month each year.

One solution is atmospheric water harvesting (AWH), a method that has been practiced for approximately 50 years, but it is not yet implemented widely. Recently, it is receiving renewed attention as a sustainable and potential component in solving the water crisis.

There are several potential advantages of AWH:

1. By enabling moisture as a water resource, water supplies can be decentralized with off-grid devices, minimizing challenges in transporting large volumes of potable water to rural areas.
2. AWH can be a safe water source as the infrastructure and water produced are separated from contaminated ground and surface water.
3. AWH accesses abundant and renewable water sources. At six trillion litres, there is six times more water in the air than in all the rivers in the world, and the average atmospheric water content is, in fact, increasing as a result of climate change.
4. AWH addresses both access to the water and the quality of the water, unlike many purification technologies.

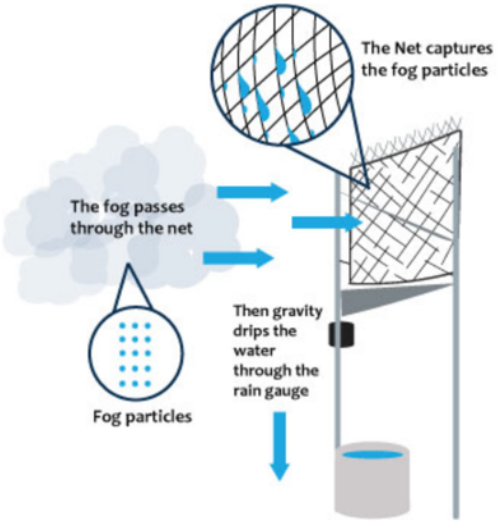
Presently, the main limitation of AWH is the low volume of water produced.

Moisture harvesters capture vapor from the air by attaching water molecules onto materials, through physical or chemical processes. In absorption, gas or liquid molecules diffuse into absorbent materials. Adsorption, another process used by AWH, is where the molecules of gas or liquid adhere to a surface through a chemical or physical interaction.

The main methods of AWH are fog collection, dew collection and using sorbent materials to collect vapor from the air.

Fog Water Collection

Traditional fog collection is very simple. A mesh is exposed to the atmosphere where fog passes through. There is archeological evidence that ancient civilizations in the Middle East and South America had used this method for gathering water. Water droplets get trapped by the mesh, accumulate, and then through the force of gravity, drop into the water collection channels below. Large fog collectors are usually 12m long by 6m high, yielding 48m^2 of water collection area and producing about 150L-750L of water per day. These systems are simple to set up and use inexpensive materials. However, fog only occurs where rainfall is low, or in arid or semi-arid areas close the ocean where clouds are formed over the sea and pushed inland by wind, so can only be used in specific geographical situations. Therefore, they will not be useful in all parts of the globe when it comes to combating water scarcity.



How Fog Water Collection Works

Reprinted with permission by Dan Fernandez, BaysideFogCollectors.com

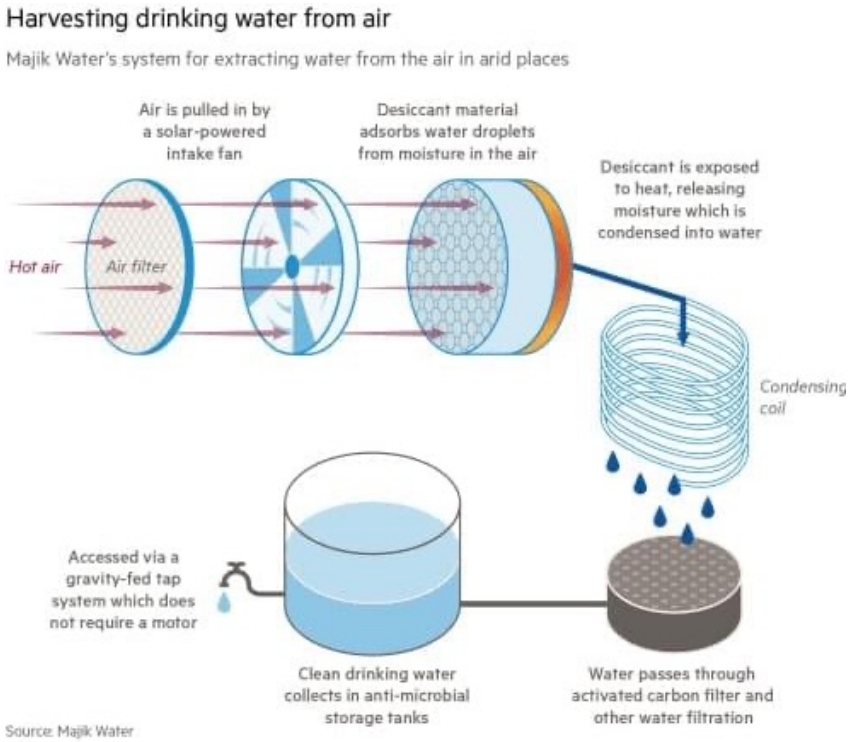


Image reprinted with permission from Majik Water, http://www.majikwater.co/

Nanotechnology

Nanotechnology is the manipulation of materials on an atomic or molecular scale. New filters made from carbon nanotubes and alumina fibers, for example, may be capable of removing sediment and pathogens, as well as traces of toxic elements such as arsenic. Nanofilters would be more efficient than existing water filtration systems and should not require high levels of water pressure to work well (as some filters do), even given their pores are much smaller than conventional filters.

Graphene as the Ultimate Water Filter

Thin sheets of graphene, a new nanotech material made of carbon atoms was only invented in 2004. This new material has the potential to transform water filtration, particularly for desalination and removing pollutants. Graphene's application in desalination could decrease the energy input requirement, which is one of the major problems with desalination today. Graphene oxide is relatively affordable and easy to produce.

A multi-layer membrane made of graphene oxide can be designed to act as a comprehensive filter, filtering out microbes, bacteria and viruses, but also chemicals, solutes and pesticides. Current filters typically target only a few unwanted substances. When these new graphene filters reach the end of their use, they will prevent water from passing, making it easy to know when to change the filter, unlike many filters currently available.

'Wrinkled' graphene, where a layer of the material has been scrunched up into a microscopic series of peaks and valleys creating nanochannels, is being studied in MIT and Brown University labs for their applications for water filtering. Current studies show water vapor has been able to pass through, while larger organic molecules have been trapped.

The GRAPHIL project aims to create innovative new filters for household water treatment with graphene ready for commercialization by 2023, and is part of the GRAPHIL Flagship, a European Commission research initiative.

Computer-Science Aided Solutions

Another area of innovation in the water section is where technology can be harnessed to manage water assets, reduce water and energy wastage.

Through data science and AI, there is already research being done and developments available to help understand one's usage of drinking water to accomplish things such as: monitor quality, improve access, and minimize the energy used to provide clean drinking water.

Smart Sensors

Smart sensors employ the Internet of Things to monitor components of physical water infrastructure.

Handpump Sensor The University of Oxford is developing a sensor for the handle of a hand-pump which will allow repairs of hand-pumps to be done much faster. In a trial done in Kenya, with the addition of a hand-pump sensor, a broken handpump was back in operation within three days, whereas without the sensor, repairs took, on average, 30 days.

Bosaq is a modular off-grid drinking purification system that converts a source of water into high quality safe drinking water with UV LED, powered by solar energy. Every unit is equipped with integrated sensors allowing for cloud connectivity so that a remote engineering team can handle and predict maintenance requirements so there is very minimal downtime. Bosaq will only set up in countries they are active in, where they have a maintenance team trained and ready to respond to data received from the smart sensors. In this way, the unit is very sustainable, providing clean water for 15-30 years.

Droople is a company with a smart sensor product developed by a computer engineer in Switzerland. The Droople product is an IoT (Internet of Things) smart sensor for intelligent management of any water device.

The product is a small device that is attached directly to the water device and uses telemetry to wireless send data from the device to a computer. The use of these smart sensors can increase the speed of adoption of sustainability and saving water by providing important data from a company's or individual's

water usage. For example, the sensors can track water consumption, predict maintenance of filters and water appliances, reduce energy and water bills, identify leaks and areas for water savings. In a school setting, it can show how many students in a school are washing their hands and the duration each wash.

Droople device is connected to any water device in the household with water data viewable on a website interface.

Image printed with permission of Droople, SA.

Chapter 8

Education and Participation

Education

Even when household treatment and filtration methods, whether traditional or innovative, are available, they still rely on human participation to be effective. Research has shown that any potential positive impact of household interventions depends on consistent use, observing proper hygiene, sanitation, and water storage guidelines.

However, it can be very difficult to get people to change their behaviors, existing habits, and beliefs. Therefore, education is an important step to achieving widespread access to clean drinking water.

Hygiene and sanitation

Hygiene is the practice of keeping oneself as well as one's surroundings clean, to maintain health and prevent disease. Sanitation refers to having access to facilities for the safe disposal of human waste and being able to have hygienic conditions for disposal of garbage, industrial waste, and wastewater.

Keeping areas (such as around the home and around school) clean and garbage free will also ensure that pathogens do not enter drinking water supply or become breeding grounds for insects or rodents.

Human intestines host a large number of bacteria. One gram of feces can contain one trillion germs, including ones that cause diarrhea such as salmonella, E. coli and norovirus. Many of these pathogens can be picked up through touching the stools of another person or animal, such as when changing dirty diapers. They can also spread when feces are found in the open, which usually occurs when toilets are not used.

Handwashing

Treatment of dirty water for drinking is important, but arguably equally important, or even more important, is handwashing. Handwashing is essential to remove pathogens from hands, as this is one of the main routes water as well as food can be contaminated. In addition, pathogens may enter the body when hands come into contact with the eyes, nose or mouth. Germs can also be transferred onto objects or surfaces, such as door handles, toys, etc.

Scientific studies show that by simply washing hands with soap, without any other water treatment intervention, communities may see up to 48% of diarrheal reduction. Furthermore, respiratory illnesses and missing school because of stomach related illnesses for children is also reduced greatly! Despite the benefits of handwashing with soap being well-accepted, in practice, handwashing is still difficult to keep up. It's estimated that, globally, only 19% of people wash their hands with soap after using the toilet.

Handwashing with soap should especially be done at two very critical times, before eating and after going to the toilet.

Accessing soap and clean water to rinse hands may not always be available or affordable. Richard Johnston explains that if soap is too expensive, another viable option is to buy powdered detergent, which is used to make soapy water. Soapy water is cheaper than bar soap and is easy to make. Several scientific studies have found that soapy water is equally as effective as bar soap in removing organisms from hands, and certainly more effective than water alone. Factors such as length of time spent handwashing, the quality of the detergent, and initial quality of water are important factors in its effectiveness, but it can be considered a low-cost effective alternative to bar soap, which could mean that handwashing frequency could be easier to adopt where the cost or availability of soap is a burden.

How to Wash Hands Correctly

Reproduced with permission from WHO, Hand Hygiene, When and How Leaflet, August 2009, https://www.who.int/teams/integrated-health-services/infection-prevention-control

The best way to educate about handwashing is through live demonstrations, according to Mr. Ropiecki.

Another solution suggested by Mr. Ropiecki in areas where soap is not readily available or is too expensive, is to make soap oneself with animal fat mixed with lye, which is a very old traditional method of making soap.

Once a source of soap is found, Ryan Blyth also suggests focusing on behavioral changes for handwashing, instead of solely infrastructural. By targeting behavioral change, improvements can be made more sustainable and long term.

He explains this could be done through "nudging", such as footsteps on the floor leading to a brightly colored hand-wash station with a mirror to make them more appealing or installing hand-wash facilities directly in the students' paths so they are difficult to avoid. Social pressure contributes to usage if the hand-wash facilities are in areas that are highly visible to others and leads the children to use the hand-wash station without being told. In addition, making hand-washing fun, such as encouraging children to sing songs while they wash their hands may make them more likely to adopt good practices.

Example of a footpath nudge, © Kamal Hossain, Save the Children. Licensed under Creative Commons Attribution 4.0. A study in Bangladesh observed that handwashing with soap after toilet use increased 64% six weeks after installation due to the footpath nudge.

In schools, he suggests creating a "WASH club", which also helps keep WASH going for longer times. This is a club run by student outside of traditional classroom settings with some key aims:

- Ensure that the schools' hygiene and sanitation areas are clean and maintained, such as keeping the handwash station clean and tidy and always stocked with soap.
- Helping to encourage other students to adopt WASH practices. Club members can teach younger children how to use the facilities.
- By putting certain children in charge of WASH, pressure on teachers who often have many other academic priorities to tend to in the school is relieved and do not have to be relied on for WASH practices.
- Children can be great advocates for change and sources of information for their family members, and village communities. They can transmit what they have learned in school WASH programs to their family or village members.

Participation

In rural areas where safe water infrastructures may not be provided by the government, involving the community to participate in the solution has the potential to increase the water system's longevity and sustainability.

From a study looking at the role of the psychological ownership in safe water management, individuals interviewed for the study were reported to have felt strong feelings of individual ownership of the community water system because of four main themes: regular use, providing utility, a status of influence in the community, or having contributed labor and/or money to the project. There was a strong relationship found between feelings of psychological ownership of the water system and greater care and maintenance of it, better perceived water taste, perceived safeness of the water source, and higher rates of people treating the water after collection.

Dr. Sara Marks, research scientist at the Swiss Federal Institute of Aquatic Science and Technology (EAWAG) and one of the authors of the previous study, adds that in a school context, children in rural areas can be encouraged to participate in creating a clean water solution as well. Most simply, the children could be involved in helping plan the location of a hand-wash station, or what color it will be. This will increase the likelihood of the children helping to take care of the system, but also become more engaged and interested in safe water. The knowledge they learn in school would then be brought home to their families.

The WASH school clubs discussed earlier can help to maintain the installations, but also empowers them to become change agents, to become experts on safe water, sanitation, and hygiene, and to help raise awareness amongst their peers and communities.

Chapter 9

Actions for Everyone

There are countless ways to contribute to helping the water crisis, starting with individual actions from each of us. This guide has provided guidance for people encountering water stresses to take action to improve their water situations themselves.

Some readers may live in an area with good quality and sufficient water, but they can still contribute to solving the global water crisis.

Water supply on the planet is cyclical and thought to be finite. A study from 2014 suggests that earth's water may be more than 4.6 billion years old. As global populations have increased, there is more demand for fresh water, and more pollutants find their way into our drinking water. Getting clean water to you is very expensive and more and more energy needs to be spent to treat, purify and transport water. Increased food consumption for the growing population also means more water, land and energy need to be allocated for growing and producing food. Energy is used to move, heat and treat water, but water is also used to make energy, including electricity and fuels.

All of this contributes to rising emissions, which affect climate change. Climate change has severely affected the global clean water supply, as well as causing droughts, flooding, pollution of natural water resources, damage to infrastructure and ecosystems. People living in undeveloped or poor countries are especially vulnerable, as they already have unstable water and sanitation systems.

Below are suggestions that anyone can take to help the water crisis.

Save water (and energy) by minimizing usage:

Turn off taps when brushing teeth or soaping dishes
Fix leaky taps and pipes
Take shorter showers of no more than 5 minutes and try not to take baths
Change shower heads to water-efficient ones
Rewear clothes that aren't very dirty to minimize laundry
Run clothes and dish washing machines only when they are full and on economy settings
Recycle water in your own household where possible
Recycle indoor water for watering plants or other outdoor uses
Invest in high efficiency toilets and water appliances when building new or replacing old
Choose water-wise plants and trees for your garden or lawn

Conserving energy is also just an important part of the equation, as energy production accounts for 15% of the world's total water withdrawals, so be mindful of your energy use too.

Increasing water supply naturally:

Think about collecting rainwater from your roof. Rainwater harvesting could help put less stress on the water supply from the sources around you. (see the section on Rainwater harvesting in this book.) A family of 4 uses around 150,000-300,000 litres of water per year. One millimetre of rain falling on one square metre of roof provides around one litre of water in a harvesting tank. Rainwater can be high-quality water for drinking, but the collected rainwater could also be used to water plants, wash cars, which would have a large impact. To put this into perspective, Americans use about 30% of their water consumption for outdoor uses, so rainwater harvesting for non-drinking usage is still impactful.

Make different food choices:
66% of total water consumption is used for producing food. One can of soda requires 174 litres of water to produce. One loaf of bread requires 908 litres of water. But, a shocking 40% of American total food supply is wasted each year, meaning that 25% of all freshwater consumed to make those foods is also wasted!

To help, eat less meat. Meat requires more water for production than any other food group. Water is needed to grow animal feed, to feed the animals, and then to process the meat. For example, one quarter pound hamburger requires 760 litres of water to produce. Producing meat and animal products make up nearly 30% of the world's water footprint and use 75% of all available agricultural land in the world. A large part of that is used to grow the feed for the animals instead of growing feed for people.

Eat more natural foods, foods grown closer to home, foods that require less water to make or grow, and foods naturally in season which saves on processing, packaging and transporting foods. In general, eat less and eat better. Reduce the amount you buy and eat, save leftovers, and try to go vegan or vegetarian a few meals a week, if not altogether. Compost food scraps or spoiled foods that you can't eat.

Avoid polluting our water:

- Don't pour oil or fats down the sink.
- Don't put chemicals or cleaning agents in your sink or toilet
- Don't dispose of any medications or drugs down your toilet
- Don't use the toilet as a wastebasket.
- Minimize use of fertilizers and pesticides in your garden
- Make sure your litter ends up in a garbage bin
- Eat more organic food which uses less synthetic chemicals
- Try to avoid using plastic bags, and bottles
- Drink less bottled water where quality tap water is available
- Plant trees! This helps to reduce erosion that washes pollution into our water sources.

Implement technology:
Users can adopt technology to aid in managing their water usage. At a single device level, there are products such as Droople (refer to new technologies section) to help monitor how your appliances and taps are using water.

At a household level, there are products such as Hydraloop, an innovative in-house water recycling system that collects, cleans and re-uses 95% of the water from showers, baths, washing machines, sinks and air conditioning units. This water is reused for toilets, appliances, gardens and pool usage.

You can use the water footprint calculator on the website watercalculator.org to see what your own household water footprint is and see ways to reduce it.

Support companies following good water practices:
Many companies have taken proactive steps to operate more sustainably, with concrete water targets.

The cosmetics company, L'Oréal, started by simply studying the efficiency of water use in its factories. They realized that would not be sufficient to reach its targets so they have developed the concept of a "dry factory", or a waterloop factory able to reuse internally recycled water over and over again in the manufacturing process. The only fresh water drawn from municipal sources is for water use by employees and for the raw materials needed in the products.

Levi Strauss found that high amounts of water are consumed in producing cotton, as well as in washing their clothes after customers buy them. In making the jeans, they now incorporate a recycled denim material called Circulose® requiring less new cotton as well as use methods to reduce the need for chemicals, and design them for longevity. They have started a program to encourage consumers to wash jeans using the 'cold setting' on their washing machines and wash them less often to conserve water and energy. They also initiated a Recycle & Reuse program which requires all their suppliers to meet certain water criteria, including a set % of recycled water in their facilities and using data science to measure the amount of recycled water used on Levi products.

Share your knowledge
You can help spread the word by sharing your knowledge about water. Share with your family, through your social network, your school, your workplace. Write letters to your local paper or contact your local governments to voice your opinion on important environmental issues.

Ms. Bostrom also suggests reminding people that water is such a necessity. In many developed countries, clean water and access to water is often taken for granted, whereas in reality, it is a big issue.

She also reinforces the importance of beginning to break the taboo on sanitation and menstrual health. In many countries, as mentioned before, girls start to drop out of school when they start menstruating. We should start educating everyone about menstruation, not just girls, but boys and adults too, with the end goal of girls feeling empowered, and hopefully staying in school.

Donate
Lastly, help can also come in the form of donating money to organizations who are already deeply involved in particular aspects of the water crisis. Here are some organizations:

Water.org

Water.org, founded by Matt Damon and Gary White, brings safe water and sanitation solutions primarily through microloans and expert resources to help people put a tap or toilet in their home. This is usually done through small, affordable loans, technical assistance, contacts, or resources. Usually, having a tap and toilet in the home means that those people, mainly women, can have improved health and more time to concentrate on their education or career prospects, rather than collecting water or being sick from diarrhea or other water related illnesses. This allows the recipients to feel that they have self-agency and are empowered to make their own futures. Once the loans are repaid, the money is then offered to another family to access safe water. 38 million people have benefitted so far from these microloans.

Gravitywater.org

Gravity Water is a non-profit that uses rainwater harvesting to provide safe drinking water for schools in countries such as Nepal, Vietnam, Indonesia,