WATER WELL

A RESOURCE ON CLEAN WATER FOR LOCAL COMMUNITIES

EDEN CHUNG

Water Well

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.

I would like to thank the following industry professionals for their insight and expertise:

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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.

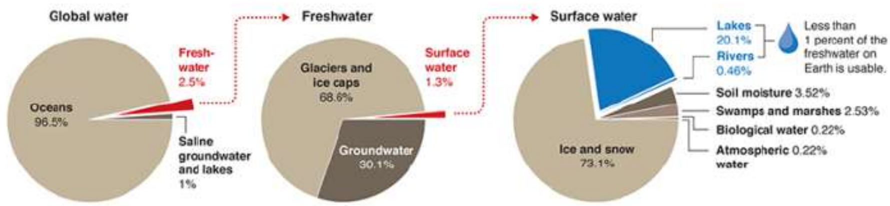
Small communities and households can act faster than governments, knowing best what their specific needs. According to the August 2021 report from the Intergovernmental Panel on Climate, we can still act to negate climate change, but it must happen immediately. Rather than depending on and waiting for 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.

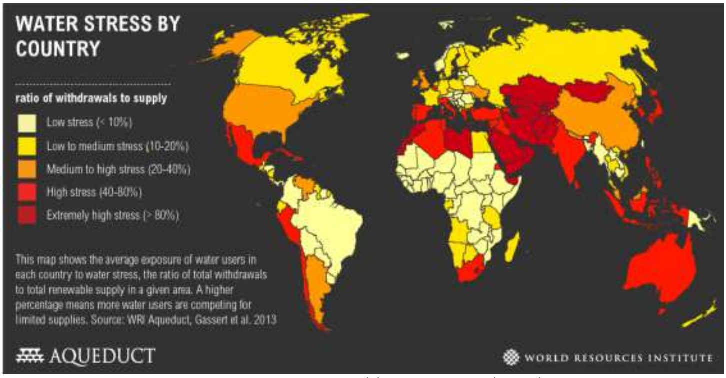
Some may think that we are only on the edge of reaching a water crisis, or that it may affect only some less developed countries, but in fact the available clean water supply has been decreasing; shortages exist on all continents. A water crisis is already happening.

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.

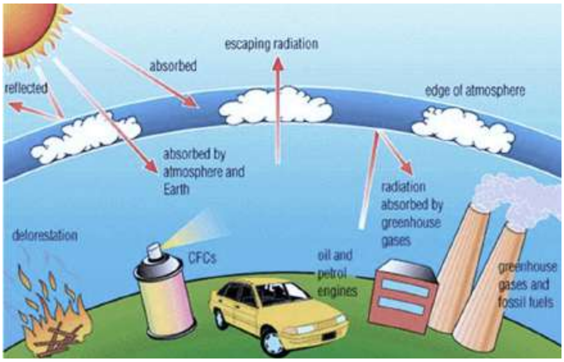
At the same time, agriculture is one of the areas most affected by water scarcity, where climatic weather extremes like droughts, floods and rising temperatures can significantly decrease the amount of crops grown and thereby impact our ecosystems, forests, lakes and wetlands, on which agriculture depends.

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.

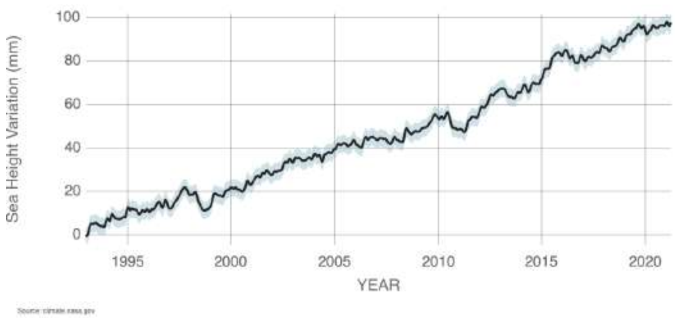
Climate change is a change in regular weather patterns of a location over an extended period, usually regarding temperature and precipitation. These changes are mainly caused by human activities which release greenhouse gases such as carbon dioxide, methane or chlorofluorocarbons, nitrous oxide, and 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.

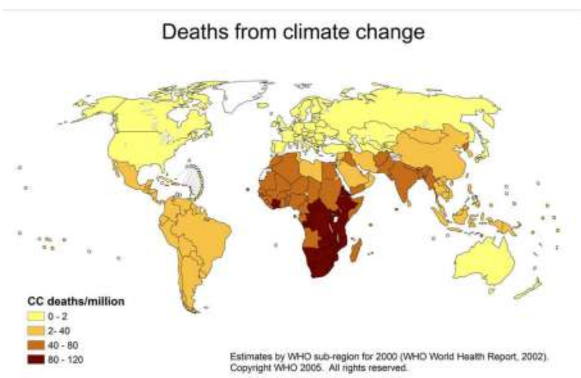


Table reprinted with permission World Health Organization
https://www.who.int/heli/risks/climate/climatechange/en/

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

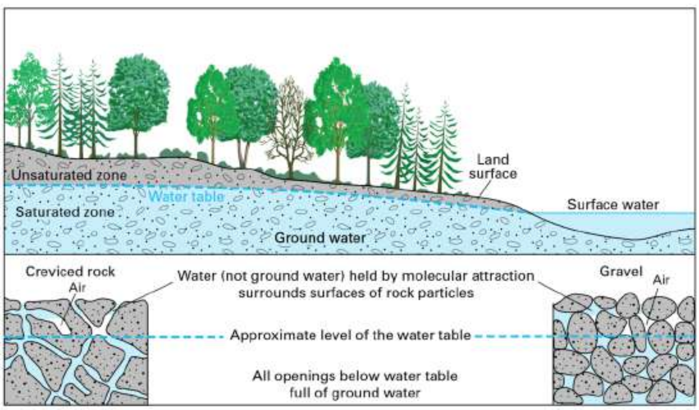
Drinking Water

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

Municipal Water vs. Private Water

Municipal Water

In many large urban areas, residents have access to municipally treated water for a cost. These are usually government provided supply systems that involve water treatment facilities, water storage facilities in the form of reservoirs, tanks and towers, and a piped underground infrastructure network to bring the water to each customer.

This water is safe to drink as it has gone through many treatment processes, which will usually follow similar steps as below:

1. Screening: filtering out large particles from the water
2. Coagulation and flocculation: chemicals such as aluminum sulfate and ferric chloride are added into the water, combining with residual particles to make larger particles that are easier to filter out
3. Sediment filtration: further filtering
4. Filtration of contaminants: using filters such as sand, gravel, or activated carbon to get rid of contaminants
5. Disinfection: killing microbiological contaminants such as bacteria or viruses, usually done through adding chlorine or chloramine
6. Storage and distribution: The clean water is stored in a large tank and distributed to houses through a piped network

Municipal water plant, Poland
Photo by Marcin Jozwiak from Pexels

Private Well Water

On the other hand, drinking water can also come from private wells, either where municipal water isn't available, or as a conscious choice. The well water comes from drilling or digging into the ground to access an underground aquifer, an underground body of rock or sediment that holds groundwater. The water is then pumped up to ground-level for usage. As the well is on private property, owners do not have to pay for water usage, only maintenance of the well and pump, as well as electricity to operate the pump (if it is an electricity driven pump). The water itself can taste fresher, as it has not gone through many treatment methods as municipal water does and may be higher in nutrients and minerals. As long as the well is sealed, well water is often protected from contamination during extreme weather conditions, like floods.

However, there are some negatives with private wells. This is the case particularly with hand-dug wells where the water is collected relatively close to the surface, putting it at risk of contamination from fecal matter. Therefore, a borehole drilled well is preferred to a hang-dug well, as the water is accessed from much deeper, meaning it is less likely to be contaminated. A well of 12 meters deep or more is recommended for less chance of contamination. A deeper well, however, is more expensive to dig and requires a more expensive pump to access the water source deeper into the ground. Pumps can be hand powered, solar, or electric, so the type and cost of energy will also need to be considered.

The owners of the wells will be responsible for any maintenance, repairs of the well, as well as regular testing to make sure the quality is safe for drinking.

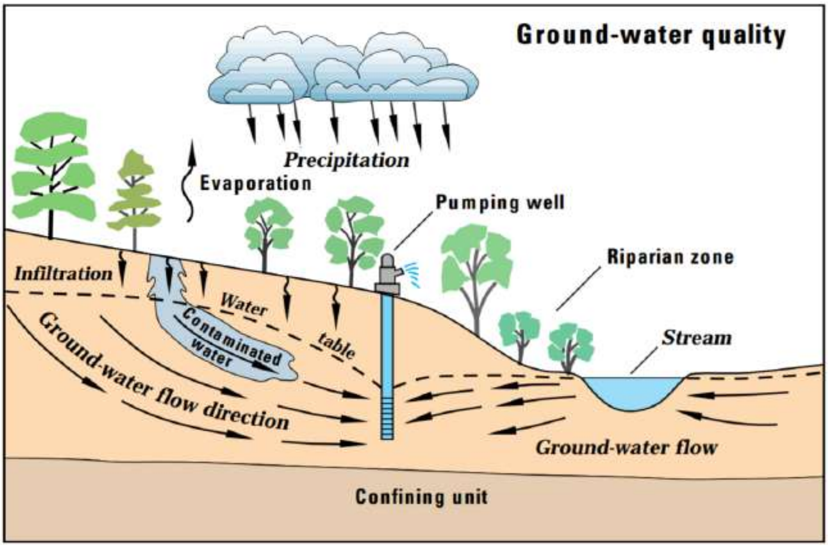
Well water can become easily contaminated with any number of substances including:

- Microbiological contaminants such as E. Coli bacteria, which is found in soil, human and animal waste.
- Heavy metals, usually coming from old pipes or runoff from industry or mining.
- Radionuclides, naturally occurring contaminants, but may also result from industry, mining, and production of fertilizer, as well as nuclear power plant waste.
- Fluoride

- Nitrates, usually entering well water from sewage runoff, industrial activity, or fertilizers.

When finding a suitable location to dig a well, a location far away from any source of feces (animal or human), fertilizers or pesticides from any farming activity, tanks of petroleum, or chemical treatments should be considered.

Contaminants in Groundwater Can Contaminate Well Water



Source: Strategic Directions for the US Geological Survey Groundwater Resources Program

As water from the well does not go through a treatment process (as municipal water does), it is highly recommended to filter the water through a household filter before consumption. (See section on Water Filtration and Treatment methods.) Well water may also contain naturally occurring iron or sulfur, which causes the water to have a different color and smell.

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

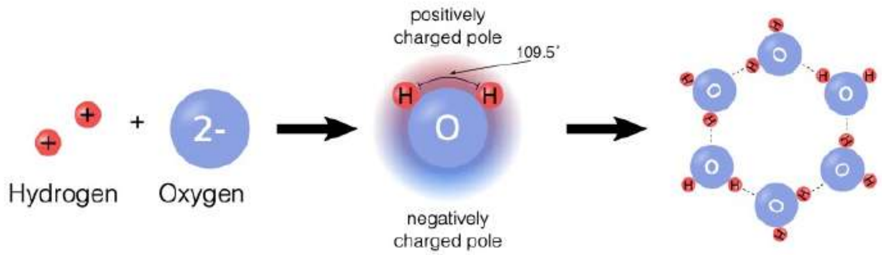
Why is Water Necessary for Life?

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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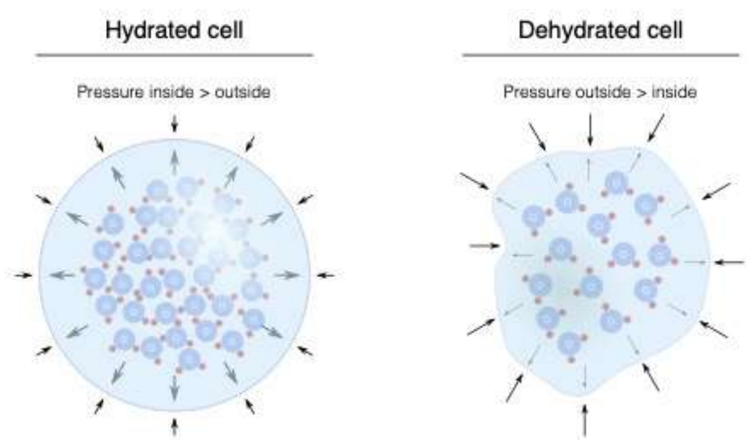
Water at the Cellular Level

In cell biology, water has a very important role too, consisting of half the volume inside biological cells. Water inside cells acts to keep pressure on the outside surface of the cell which helps to keep the cell's volume and structure.

Maintaining this structure is a protective measure, allowing a cell to prevent harmful molecules from entering the cell. In addition, the structure is critical for proteins to function inside the cell and for DNA to direct cells to follow its instructions for making future cells, human growth and reproduction.



Water impacts cell shape. Water creates pressure inside the cell that helps it maintain shape. In the hydrated cell (left), the water pushes outward, and the cell maintains a round shape. In the dehydrated cell, there is less water pushing outward so the cell becomes wrinkled. Illustration reprinted with permission by Daniel Utter and Science in the News.

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.

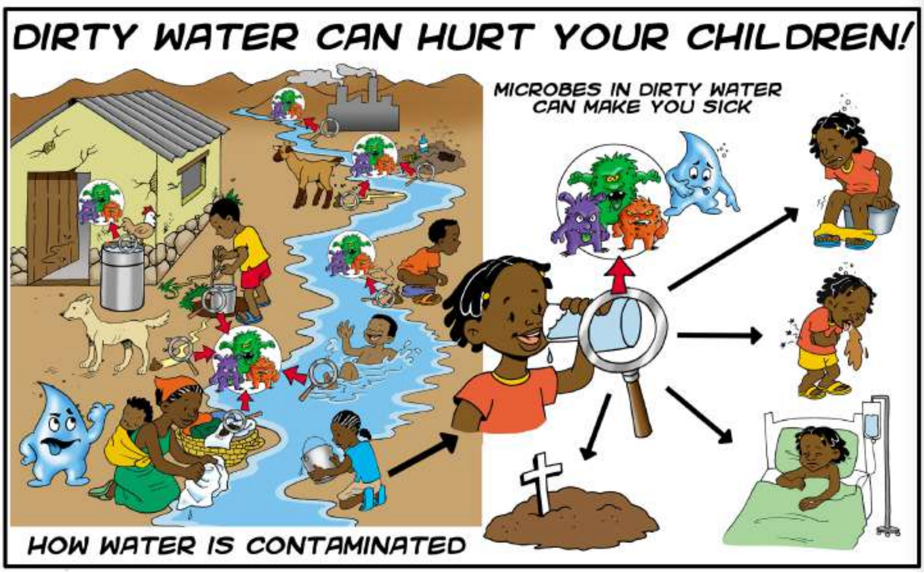
- Drinking water helps to keep your joints, spinal cord and tissues lubricated and cushioned.
- Drinking water helps to pass stools easily.
- Drinking water helps your brain to work properly, such as making hormones and neurotransmitters. Dehydration has been shown to impair brain function, concentration and short-term memory. Mild dehydration can cause fatigue.
- Sufficient water keeps the skin hydrated. Skin that is well-hydrated will form a stronger barrier to protect against bacteria and other germs.
- Severe dehydration can cause brain swelling, kidney failure and even seizures.

The Institute of Medicine of the National Academies recommends adult men to drink 3.7 litres of water daily, women 2.7 litres daily, and children around 1-2 litres daily.

Every year, more people die from drinking unclean water than from all forms of violence, including war. Clean drinking water is essential for a healthy body.

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

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

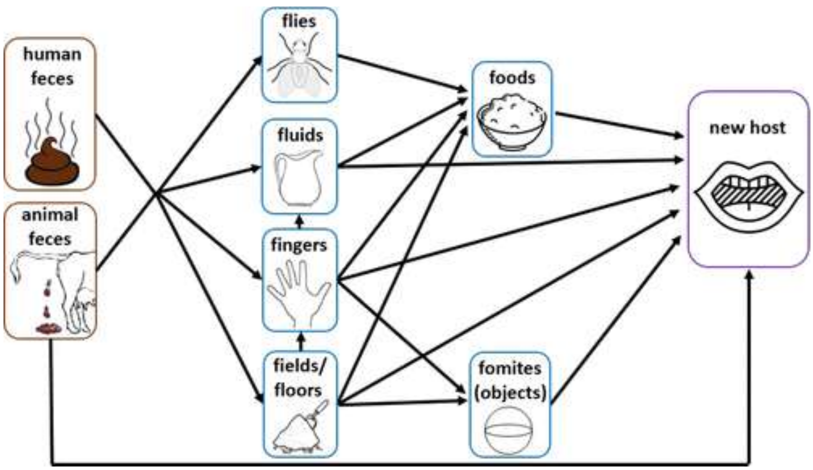


Image reprinted with permission "Figure Pathways of exposure to fecal contamination (from Wagner, E. G.; Lanoix, J. N. Excreta Disposal for Rural Areas and Small Communities; Monograph Series 39; World Health Organization: Geneva, Switzerland, 1958 https://pubs.acs.org/doi/10.1021/acs.est.0c02606."

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.

Salmonella can cause nausea, vomiting, abdominal cramps, diarrhea, fever, chills, and headache. It is rarely fatal, but it can kill people with weaker immune systems such as the elderly, the young, and those suffering from cancer or HIV/AIDS.

Salmonella can be removed from water most easily by boiling.

Typhoid Fever

The bacteria salmonella typhi infects the intestinal tract and blood, often referred to as typhoid fever. Like many other bacteria, it is transmitted through the fecal-oral route, which can occur through consuming contaminated food or drink prepared by an infected person, contact with feces of infected humans, or consumption of food that has been contaminated by sewage. The disease is very common in areas where sewage and water treatment systems are poor.

Symptoms of typhoid fever are very serious and include constipation, fever, headache, fatigue, dizziness, which can sometimes result in death. Antibiotics are required to treat the infection, as without the antibiotics, the symptoms may last for months, with the death rate up to 20%.

Shigella dysenteriae

Shigella dysenteriae is a bacteria that causes shigellosis, also found throughout the world. It may enter the water through sewage overflows, sewage systems not working properly and storm water runoff. Wells are very vulnerable to contamination after flooding.

Symptoms of the shigella infection usually include diarrhea, fever, and stomach cramps, usually starting 1-2 days after infection and lasting for 7 days. Usually, people will recover without the need of antibiotics, but those with weaker immune systems may require them.

Just like many other pathogens, boiling or disinfecting water supplies will remove shigella.

Vibrio cholerae

Vibrio cholerae is a bacteria that infects the intestines causing the disease cholera. Very prevalent in the 1800s, cholera has become limited in developed countries, due to good treatment of sewage and drinking water. V. cholerae can be found in contaminated food or water, as well as some rivers and coastal water. It spreads through fecal matter, meaning it can spread with bad sewage systems or floods.

Most people infected with V. cholerae are asymptomatic, meaning they do not have any symptoms. But those who exhibit symptoms will suffer from watery diarrhea, along with stomach pains, leg cramps, mild fever, and vomiting. If not treated, cholera can lead to severe dehydration, which can cause death within several hours.

According to Michael Ropiecki, American entrepreneur working in Sierra Leone, cholera was one of the most common diseases causing diarrhea, which he witnessed in his years in the field in Sierra Leone. Often, people will suffer from diarrhea and vomiting at the same time, which can cause them to die from dehydration if they are not sent to the hospital to get intravenous treatment.

<u>Cryptosporidium</u>

Cryptosporidium is a parasite causing another diarrheal disease known as cryptosporidiosis, protected by an outer shell, allowing it to survive without a host for long periods of time. The parasite infects both animals and humans. The parasite can be spread in many ways, but water is the most common way.

Symptoms usually start between 2-10 days after infection, with the most common symptom being diarrhea. Other symptoms may include stomach cramps, dehydration, nausea, vomiting, fever, or weight loss. It is also possible to be infected with cryptosporidium and have no symptoms. For people with weaker immune systems, cryptosporidiosis can prove fatal.

The outer shell also makes it resistant to chlorine disinfection, making chlorine less effective. Boiling is very effective in killing cryptosporidium.

<u>E. coli</u>

E. coli, a bacteria, is naturally present in the intestines of the human body and animals. Most strains of E. coli are harmless, but specific strains may cause diarrhea. E. coli is spread from contaminated water or food, such as raw vegetables and ground beef. It is also possible to get infected by swimming in pools or lakes contaminated with stool.

Healthy adults will usually recover from E. coli within a week, but younger children and the elderly are at a higher risk of developing kidney failure, which may be fatal. During infection, usually 3-4 days after being exposed, symptoms include diarrhea, stomach cramping, nausea, and vomiting.

Rotavirus

Rotavirus is a contagious virus causing diarrhea, resulting in more than 600,000 child deaths annually. There is now a vaccine against it, but previously, many children were infected with the virus at least once before turning 5 years old. The virus can spread through hand-to-mouth contact, usually from stool.

Rotavirus can usually be treated at home by taking extra fluids to prevent dehydration, but in severe cases, additional fluids may be required through an IV in hospital.

The rotavirus infection will usually start within 2 days of exposure, with symptoms including fever, vomiting, and diarrhea.

Trachoma

Trachoma, a disease of the eye, is caused by the bacteria Chlamydia trachomatis. It can cause people to go blind, and the damage is irreversible. It is the main cause of blindness worldwide, causing 1.9 million people to go blind or visually impaired.

In trachoma ridden areas, the disease is the most common in young children, where rates can be as high as 60-90%. Usually, the immune system can recover from a single infection, but re-infections are very common. After many infections, the inside of the eyelid can become severely scarred, causing the eyelashes to rub against the eyeball. If untreated, this results in visual impairment or blindness.

Trachoma infections spread through personal contact (hands, clothes, or bedding), or by flies that have been in contact with an infected person. Inadequate hygiene, access to water and sanitation increases the transmission of C. trachomatis.

Schistosomiasis

Schistosomiasis is a disease caused by parasitic worms called Schistosoma. Infection occurs when people come into contact with water infested with the parasite larvae. The water becomes contaminated when those infected with schistosomiasis pollute sources with their excreta, which contain the parasite eggs.

The symptoms may include abdominal pain, diarrhea, and liver enlargement.

Dracunculiasis

Dracunculiasis is a parasitic disease that is soon reaching eradication. During the 1980s, there were around 3.5 million cases of dracunculiasis, which has dropped to only 54 cases in 2019. One year after infection, a blister forms, usually on the lower leg, where worms will escape. Often, those infected will soothe the pain by immersing the leg in water, where the worm will release larvae. Then, those who drink this contaminated water will be infected with the baby worms.

The disease is not usually fatal, but those infected will be affected for weeks. There is no vaccine or medication to treat patients, but there are many prevention methods. This includes preventing contamination of drinking water, filtering water, cleaning and bandaging the infected areas of skin.

Lymphatic filariasis

Lymphatic filariasis, or elephantiasis, is a parasite transmitted through mosquitoes. Lymphatic filariasis affects the lymphatic system and leads to enlargement of body parts which causes pain and disability. These parasites live in the lymphatic vessels for around 6-8 years, producing microfilariae, or immature larvae. When mosquitoes bite an infected host, they pick up microfilariae, which will develop into mature larvae that are then transferred to others.

Infection usually occurs during childhood years, but swelling occurs later in life, sometimes even leading to permanent disability. It can also cause damage to the kidneys and the immune system.

According to Dr. Annie Sparrow, pediatrician and Associate Professor at The Mount Sinai School of Medicine, in many countries, children are often infected with worms and multiple parasites at once. With this burden of disease, if they catch rotavirus, cholera, or similar diseases, the effects will be much worse.

In addition, she mentions deworming is one of the most important actions to keep children in school. Deworming can be done through pills, taken yearly.

Toxic minerals and metals

Calcium and magnesium

Calcium is the 5th most common element in the Earth's crust, often found as calcium carbonate. As water comes into contact with soil and rock, small concentrations of minerals such as calcium or magnesium are picked up.

Limestone, a specific type of rock, is made up of calcium carbonate, so water coming into contact with limestone often has a high concentration of calcium.

Magnesium, on the other hand, is one of the most abundant cations (positive ions) in the body. In the body, it helps synthesize protein and nucleic acid, regulate blood pressure, and maintain heart health.

Water with a high concentration of calcium and magnesium is called "hard water". The WHO classifies water at different concentrations as follows:

Classification	mg/l or ppm	grains/gal
Soft	0 - 17.1	0 - 1
Slightly hard	17.1 - 60	1 - 3.5
Moderately hard	60 - 120	3.5 - 7.0
Hard	120 - 180	7.0 - 10.5
Very Hard	180 & over	10.5 & over

NOTE: Other organizations may use slightly different classifications.

The hardness of water affects the capacity to bubble up soap; hard water requires more soap to bubble up, whereas soft water requires less.

Both calcium and magnesium are essential minerals for the body and benefit human health. Our bodies actually have a natural storage of calcium, around 1200g stored bones and teeth.

A lack of calcium can cause negative health effects, such as:

- increased risk of osteoporosis, low bone mass increasing the risk of fracture
- kidney stones
- hypertension, otherwise known as high blood pressure, and strokes
- obesity

A lack of magnesium can cause:

- endothelial dysfunction, which is when blood vessels on the heart's surface constrict
- decreased insulin sensitivity
- hypertension

However, food, not water, is the main source of calcium, with dairy products having a high amount of calcium, often consisting of over 50% of calcium in a diet. Some vegetables also have calcium, such as green leafy vegetables and broccoli.

Magnesium is also found in many foods, especially fibrous foods. Some foods rich in magnesium are almonds, spinach, peanuts, black beans.

There is a low risk of ingesting too much calcium, as a mechanism in the intestine protects the body by excreting excess calcium through the kidney. Similarly, the kidneys excrete excess magnesium. However, hypermagnesemia exists, but this usually only affects people with poor kidney function.

<u>Iron</u>

Iron is another material that is very abundant in the Earth's crust, constituting more than 5% of the Earth's crust. Iron as an element is not often found in nature, as its ions, Fe^{2+} and Fe^{3+} will combine with oxygen and sulfur compounds to form oxides, hydroxides, carbonates and sulfides. Naturally, iron is most often found as an oxide.

Water can also be contaminated with iron. This occurs when rainwater washes through soil containing iron, dissolving the mineral. It can be found in water in two different forms, the soluble ferrous iron or insoluble ferric iron.

Similarly to other metals, iron can be found in food too, such as liver, kidney, fish, and green vegetables.

Iron is also essential for humans, with the minimum daily requirement ranging from 10-50mg per day. However, too much iron can impact health too. Excess iron is sent to the liver, heart and pancreas, and can cause liver disease, heart problems and diabetes. In addition, concentrations of 200-250 mg/kg of body weight can be lethal but there have been cases of death from ingestion of iron at a level of only 40 mg/kg of body weight.

The presence of iron in water can turn it into a reddish-brown color and gives it a metallic taste. In addition, clothes washed by high-iron water can stain. It will also turn tea, coffee and potatoes black, making them less appealing to eat.

The presence of iron in water also encourages the growth of bacteria within waterworks and pipes, which causes a slimy coating to appear on the pipes.

Michael Ropiecki explains that from his experience in Sierra Leone for example, water is often iron contaminated which may be easier to identify visually and by smell than other metals as it has an undesirable smell and look, as well as staining clothes red.

Manganese

Manganese is another naturally occurring mineral, usually occurring along with iron, but it is rarely found in the elemental form; instead, it can be found as a component of over 100 minerals. It is found in soil, food, as well as water. In water, it can be found naturally both in surface water and groundwater, but human activity has caused manganese pollution in many areas. Manganese in water is quite common, with 70% of groundwater sources in the US containing manganese, but the levels are usually below the public health limit.

Food rather than water contributes more significantly to daily manganese intake. Manganese can also be found in many foods, such as leafy vegetables, nuts, grains and animal products. People who drink more tea tend to have a higher manganese intake.

Small amounts of manganese are essential for the body; cellular enzymes require manganese and manganese is important for several physiological processes. But water with too much manganese can cause health issues. In young children, drinking water with high manganese concentrations can affect brain development. In addition, too much manganese can cause loss of appetite, slowed growth and reproductive issues.

Similarly to iron, manganese can change the color of water and cause an unpleasant taste, as well as staining laundry.

Nitrates/nitrite

Both the nitrate and nitrite ions can occur naturally both in soil and groundwater through the nitrogen cycle, in which nitrogen from the Earth's atmosphere is converted into nitrogen compounds. However, the natural concentrations are usually quite low. Nitrate concentrations in drinking water become high as a result of human activity, such as runoff from fertilizer, wastewater or landfills. The nitrate ion is the more stable ion, so it is usually found at higher concentrations than the nitrite ion.

Nitrates are used in inorganic fertilizers, in explosives, as well as food preservatives. Therefore, the contamination of water is usually as a result of agricultural activity.

The increase in the use of inorganic fertilizers throughout the past years has caused the nitrate ion to increase globally.

At low concentrations, neither nitrate or the nitrate ion are harmful, but at higher concentrations, they can cause health effects. For babies and infants, high nitrate and nitrite concentrations can cause methemoglobinemia, otherwise known as the blue baby disease, causing babies skin to turn blueish grey due to a lack of oxygen. Methemoglobinemia can affect adults, but at much higher doses. There are also links between nitrate and nitrite concentrations and thyroid cancer.

The current WHO limit for nitrates is set at 50 mg/L, but according to Richard Johnston, Technical Officer at the Joint Monitoring Program at the WHO, the limit may be changed once the WHO revisit the nitrate and nitrite ion. At the moment, the WHO limit hasn't been lowered as nitrates in water mainly only affect young babies, representing only a very small proportion of the population.

According to Yves Bersier, Manager of Drinking Water at the Industrial Services of Geneva (SIG), nitrates in Geneva, Switzerland have been low due to proper agricultural practices through the education of farmers. The farmers are aware of the exact amount of fertilizer to use, to prevent excess runoff, highlighting the importance of education to minimize contamination of our waters.

Asbestos

Asbestos is a category of fibrous silicate materials either containing iron, magnesium, calcium or sodium. Water can often get contaminated by dissolving materials containing asbestos. More significant, however, is asbestos in piping. In the 1900s, most water pipes contained concrete and cement with asbestos. As the pipes degrade, due to weather or corrosion, the asbestos fibers contaminate the water supply.

There are known effects to ingesting asbestos, such as asbestosis, bronchial carcinoma, as well as links with cancers. Asbestos in water can also affect local wildlife.

Barium

Barium is found as various compounds, most frequently barium sulfate, in many types of rocks, and enters both groundwater and surface water through leaching of these rocks. It is also used as a drilling fluid, in a wide variety of products such as plastics, rubbers, paint, glass, among many others. Barium in water is mainly from natural sources rather than human. The concentration in water tends not to be very high as the barium ions are sometimes absorbed onto metal oxides and hydroxides.

However, food is usually the main source of ingestion rather than water, such as seaweed, fish and certain plants, unless the barium concentration in water is very high.

Barium is not an essential element for human health, but conversely, high concentrations can cause health effects. There have been links with barium and effects on blood pressure, negative effects to the kidneys, convulsions and paralysis. At high doses, death can occur within a few hours or a few days.

Chromium

Chromium is another naturally occurring element, found in rocks, plants, soil, and animals. Several foods, such as meat, fish, fruit, and vegetables contain chromium, usually at concentrations between 10-1300 µg/kg. In addition, utensils used to prepare the food can leach chromium. Industrial processes use chromium, so chromium has been leaked into the environment by poor storage or poor waste disposal. In water, it is odorless and tasteless.

In water, chromium is typically found in surface water at concentrations between 0.2-1 g/L. In groundwater, concentrations tend to be lower, typically at less than 1 µg/L. Chromium intake is usually mainly from food, but drinking water can be substantial at concentrations above 25 µg/L.

Chromium is an essential element for human health, recommended at 0.5-2 µg of absorbable chromium per day. However, too much chromium can cause negative effects. At concentrations between 1-5 g of chromate, severe acute effects can occur, such as gastrointestinal disorders and convulsions. In terms of chronic effects, there are links with lung cancer as well as death due to lung cancer.

Copper

Copper is another naturally occurring metal. It is used in many products, such as wiring, coins, cooking utensils; plumbing systems; fungicides, algicides, insecticides; as well as being added to fertilizers and animal feeds. Copper is found in foods, such as liver, seafood, nuts and seeds or from drinking water contaminated by corroded copper pipes, farming, or industrial activities. Copper-contaminated water may have a light blue or blue-green color and a metallic, bitter taste, usually starting from concentrations around 2.4 mg/L.
Copper can be found in surface water, groundwater and seawater at a median value of 0.01 mg/L. However, copper concentrations vary greatly with water characteristics (pH, water hardness, copper in distribution system).

The body requires copper among an intricate mix of other essential elements to form red blood cells and help keep blood vessels, nerves, immune system, and bones healthy. Recommended level for an adult is typically 900 µg per day;

in the US, the average copper intake was 1.2-1.6mg per day for adult males and 1-1.1 mg per day for adult females. During pregnancy, the recommended limit is slightly higher. In the body, copper is required for many enzyme systems to work. Lack of copper can cause anemia, neutropenia, and bone demineralization.

However, high concentrations can cause negative effects. Acute effects include vomiting, diarrhea, stomach cramps, nausea, liver damage, and kidney disease. The lethal dose is between 4-400mg of copper ion per kg of body weight. There is no clear correlation with any chronic effects at concentrations between 1-10 mg/day, except for those with the Wilson disease gene.

Aluminium

Aluminium is the most abundant metal in the Earth's crust, making up 8%. It can occur naturally as compounds such as silicates, oxides and hydroxides. Aluminium has high usage as a structural material in industries like construction, automotive, and aircraft. It is also used as a food additive, and aluminium utensils and wrappings can increase the amount present in food.

Aluminium can enter water through leaching from rocks and soil, but it is also used in water treatment methods, as coagulants to reduce organic matter, color, turbidity, and microorganism levels, so this is another method by which it enters water. However, the two most common aluminium compounds, aluminium oxide and aluminium hydroxide, are insoluble. In addition, aluminium metal develops a film of aluminium oxide when in contact with oxygen which prevents it from reacting with water.

On average, adults intake around 5 mg/L per day from food, and only around 0.1mg/L from water, but very little of this is actually absorbed into the body. Therefore, there is no strong correlation with acute effects. However, scientists have theorized the link between aluminium exposure and chronic diseases such as nerve damage and Alzheimer's disease. Aluminium may have an effect on aquatic life as it is toxic to several types of fish at concentrations higher than 0.1 mg/L.

Arsenic

Arsenic occurs naturally in the Earth's crust, occurring in many rocks and sediments. It is also used in several industries such as animal feed, wood preservative and pesticide. Arsenic can also be present in foods, such as fish, shellfish, meat, poultry, and dairy products. However, the arsenic levels tend to be much lower than in groundwater.

Arsenic may enter water from the natural rocks, making groundwater a much higher risk than surface water. Mining may also release arsenic into water. In many countries, including Argentina, Bangladesh, China, India, USA, arsenic levels are high in groundwater sources. Arsenic in water is odorless and tasteless, so private water supplies should be regularly tested.

People can be exposed to arsenic not only through drinking contaminated water but also through using contaminated water to prepare food, eating contaminated food or smoking tobacco.

Arsenic is highly toxic and problematic even low levels can. Acute effects include vomiting, abdominal pain and diarrhea, followed by numbness and muscle cramping, and even death. In terms of chronic effects, usually within 5-10 years, pigmentation changes can be found on the skin, which is usually a signal for skin cancer. There are also links with bladder and lung cancer, as well as affecting pregnancies.

Arsenic is a major issue due to the many health effects, and the WHO says that over 140 million people in over 50 countries have been drinking water with arsenic levels higher than the WHO guideline of 10 μg/L.

Mercury

Mercury occurs naturally in small amounts in Earth's crust as a shiny, silver-white metal. It is a unique metal as it is a liquid at room temperature and will slowly evaporate into the air. It has also been released through volcanic activity. Mercury has been used in thermometers, lamps; mercury compounds are used in batteries and the chemical industry. Mercury is also found naturally, such as in large fish (bass, shark, swordfish, tuna) which feed on smaller fish. Luckily, the increasing concern for its environmental effects has caused its use to decrease.

Mercury can be released naturally from rock and soil, but human activities increase mercury in drinking water. Mercury can come from burning of coal and oil, releasing of mercury from metal smelters or the incineration of mercury containing materials like batteries. From there, rain can transport mercury into surface water, or it can seep underground from waste sites.

Naturally occurring mercury in water tends to be at low concentrations, less than 0.5 μg/L, but depending on the location (presence of mineral deposits), groundwater concentrations may be higher.

Acute effects due to high doses of mercury usually cause the same symptoms, such as shock, cardiovascular collapse, and severe gastrointestinal damage, which can be fatal. Effects can be caused both by water related ingestion, but also by air exposure, at concentrations above 0.5 mg/m^3.

Lead

Lead can be used in plumbing materials and faucets, so lead can enter drinking water when water erodes such plumbing materials, but depends on the pH, temperature, and water softness. Lead pipes are usually found in older cities and homes, built before the 1980s. Lead can also be found in batteries, alloys, pigments, and ammunition.

Food may also contain small amounts of lead, usually when the water used to cook or cooking utensils contain lead.

On average, humans ingest 5 μg/L of lead from water, but the WHO estimates 80% of the daily intake of lead is from food and dust rather than water. Adults only absorb 10% of lead in food, but children absorb between 4-5 times as much.

Lead is known to have negative effects, and is a higher risk for infants, young children and pregnant women. Some of these acute effects include dullness, restlessness, irritability, poor attention span, kidney damage, and hallucinations. After 1-2 years of exposure to lead, chronic effects can be seen, such as muscle weakness, gastrointestinal symptoms, and disturbances in mood. There are also links with renal disease and hypotension. Lead may also cause reproductive dysfunction in females.

Fluoride

Fluorine is very reactive and so does not occur naturally in its elemental state, instead existing as different fluorides in many minerals, such as fluorspar, cryolite and fluorapatite. Fluorine compounds are used in aluminium products, in the steel and glass fibre industries, and production of phosphate fertilizers. Traces of fluorine are also found in many foods, but kale and endive have the highest levels of fluorine. Fluoride is also used in toothpaste, which may sometimes be in high concentrations; for example, some toothpaste contains 4-6 mg/kg of fluoride.

Fluorides can usually be found in varying concentrations in water, with higher concentrations usually in groundwater. However, the concentration in groundwater is affected based on the type of rock the water is flowing through, but is not usually higher than 10 mg/L. The WHO recommended limit is 1.5 mg/L of fluoride.

Daily fluoride intake seems to be mainly from food, then drinking water. However, swallowing toothpaste can increase the daily intake. Finally, in some areas, fluoride intake may include the air, such as in China where coal with high fluoride content is burned.

Fluoride is an essential element, but the minimum requirement is unclear. Acute effects start at doses higher than 1 mg of fluoride per kg of body weight. On the other hand, there have been many studies on chronic effects from drinking water. At low concentrations, fluoride provides protection for the teeth, but at high concentrations (between 0.9 and 1.2 mg/L), fluoride can have a negative effect on tooth enamel. A high intake may also cause skeletal fluorosis, which causes weakened bones.

Radioactive substances

Radon

Radon, a radioactive gas, occurs naturally through the breakdown of radioactive elements present in soil, rock, and water. Radon produced in the ground can dissolve and contaminate groundwater. In addition, radon in water can escape into the air when contaminated water is used to shower, wash dishes or cook. However, radon in surface water is not an issue, as the radon is usually released into the air before drinking.

Radon gas can cause lung cancer, as the decay of radon gas into radioactive particles can get trapped in the lungs. Approximately 20,000 deaths occur each year in the US caused by radon gas. Ingested radon is also linked with internal organ cancers such as stomach cancer. However, only 1-2% of radon in air is from drinking water, so the risk from water is lower. Still, a report estimates 168 cancer deaths a year from radon in drinking water in the United States.

Uranium

Uranium is a radioactive element that occurs naturally, in granites and other mineral deposits. It is used as catalysts, staining pigments and fuel in power stations. It can enter drinking water through leaching from soil, rocks, or from processing plants. It can also be found in food, with the highest concentrations found in shellfish, and slightly lower concentrations in vegetables, cereals and fish.

Uranium is usually found in very low concentrations in drinking water, at an average of 2.5 μg/L in the US in the 1980s. However, uranium can sometimes occur at very high concentrations; some private wells in Canada were found to have concentrations of up to 700 μg/L.

Most of the uranium ingested is excreted, but small concentrations are absorbed and brought through the bloodstream. Uranium has negative effects on kidneys, leading to inflammation of changes in urine.

Radium

Radium is another naturally occurring radioactive element, found in rocks and soil. It is also formed when uranium decays. Therefore, radium can contaminate groundwater sources. In addition, deeper wells have a higher probability of containing larger concentrations or radium than shallower wells. Radium in surface water is usually quite low. Radium in water is colorless and tasteless, so private wells should be tested regularly.

Radium, similarly to uranium, is mainly excreted, but around 20% is absorbed. Radium in drinking water rarely causes negative health effects. Too much radium can cause cancer, kidney damage and birth defects.

Pesticides

Pesticides are chemicals used to kill pests, usually used to protect crops. Some cheap pesticides can stay in water and soil for many years. Pesticides can contaminate both groundwater and freshwater water due to runoff after excess rainfall. The amount leached depends on the amount applied, where, and how it is applied.

Pesticides can be toxic to humans and have both acute and chronic health effects, but the effects depend on the type of pesticide. Some affect the nervous system, whereas others irritate the skin or eyes. Some pesticides may cause cancer.

Pharmaceuticals

Pharmaceuticals, any drugs used for medicinal purposes, can also contaminate water. They contaminate water through human excretion, drugs flushed down the toilet, and pharmaceutical manufacturing facilities. Antibiotics and hormones are also used in the cattle industry and may end up in water.

Pharmaceuticals in water can affect the health of wildlife, including insects, fish, and birds. However, the concentrations in water are usually at a much lower level than the dose intended to work for humans, so health effects for humans are less likely.

In addition, pharmaceuticals do not tend to be treated in wastewater treatment plants, and tend to be found in higher concentrations in urban areas.

Chapter 4

Actions for the Global Problem

Governmental and Institutional Actions

As water risks continue to increase, exacerbated by climate change, aging water infrastructure, increased demand from population growth and increased pollution levels, different solutions need to be found.

Governments at the national, state, and municipal levels contribute to ensuring access to affordable and reliable supply of water. Some of their actions include:

- Reforming policies, addressing environment, energy, agriculture, trade, economics, and development
- Developing and implementing water quality standards
- Desalination plants
- Developing better water filtration systems
- Promoting water stewardship: Water conservation technologies, recycling wastewater, collecting rainwater
- Protecting wetlands, which collect and purify water
- Improving irrigation efficiency in agriculture
- Increasing water storage in reservoirs

Progress on water related improvements is crucial to meeting the UN's long term development goals to provide universal access to basic drinking water, which will in turn reduce child mortality and improve human health. Meeting those goals will definitely depend greatly on governance and finance from countries' institutions and administrations. However, projections show that many developing countries are at least 100 years away from being able to provide clean water for all with only government-funded improvements (such as boreholes, pumps and piped infrastructure networks). Providing safe and good quality drinking water through piped-in water to each household in the world is an important goal but very difficult to achieve. What else can be done?

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.

Wells

As briefly mentioned previously, there are three main types of private drinking water wells to access the water table underground.

Dug wells are normally hand-dug with a shovel to reach the water table. The well hole is lined with stones, bricks, tiles, or other materials to prevent the hole from collapsing, and ideally should be covered. They have a wide diameter as they are dug by hand. Dug wells normally cannot be dug deeper than the water table, so they are generally shallow (around 3-9 meters) and do not have a continuous casing, which means they are at a high risk of contamination from nearby sources. They are also susceptible to going dry if the water table lowers below the well bottom.

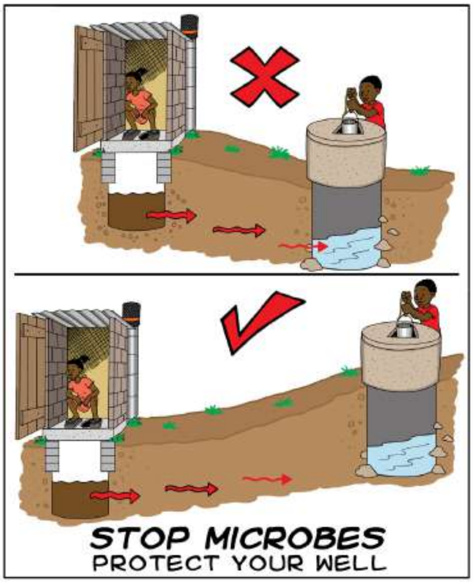
"Deeply Dug Well" by avialpert is licensed with CC BY-SA 2.0

Driven wells are made by driving small diameter pipes deep into the ground (about 9 to 15 meters) where the earth is soft, made from sand or gravel for example. Although deeper than hand-dug wells, driven wells can still only access shallow water, so can still be contaminated from surface pollutants.

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

Studies need to be performed at the location prior to construction to ensure the well is situated in the right place, sufficient groundwater of safe quality is being accessed, the volume of water needed by the community is sufficient, and that it is well-constructed according to recognized standards. From this, it can be determined whether it is the most cost-effective solution.

Wells should be located upstream from rainwater flows. Rainwater can collect bacteria or contaminants at surface and if this flows towards the well, those contaminants can easily seep into the well water causing health issues.

A simple overview of borehole drilling in a short, animated film can be found at: https://vimeo.com/channels/drilling.

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.

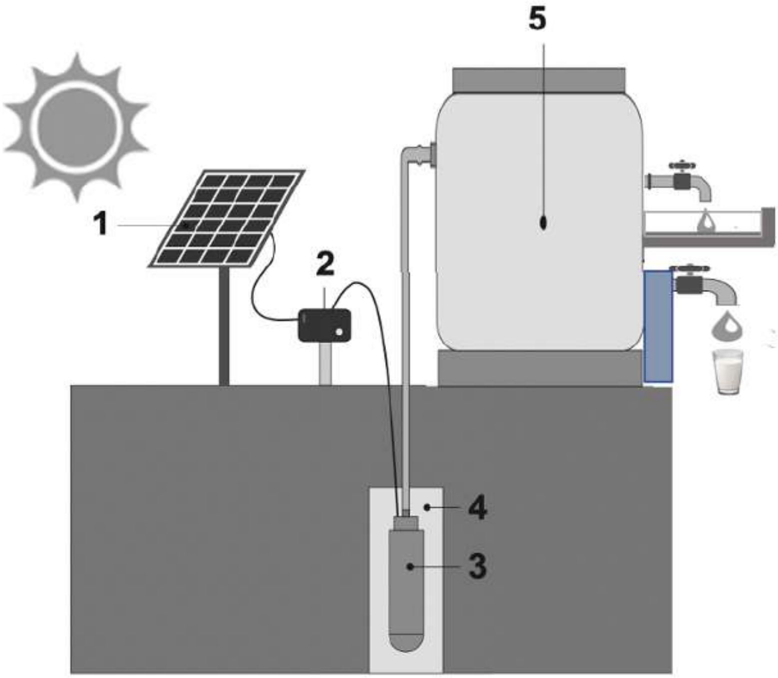
"Kononga in Yatenga, Burkina Faso" by CGIAR Climate

Pumps powered by different energy sources are also becoming more widely used, ranging from human, solar, wind to diesel, or also grid electricity powered.

Solar powered pumps are submerged pumps that use energy from the sun to work. They have now become a viable option due to the fall in costs during the last decades of solar photo-voltaic panels. Solar energy is considered the cleanest and most plentiful renewable energy source available; fuel is not needed to be paid for, so ongoing operation costs are low. However, the upfront cost of a solar pump is much more expensive than a hand pump.

Sean Furey, Director of Swiss Resource Centre and Consultancies for Development, cautions to be particularly aware of the borehole diameter requirements for a solar pump, often wider than that needed for a simple hand-pump. In rural communities, often this requirement may not be known beforehand and the borehole would need to be redrilled.

An extensive guide for details of solar pumps is available for free download at https://practicalactionpublishing.com/book/2507/solar-pumping-for-water-supply



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

Example of a Solar Pump Water Installation

Rainwater Harvesting

Rainwater harvesting is an extremely old method, used in many ancient civilizations, which involves collecting and storing rainwater for human use from rooftops, land surfaces or rock catchments. The collected rainwater can be used for household drinking water, agriculture, washing, or a backup supply of water during dry seasons or breakdowns of other water supply sources.

Interest in the method has been reviving in the mid-20th century due to many factors such as:

- Lack of ground and surface water availability and then poor quality of that water
- More and more pressure on water resources with growing population
- Use of materials like tile and iron roofs instead of grass/thatch, which makes it easier to direct the rainwater
- More effective and cost-friendly tank designs coming out on the market

Storage systems can range in complexity, from simple rain barrels to more complex systems such as pumps or larger tanks. The recommendation is to use "dry systems", which are systems that do not hold any water in pipes after raining stops, to prevent the creation of breeding grounds for mosquitos and other insects. Wire mesh can be built on top of the pipes to prevent debris from entering the pipes and tank.

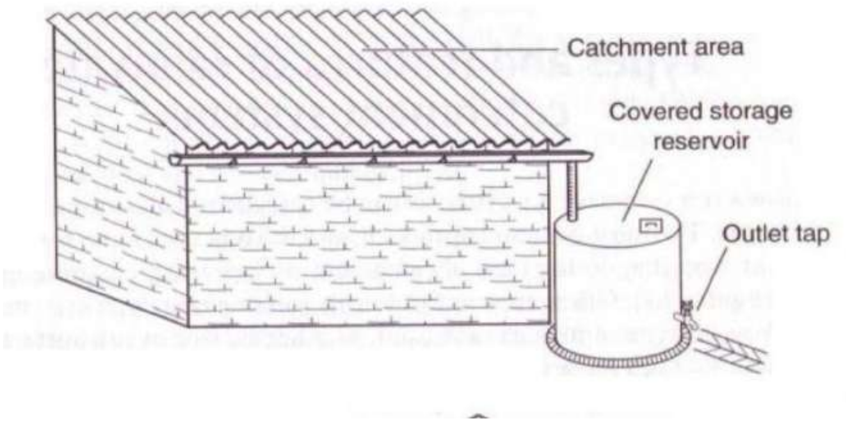
If rainwater is used for drinking water, it should still go through a treatment method such as flocculation, settlement, or chlorination.

Advantages

- Convenience as water can be provided near the point where water is needed, saving time for women or water fetchers, or eliminating the need for complex and costly distribution systems
- Can complement other water sources, relieving pressure on limited water supplies, or during natural disasters.
- People have full control over their own catchment systems, improving household water security and minimizing operation and maintenance problems.
- Technology is very simple to construct, install, and operate, based on traditional methods
- Rainwater is free
- Rainwater often is usually superior in physical and chemical properties to surface and groundwater which may be contaminated.
- Since rainwater systems typically use existing structures like rooftops, they have few environmental impacts compared to other developments like dams or piped networks.
- Rainwater for domestic use emphasizes small-scale, community-based, self-help development.

Disadvantages

Unfortunately, rainwater harvesting depends on the weather. During the wet seasons, rainwater harvesting will produce lots of water, but during dry seasons, another source of water is needed. Regular maintenance and cleaning are still required, storage tanks if not properly covered and maintained could become breeding grounds for mosquitos.



Source: Center for Affordable Water and Sanitation Technology (CAWST), Introduction to Household Rainwater Harvesting, November 2011 Manual, licensed under CC BY-SA 4.0

These are several examples of ways to self-supply water. Having a convenient supply of water means less stress in worrying about where water will come from, less wasted time water fetching and more time for productivity. Research has shown that water consumption increases two or three times when a water source is available on site, with the additional consumption likely to have been used for hygiene purposes and therefore able to increase health.

Chapter 6

Local Solutions: Treatment of Drinking Water

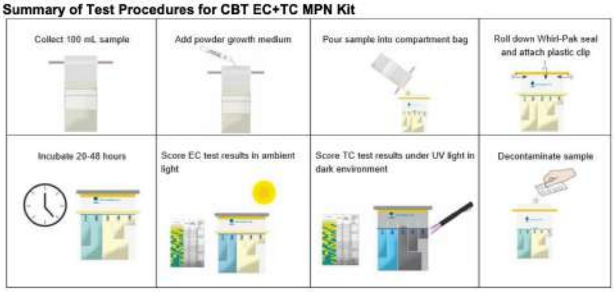
Water testing

To choose the right treatment method, it is important to know what contaminants are in a user's water. Some sources of water may have a higher contamination of chemicals, whereas others will be high in microbial matter.

A water analysis test can either be done through a laboratory, or through at home kits. Richard Johnston recommends several easy to use home kits:

1. Microbiological Water Quality Test Kits from Aquagenx. This test kit is easy to use, requiring users only to pour 100 mL of water in the plastic bag kit. Afterwards, the growth medium is added, then incubated for between 20-48 hours at ambient temperature. Then, the presence of E. coli, total coliforms or other bacteria can be found through the color matching kit. The kits are easy to use, require little training, are easy to interpret results from, are cost effective and eliminates the need for lab testing, electricity, chilling of water samples, and transportation of water samples.

Summary of Test Procedures for CBT EC+TC MPN Kit



How to Interpret Color-Change Test Results

Color of compartment in Compartment Bag	Yellow/Yellow Brown in ambient light and does not fluoresce blue under UV light	Yellow/Yellow Brown that ... fluoresces blue under UV light	Blue/Blue Green in ambient light	Blue/Blue Green that... fluoresces blue under UV light
E. coli	Negative	Negative	Positive	Positive
Total Coliforms	Negative	Positive	Positive	Positive

"CBT EC+TC MPN Kit for *E. coli* and Total Coliform bacteria"
Image reproduced with permission from Aquagenx, https://www.aquagenx.com/

2. Simple nitrate tests, such as one produced by Hach.

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

Activated carbon
Activated carbon is a technology that absorbs contaminants onto the surface of a filter, where they were first used in 450 BC in the form of charcoal.

This treatment method works through contaminants sticking to the surface of carbon granules or being trapped in the many small pores of activated carbon, which is known as adsorption. The carbon is said to be “activated” because it goes through a process where it is subjected to a stream, (a gas such as water, argon or nitrogen), then exposed to a very high temperature, between 800-1000°C. This process creates many pores in the carbon.

The installation of carbon filters is relatively easy, but skilled technicians are needed to monitor the effectiveness of the filter over time. In addition, activated carbon filters must be replaced regularly, as after high usage, the carbon surfaces are saturated, meaning they can no longer absorb any more pollutants.

These filters are effective in removing chlorine, fluorine and radon from water, but it is not as effective in removing pathogens, metals, or nitrates. Therefore, it is best if it is used in conjunction with another type of treatment device.

Advantages
Activated carbon filters are easy to install, and the materials used to construct them are readily available.

Disadvantages
The filter has to be replaced regularly, and skilled labour is required at regular intervals to check the filter is functioning properly.

Biosand filter

Biosand filters are an improvement to slow sand filters, which have been used for over 200 years. It was invented by Dr. David Manz in the early 1990s at the University of Calgary. The filters can vary in size, between 18L buckets to 1000L tanks. As of 2013, it is estimated that over 650,000 biosand filters have been implemented all over the world, improving over 4 million peoples' water supplies.

It consists of a container, made of either concrete, plastic, or stainless steel, holding layers of sand with microorganisms in the top 2cm of sand, known as the biolayer. Water is poured into the top of the biosand filter, where it seeps through the sand. The microorganisms in the biolayer will kill pathogens in the dirty water, while the sand removes big solids from the water. Finally, the biosand filter should be covered with a lid to prevent further contamination of the water. Afterwards, the water has filtered through the layers of sand, it collects at the bottom of the filter, and then pushed up to a tube on the outside of the filter.

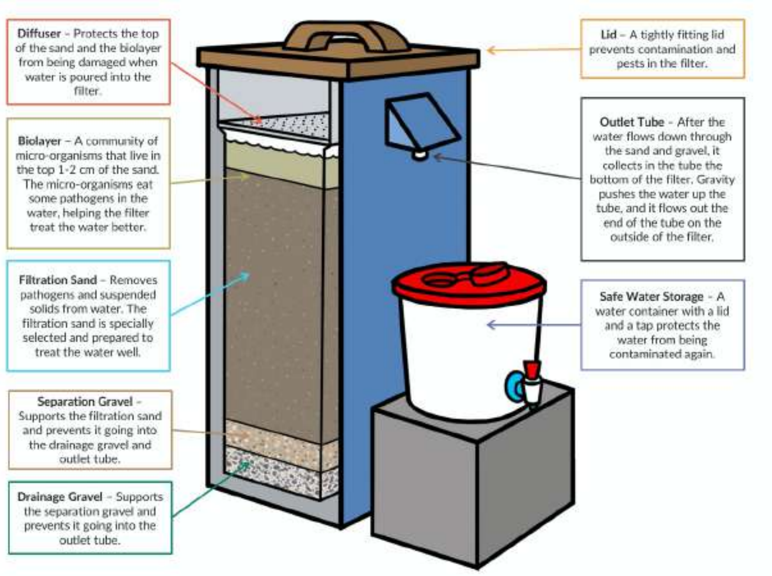


Image: "What is a Biosand Filter" by CAWST,licensed under CC BY-SA 4.0

Unlike slow sand filters, water from biosand filters is not continuously flowing. The filter is always completely filled with water, so when a new batch of water is poured into the filter, the water poured in previously is filtered out. The filter should be used at least once per day, to ensure that the microorganism in the sand has enough oxygen. Ideally, only one batch of water is treated per day (to allow 24 hours of treatment), but the biosand filter will also work with more batches, but the performance will be reduced (less hours in contact with the filter).

It is very important to note that all kinds of water can be used with a biosand filter, except water that has been chlorinated. Although the chlorine kills the pathogens in the water, it will also kill the good microorganisms in the biosand filter. The filter will also work with turbid water, but at turbidity higher than 50 NTU (Nephelometric Turbidity Units), the filter will clog more quickly and run more slowly, requiring more frequent cleaning. Therefore, high turbidity water should ideally be strained or settled beforehand.

Over time, the sand becomes clogged with sediments, slowing the flow. To clean it, a swirl-and-dump cleaning process is used. In addition, the lid and outlet should be regularly cleaned.

Biosand filters are the most effective against cryptosporidium and giardia, at over 99% efficacy. Next, it is over 90% effective against bacteria. It is the least effective at removing viruses and turbidity.

Effectiveness

Parameter	Effectiveness	Laboratory Efficiency	Field Efficiency
Bacteria	Effective (>90%)	98.7% [1]; 98.4% [2]; 97.9% [3]	98.5% [4]; 92% [5]; 87.9% [6]; 88.4% [7]; 92.4% [8]; 95% [9]
Viruses	Somewhat Effective (>80%)	85.9% [3]	
Cryptosporidium	Very Effective (>99%)	99.88% [10]	
Giardia	Very Effective (>99%)	>99.99% [10]	
Turbidity	Somewhat Effective (>80%)	87% [3]	85% [4]; 82% [5]; 69% [6]; 29.5% [7]; 82% [9]

* All laboratory and field efficiency values shown are from independent testing only.

Table: "Biosand Filter Effectiveness" by CAWST, licensed under CC BY-SA 4.0

Advantages

Once the biosand filter has been bought, there are few recurring costs. After time, the lid and storage containers may have to be replaced, but the filter itself should not need replacement. They are also quite durable.

No power is required for the filter to work; gravity makes it work.

Disadvantages
However, biosand filters can be very heavy, especially if made of concrete, often taking at least two people to lift an empty filter (no sand or water). This makes it difficult to move around the house.

Boiling

Boiling is one of the oldest methods of filtration, and also the most commonly used method. It is a very simple method, consisting of bringing water to a temperature of over 100°C, which is the temperature at which most pathogens die. Without a thermometer, water should be heated until big bubbles appear, providing an indication that the water is at a high enough temperature to kill all the pathogens. The WHO recommends that water be heated until this point, but other sources, such as the US Centers for Disease Control and Prevention, and CAWST, recommend keeping the water at a boil for one minute.

However, boiling only removes pathogens, and does not remove turbidity nor chemical contaminants. Therefore, turbid water should be settled or filtered before boiling.

Boiled water is also at a high risk to recontamination, as it is often transferred from the pot into dirty containers, contaminating the previously clean water. To avoid this, the water should be stored in the pot used to boil it, and with a lid on top. The pot and lid should be regularly cleaned as well.

Advantages

Boiling is an effective method as it kills most pathogens, and it is also a very easy and widely accepted method. Another advantage is that no additional devices must be bought, if users have a kitchen, so nothing has to be bought nor replaced.

Disadvantages

Boiling can be very time consuming, especially when trying to treat high volumes of water. As mentioned before, it also does not remove chemical contaminants, and also does not remove taste, smell or color. In addition, the water that has been boiled must settle for some time to allow it to cool down, which may put it at risk for recontamination. Finally, electricity or fuel use may be expensive.

Ceramic Candle Filter

Ceramic candle filters are simple devices made of hollow cylinders connected to the bottom of a container. Water is poured into the top, where it slowly flows through pores in the candle(s) into a lower container. Attached to the lower container is a tap. Because the flow rate is quite slow, devices often contain more than one candle.

Image by Charoen Krung Photography/Shutterstock.com

This filtration device works through physical processes such as mechanical trapping and absorption, which removes pathogens and any suspended materials. Sometimes, colloidal silver, an antibacterial, is added, helping to remove pathogens, but also preventing growth of bacteria in the candle itself. The colloidal silver breaks down pathogens' cell membranes, effectively killing them.

All types of water can be used, but water at turbidity levels greater than 50 NTU may increase clogging of the pores, so ideally should be strained or settled first.

For the best usage, candles should be replaced every 6 months to 3 years, depending on the product. This is to protect against small cracks in the ceramic, which reduce the effectiveness of the filter, as some water will not complete the entire filtration process. In addition, the candles must be cleaned regularly using a cloth or a soft brush, which removes any material clogging the pores. The lower container, including the tap and the lid, should also be cleaned regularly. However, clean water must be used during cleaning, otherwise recontamination may occur.

Finally, ceramic candle filters are the most effective against bacteria and protozoa, but less effective against viruses.

Effectiveness

Parameter	Effectiveness	Laboratory Efficiency	Field Efficiency
Bacteria	Very Effective (>99%)	>99% [1,2,3,4]; 99.996% [5]; 99.9998% [5]; 93-99.6% [6]	
Viruses	Effective (>90%)	>90% [7,8]	
Protozoa	Very Effective (>99%)	>99% [8]	
Turbidity		88-97% [2]; 58-94% [6]; 98.7% [5]; 98% [5]	97-99% [2]
Colour		96.5% [5]; 96.9% [5]	

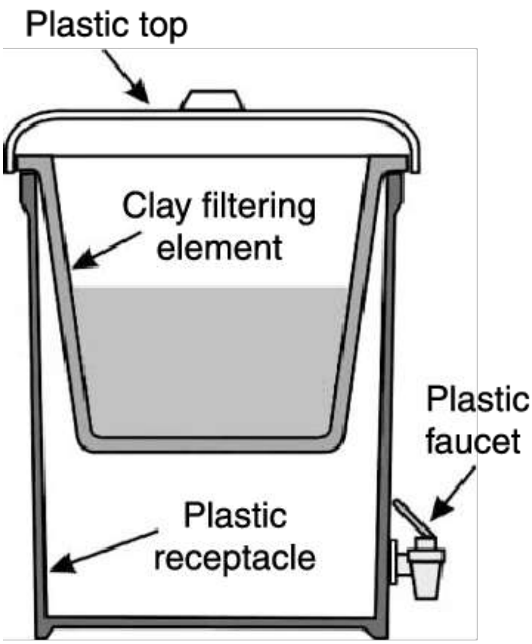
* All laboratory and field efficiency values shown are from independent testing only.

Advantages
Ceramic candle filters are cheap and easy to use and clean. In addition to removing contaminants, these filters will also improve the taste, smell and color of the water. Finally, they are also durable, and unlike some other filters, are much easier to move and transport.

Disadvantages
On the other hand, they are not so effective against viruses, and are ineffective against the treatment of chemical contaminants. The flow rate also tends to be reasonably slow, at 0.14 L/h for 1 candle, or 0.23 L/h for 2 candles.

Ceramic pot filters

Ceramic pot filters have been around for hundreds of years. It consists of a porous ceramic filter pot (made of clay, sometimes mixed with sawdust or rice husks) placed on top of another container. There are many designs, but the most widely used is the Potters for Peace design, shown below.



Ceramic Pot filter as promoted by Potters for Peace.org

This design consists of a flowerpot shaped clay filter, resting upon a plastic receptacle, complete with a tap. Like candle filters, colloidal silver may also be added to the clay mixture due to its antibacterial properties. A lid is usually provided to cover the clay filter to prevent further contamination.

These filters usually have a diameter of around 30 cm, with a depth of 25 cm. Usually, the clay filter can hold between 6-10L of water, while the receptable can hold between 20-30L.

Dirty water is poured into the ceramic pot, which slowly passes through miniscule pores in the ceramic pot, collecting in the lower receptacle. Then, when water is desired, the tap is used. Pathogens are removed through physical processes, namely mechanical trapping and absorption.

Similarly to ceramic candle filters, water at turbidity higher than 50 NTU may clog the pores in the ceramic, so it should be strained or settled beforehand.

The filter should be replaced every 1-2 years to protect against small cracks in the ceramic that develop over time, although they can last over 5 years. In addition, cleaning must be done regularly with a cloth or soft brush to clean the pores. The lower container, tap and lid should also be cleaned, using clean water to avoid contamination. Some products have more specific guidelines to cleaning; for example, in some products, soap and chlorine should not be used.

Overall, ceramic pot filters are less effective in removing pathogens than the ceramic candle filter. They are the most effective against protozoa, and also reasonably effective against bacteria, but less so against viruses.

Parameter	Effectiveness	Laboratory Efficiency	Field Efficiency
Bacteria	Effective (>90%)	>99% - >99.999% [1,2,3,4,5,6,7;;;;]	96% [8];; 98% - 99.99% [9]
Viruses	Somewhat Effective (>80%)	90 - 99% [2]; 77-99% [4]; 96% [7]; 68-74% [1]; 38-74% [1,10,11]	
Protozoa	Very Effective (>99%)	>99% - >99.999% [4,7,10]	
Turbidity		83% [12]; 94-98% [13]; 99% [14]; 98% [6]	
Iron			>90% [14]
Colour	Effective (>90%)	96.3% [6]	

* All laboratory and field efficiency values shown are from independent testing only.

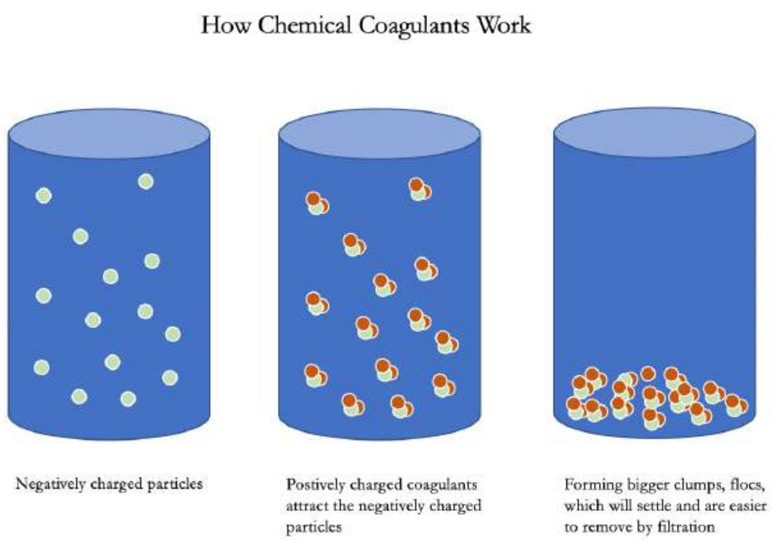
Advantages
Very easy to use and is generally an accepted method. They are also reasonably cheap and have been proven to reduce diarrhea disease for users.

Disadvantages
However, they are not so effective against viruses. In addition, these filters have to be replaced reasonably often, compared to some other treatment devices. They also must be cleaned regularly, which may be an inconvenience. Finally, although the flow rate is slightly higher than ceramic candle filters, it is still reasonably slow, at 1-3L/hour (depending on product).

Chemical coagulants

Chemical coagulants are used in the sedimentation step of water treatment. Coagulants in themselves do not treat water, but they help sand, silt, and clay join together to form large clumps, which makes them easier to settle at the bottom of the container. Some coagulants often used include aluminium sulfate, polyaluminium chloride, or iron salts.

Chemical coagulants work because turbidity-causing particles are usually negatively charged. Therefore, when adding chemical coagulants, positively charged, the negatively charged ions are attracted to the coagulants, the positively charged ions. These bigger clumps, called flocs, settle faster, and are also easier to remove by filtration. Finally, some bacteria and viruses may stick to the flocs, so chemical coagulants may also remove some pathogens from the water.



The use of chemical coagulants usually occurs in two stages: rapid mixing and slow mixing. First, rapid mixing disperses the coagulants evenly in the water, making sure the chemical reactions go to completion. Afterwards, slow mixing helps increase particle collisions and encourage the formation of flocs.

Advantages

Chemical coagulants are very simple to use, and quite inexpensive. The chemicals used are also relatively abundant. Finally, the improvement of the turbidity of water improves the efficacy of any subsequent filtration processes.

Disadvantages

Qualified personnel are required to calculate the accurate dosage of chemicals to be used. The process can also be time consuming as the flocs take time to settle.

Chlorination

Chlorination is a very common method of disinfecting water. This method uses either a solution of chlorine or chlorine tablets, which kills many pathogens in water. Chlorination has commonly been used in emergency situations as tablets can be dropped into any source of water. Tablets will usually dissolve fully in less than one minute, then the water should be left to sit for 30 minutes.

One type of tablets contains sodium dichloroisocyanurate, which when added to water, releases hypochlorous acid. This acid kills pathogens.

The effectiveness of chlorination depends on turbidity, organic matter, ammonia, temperature, and pH. If water is very turbid, it should be settled or strained before chlorination, improving the reaction between chlorine and pathogens. At a pH of over 9, chlorine is unreliable.

Chlorine must be dosed correctly. Each product will have different instructions, but the correct amount must be added because a low concentration will not disinfect the water sufficiently, but an overly high concentration will make the water taste and smell different.

Chlorination is effective in reducing bacteria and certain viruses, but there are some protozoa that are not removed, such as cryptosporidium and giardia.

Image by Caron Badkin, Shutterstock.com

Advantages

Chlorination has a high acceptability, with many people using it. There is usually excess chlorine present in water even after the 30 minutes, called residual chlorine, which protects the water against recontamination, which is a big positive of chlorination that other treatment methods do not provide.

Disadvantages
This method does not protect against protozoa, and also is not very effective in turbid waters. In addition, chlorine can create a change in taste and odor, which many people may dislike. Finally, as Michael Ropiecki explains, the correct dose must be calculated, which may make it difficult for some to use (maybe those who may not have had the opportunity to have an education). Finally, there is a recurring cost, as chlorine tablets must be bought regularly.

Mr. Ropiecki explains that chlorine is a great treatment method, but it does require calculations from humans to dose correctly. An in-line piped filter where chlorine is automatically dosed can be simpler for the community and requires only refilling chlorine in liquid or tablet form when depleted.

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

Ion exchange

Ion exchange systems involve the swapping of negative and positive ions in water. There are two types: water softeners and anion exchange devices. Water softeners remove cations, positively charged ions, replacing them with sodium, whereas anion exchange devices remove anions, negatively charged ions, replacing them with chloride.

They are effective in removing many chemicals that other treatment devices do not remove, such as nitrates, chloride, silica, radium, uranium, arsenic, barium, and boron, among many others.

This exchange occurs in a tank filled with a material such as resin. As water passes through the resin beads, the resin absorbs the anions while releasing chloride into water.

Advantages

Ion exchange systems produce fast results and require very little maintenance. Depending on the makeup of a user's water supply, different ion exchanges can be chosen to remove specific contaminants.

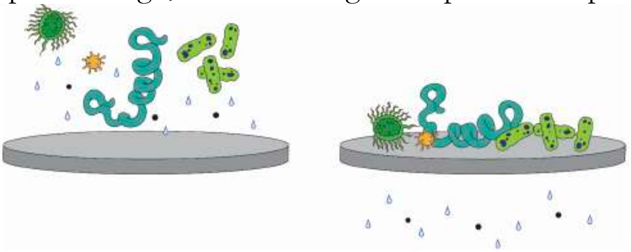
Disadvantages

It is best if the water goes through a filtration or sedimentation step beforehand, as the water cannot be too turbid. The equipment is also quite expensive, including the chemicals which can be costly.

According to Claire Moody, a Public Health Scientist at Anglian Water Services, when the nitrate levels exceed the WHO limit, the water goes through an ion-exchange treatment, where nitrate is substituted for chloride. This treatment method has proved to be effective as the nitrate results have complied with the WHO standard for many years.

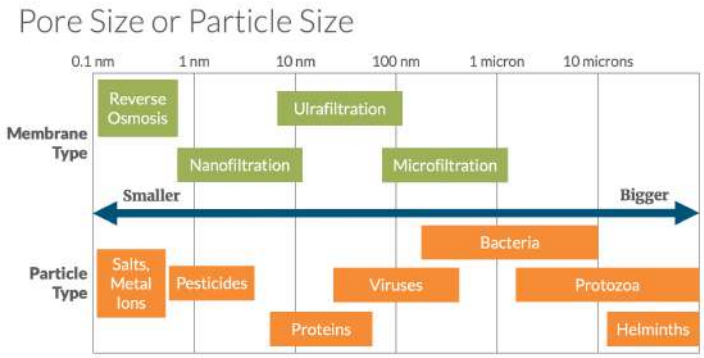
Membrane filter

Membrane filter use started in the 1960s. They are a broad category and exist as many types and setups. However, simply, membrane filters involve passing water through a surface with pores small enough to prevent other particles and substances to pass through, while allowing water particles to pass.



Membrane filters can be classified based on the size of the pores.

- Microfiltration: 0.1-10 microns
- Ultrafiltration: 0.01-0.1 microns
- Nanofiltration: 0.001-0.01 microns
- Reverse osmosis: less than 0.001 microns



Filtration spectrum of reverse osmosis, nanofiltration, ultrafiltration, microfiltration and particulate filtration relative to the pore size of the common material. Source: SSWM. Info, RADCLIFF and ZARNADZE(2004)

Microfiltration has the largest pores, so are the least effective. Sometimes, the pores are bigger than some bacteria and most viruses. Therefore, microfiltration is not usually used as a treatment step in itself, but instead used as a pre-treatment step. Ultrafiltration is more effective and will remove most pathogens including bacteria, protozoa, helminths, and many viruses. However, small viruses may still pass through. Nanofiltration and reverse osmosis are very effective in removing pathogens, but they are more commonly used for water desalination and the removal of dissolved contaminants.

Pressure is needed to force the water through the pores. When the pores are slightly bigger, for microfilters and ultrafilters, gravity usually provides enough force. However, for nano filters or reverse osmosis systems, a vacuum system is sometimes used.

Turbid water may clog the pores of the membrane filter, so straining or settling should be done beforehand if the water is very turbid. Overtime, even with non-turbid water, the membrane filter will need cleaning. Depending on the product, this could be done through backwashing.

Advantages
Membrane filters are usually less expensive than some other technologies, especially micro or ultra-filtration. In addition, there are no energy costs (micro/ultra-filtration). They also offer great flexibility, as there are many different sized pores based on the needs of the user.

Disadvantages
When backwashing the membrane filter, dirty water can be produced. In addition, the membranes may have to be replaced reasonably often.

Natural Coagulants

Natural coagulants are natural products, coming from plants, algae, or animals, that help with coagulation and flocculation. For example, extracts from the Moringa oleifera tree seeds can be used.

Photo credit: "Moringa seeds" by treesforlifeinternational is licensed with CC BY-SA 2.0.

These natural coagulants have a positive charge. In water, particles that cause turbidity, such as sand, silt, and clay, are negatively charged. Therefore, the coagulants stick to turbidity-causing particles, forming larger particles known as flocs. Flocs are then easier to filter out or settle. Sometimes, bacteria or viruses may also stick to the coagulants, so coagulation may reduce some pathogens in water.

The dose required depends on the natural coagulant and the makeup of the water. Usually, natural coagulants must be prepared, as they are not usable in their natural form. This may include peeling and cutting or drying and crushing into a powder.

The coagulants should be added to the water, then stirred for a few minutes, to encourage the formation of flocs. Afterwards, the flocs should be given some time to settle, then the water is filtered. Natural coagulants are very effective in decreasing the turbidity of water.

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

A joint Yale University and University of Virginia study from 2008 found that the Prickly Pear Cactus contains unique properties that can filter out water sediment, bacteria, and other contaminants. Mexican communities once used the cactus to filter water. If available, slicing the cactus, boiling it, then adding it to unfiltered water could be a very inexpensive and effective means of household level treatment of water.

Photo credit: Stan Shebs, Wikipedia/Creative Commons: Attribution-sharealike 3.0

Ozonation

Ozonation is a process where ozone, a form of oxygen, is added to unclean water. Ozone is a very strong oxidizing agent and kills many bacteria and viruses. Because of its oxidizing properties, iron and manganese in water will be oxidized to larger solid particles that are easier to filter out.

The effectiveness of ozonation changes depending on the contact time with water, but in general, less time is required than for chlorine. The amount of ozone used depends on the concentration of contaminants in water, as ozone reacts with each contaminant, leaving less ozone to treat other contaminants. A typical dose would be between 1-2 mg of ozone per liter of water. In addition, ozone works over a large range of water pH, but is the most efficient at pH just above 7.

However, ozone can cause some issues as it may react with chemicals in the water to produce harmful products. For example, bromide in water reacts with ozone to form bromate, which has shown to be carcinogenic in rats.

It is important to ensure the ozone generators are not leaking, because ozone is a toxic gas. There are several health effects including headaches, dry throats, and irritation and burning of the eyes.

Settling
Settling has long been used throughout history. It consists of leaving water untouched for some time, allowing gravity to settle larger particles, including turbidity-causing particles (sand, silt), as well as larger pathogens (some protozoa and helminths).

Depending on the water quality, water should be settled for a few hours to a few days. Afterwards, the settled water is carefully removed and put into another container, without disturbing the sedimented particles. The containers should be cleaned thoroughly after each use.

Advantages
It is effective at reducing large particles in water and in decreasing the turbidity of water. To be more effective, this method could be combined with a coagulant (either natural or chemical) to reduce smaller particles. Settling is a very cheap method, as it does not require any additional material apart from containers of water.

Disadvantages
Settling does not remove most bacteria or viruses from water, so it should usually be used in conjunction with another water treatment method. It may also take some time for water to settle, so users may want to use three (or more) containers, to ensure water is available every day.

The next several methods involve using the sun's energy to treat water. As energy demands increase in the world, renewable sources become very important. Solar energy is limitless and clean.

Solar disinfection

Solar disinfection is a relatively new method, first presented by Professor Aftim Acra in 1984. Within the next decade, research at Eawag developed a standard procedure for solar disinfection, known as SODIS. Today, over 2 million people use SODIS daily for their drinking water needs.

This method consists of using rays from the sun to kill pathogens in water through UV-A radiation and infrared radiation. Ultraviolet light is a type of electromagnetic radiation, part of the natural energy produced by the sun for instance, that is invisible to most humans. UV-A is one of the subtypes of ultraviolet light and has a longer wavelength. Infrared radiation is the type of radiant energy invisible to human eyes but sensed as heat by the body.

UV-A radiation leads to the build up of protein in cells, which ultimately kills them. Infrared radiation heats the water. Most pathogens will die when exposed to both temperature (caused by infrared radiation) and UV-A light. The perfect temperature is at 50°C.

A transparent bottle must be used for the sun rays to reach the water. In addition, the plastic bottle must be PET (polyethylene terephthalate). PVC (polyvinyl chloride) bottles must not be used as they contain additives that can leach into the water. Glass bottles may work, but they are not as effective because less UV-A light is transmitted.

The bottles should be placed on a roof or rack in the sunshine. Depending on the weather, the time must be adjusted. For example, if clouds are minimal, bottles should be left for 6 hours. If the sky is more than 50% cloudy, the bottles should be left for two days. Finally, SODIS will not work on days with continuous rainfall. However, SODIS can be improved if they are placed on surfaces reflecting sunlight, such as aluminium or zinc, corrugated roofs for example. SODIS methods are more efficient depending on the geographical location of the area, with the best locations in between 15° and 35° from the equator.

The water must have a turbidity lower than 30 NTU. At high turbidites, the particles in the water block the sun rays, reducing the radiation reaching the water. The bottles should also be cleaned regularly, with clean water.

The SODIS method consists of the following simple steps:

1. **Wash a plastic bottle:** The bottle must be clean, transparent, col- ourless, 2l in volume or smaller, and have all plastic or paper labels removed. We recommend using PET bottles and to wash them with soap before the first usage.

2. **Fill bottle with water:** Potentially contaminated water is filled into a PET bottle. The water should not be very turbid.

3. **Expose bottle to the sun:** The bottle is exposed to direct sunlight for one full day (at least 6 hours including noon hours) on mostly sunny days, or 2 days when the sky is more than 50% clouded. On days of continuous rainfall, SODIS should not be used.

4. **Store water:** The treated water is stored in the bottles until con- sumption in order to avoid re-contamination.

Advantages

Solar disinfection is simple to use, and there are no costs if the plastic bottles are reused. This method also does not change the taste or smell of water, which some other methods do and is effective against pathogenic bacteria. Recontamination is also lower because the water does not need to be transferred to another container.

Disadvantages

Water may have to be treated beforehand to reduce the turbidity. It is also difficult to treat lots of water at once, as bottles are usually limited to 1-2L in size. The time needed to fully disinfect water is long. SODIS has limited effectiveness against certain viruses and protozoa and requires sufficient sunlight.

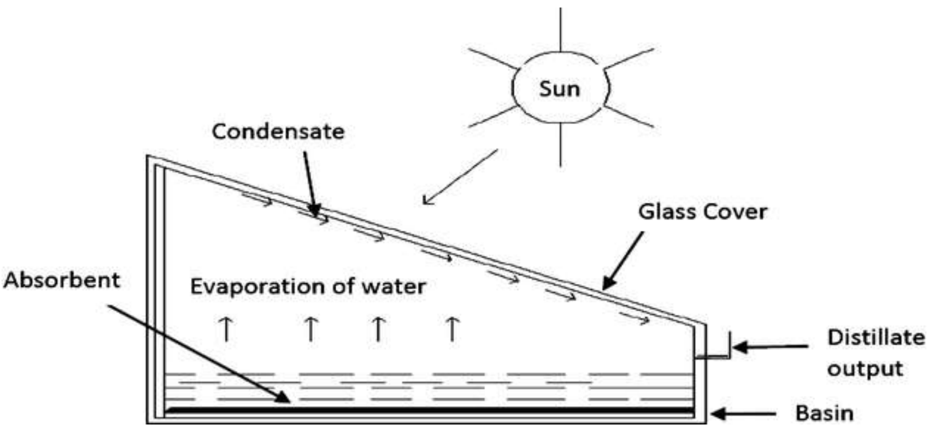
For more informarion, this open-source document is available for free download. “SODIS manual: Guidance on solar water disinfection” by Sandec, the Department of Sanitation, Water and Solid Waste for Development at The Swiss Federal Institute of Aquatic Science and Technology.
https://www.sodis.ch/methode/anwendung/ausbildungsmaterial/dokumente_material/sodismanual_2016_lr.pdf

Solar Distillation
Solar distillation is a treatment method that has been used for many years. The process consists of using the sun's energy to evaporate water, then capturing the water vapour and condensing it back into a liquid.

Through this method, contaminants, including pathogens, chemicals, and minerals are not evaporated, so they are left behind. They generally produce pure water and do not need any outside source of energy.

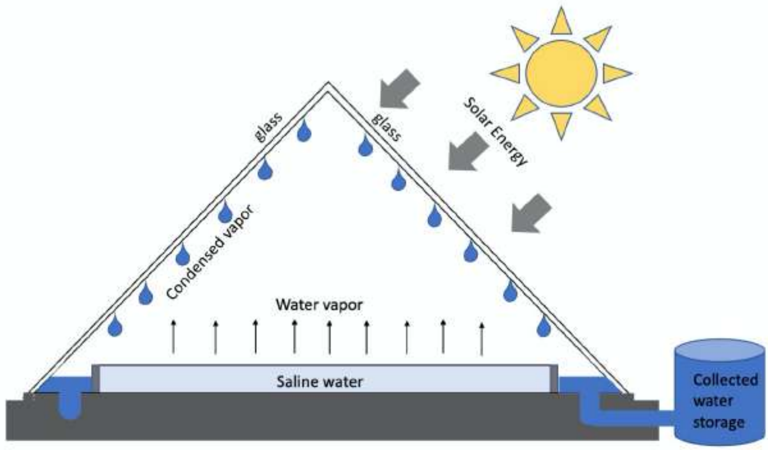
Many different designs exist, but they all consist of a water source, where water is evaporated, then drips into another section, which will be clean water. Designs can also range in size. Household filters can be as small as $0.5m^2$, but community filters also exist, which can hold up to 600 m^2 of water.

Below is a diagram of a solar still. It distills or purifies water through the processes of evaporation and condensation.



Basic Structure of a Passive Solar Still

Reprinted from Manchanda, H., Kumar, M. A comprehensive decade review and analysis on designs and performance parameters of passive solar still. *Renewables* **2,** 17 (2015). https://doi.org/10.1186/s40807-015-0019-8, Creative Commons Attribution 4.0 International License



Solar distillation is most effective in warmer and sunnier climates. As such, it does not work on cloudy days, similarly to SODIS. However, to improve the rate of treatment, "active" solar stills exist. These are solar stills that use additional thermal energy from an external source to increase the rate of evaporation.

Advantages
This method produces pure water, even from highly salted sea water, and is very cheap, requiring little to no maintenance (some regular cleaning) or skilled operators. Another advantage is there are no additional costs after the base device, such as energy or electricity costs.

Disadvantages
Distillation is a very slow method with low productivity of clean water, as it requires a considerable amount of solar energy to heat up and evaporate water. The waste from the solar still may also cause contamination itself if it is not disposed of properly. Finally, solar still cannot be used at night or on cloudy days, which decreases the amount of time it can be used, compared to other water treatment methods.

<u>Solar pasteurization</u>

Solar pasteurization is a method similar to boiling, but instead of reaching 100°C, the water reaches a slightly lower temperature, around 65-75°C, but over a longer time. If water is at 65°C for 6 minutes, all pathogens will be killed.

Pasteurization is usually done through solar cookers, which are insulated boxes, made of either wood, cardboard, plastic, or woven straw. The cookers have reflective panels to direct sunlight into the water, heating it. Two methods can be used to determine whether the water is at the right temperature: either a thermometer, or an indicator, such as beeswax (melts at 62°C), or soya bean fat (melts at 69°C).

This method requires moving the solar cooker frequently to ensure it is always at the optimum area and never in the shade. It will also not work on rainy or cloudy days.

After pasteurization, water is susceptible to recontamination, so safe storage is required after treatment.

Solar pasteurization is very effective in removing pathogens, although it takes a reasonable amount of time.

A solar pasteurisation device in the shape of a box with a glass cover and a reflecting interior and folding lid. The water container is put inside the box and heated with solar heat. Source: CAWST (2009), licensed under CC BY-SA 4.0

Advantages

As it only uses the sun's rays, there are no additional costs from electricity, chemicals, or fossil fuels, as boiling does. In addition, there are many simple designs available which are inexpensive.

Disadvantages

Depending on the weather, this method may not always work. It also will not reduce turbidity, odor, taste, or color from water, nor will it remove chemical contaminants. Users will also need to wait for the water to cool after pasteurization, which may put it at risk for recontamination. Finally, either a thermometer or an indicator must be used, whereas for boiling, there is a visual indication through the bubbles.

Straining

Straining is another very old water treatment method; it has been used for centuries. This method consists of passing water through cloth, which filters out sand, silt, clay, and some pathogens out of the water.

The cloth is usually folded over four times to increase the layers the water must pass through. If not folded, the pore size is between 100-150 microns, but after four folds, the pore size is reduced to 20 microns. It is a similar idea to membrane filtration, but the pores are much bigger.

The cloth should be washed with clean water after each use, to remove the contaminants from the cloth. Once the threading becomes loose, the cloth should be replaced.

It is quite effective in removing the bacteria causing cholera in water, as well as many helminths and eggs. However, most viruses pass through.

Image: "Pakistan floods: Making water safe for drinking" by Oxfam International is licensed with CC BY-NC-ND 2.0.

Advantages
This method is very simple and easy to use. Most people have easy access to cloth at relatively cheap prices, and there is no equipment needed. It is also useful in reducing the turbidity of water. Finally, the filtration process is fast, compared to other methods.

Disadvantages
Water is wasted in this filtration process as the cloth must be washed after every use. It is also not very effective for the removal of both bacteria and viruses, as well as chemical contaminants.

Water transport and storage

Safe water storage is a term referring to keeping treated or filtered water in a container that prevents the water from being contaminated again. Some guidelines for safe water storage include:

- Water should be collected and transported in covered, clean containers without touching people's hands if possible.
- Small openings in the container are better than wider ones to minimize the water exposed and reduce contamination from hands, cups or ladles into the stored water.
- Containers should not have been previously used for chemicals or toxic substances, as traces will remain in the container.
- Containers should be cleaned with soap and brushes, or a chlorine solution on a regular basis.
- Once the containers reach a household or school where they will be used, it is important for the containers to be covered and not exposed to the open air.
- When collecting drinking water from the containers, the water should be poured out or tapped out of the container by a spigot, instead of dipping a cup or other object (which may already be contaminated) into the storage container and contaminating the whole container of water.

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.

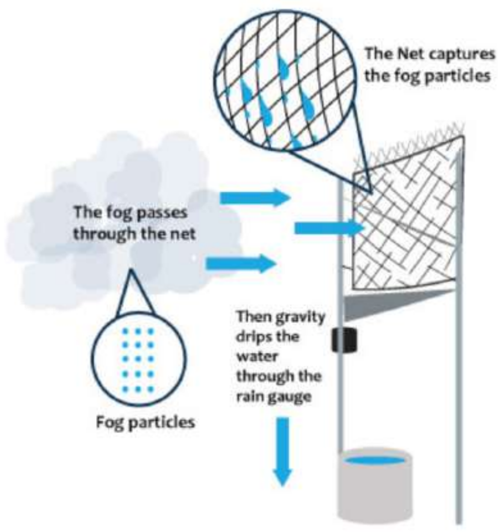
Presently, the main limitation of AWH is the low volume of water produced.

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

Mount Boutmezguida in Morocco is the largest fog-harvesting project in the world, filtering more than 6,300L of water daily, which serves a community of 1,000 people. The area receives only 5" of water in rainfall per year, so the fog-harvesting project has drastically improved lives of many women who used to walk extremely long distances to fetch water.

Certain animals and plants have unique mechanisms for survival in areas with little rainfall, which could provide inspiration for investigations on bioinspired fog water harvesting methods. For example, researchers are studying the Namib desert beetle, which collects water on its back, through water attracting bumps and microgrooves, where it then condenses and trickles directly into the beetle's mouth. Another example are spiders. Spider web silks collect water through a combination of its spindle-knot structure with their rough surfaces, and web joints which are less rough. Water droplets are driven towards the rough knots from the joints. There are also several plants which use mechanisms, such as being covered with hair-like needles to reduce exposure to sunlight, to increase storage of water.

Scientists at the University of Virginia are studying ways to tweak the simple design of fog nets to be more effective at capturing water. Inspired by a natural method, California redwoods' collection of fog on their pine needles, researchers have removed horizontal wires from the mesh, preventing water droplets from getting trapped in the mesh and capturing water three times more effectively than traditional nets.

At MIT, scientists have discovered that passing an electrical field of charged particles through the collecting mesh draws droplets towards the mesh as a magnet, increasing its ability to collect water.

This link provides detailed instructions on building a simple fog collector, with photos, complete list of materials, and step by step instructions. https://www.baysidefogcollectors.com/sfc-assembly-instructions-1

Dew Water Collection

As previously mentioned, not all locations have suitable conditions for fog harvesting. Water droplets that form due to condensation of vapour on a surface at a temperature below its dew point temperature is called dew water, which can be harvested for drinking water even in the driest climates. Dew water collection devices rely upon radiative heat loss, are simple, and don't require power sources as fog harvesting does. However, fog harvesting doesn’t yield large amounts of water, so are better suited to serving small communities.

Kothara village in India has the first large-scale drinking water production plant using dew condensers, which also harvest rainwater. Together, the plant produces 150,000 L per year of filtered drinking water.

Desiccant-based Water Collection

Desiccant materials are materials that can absorb moisture through both adsorption (liquid soaked up like a sponge) and absorption (individual molecules gathering on surfaces) in a three staged process. Some examples of desiccant materials are silica gel, zeolites and $CaCl_2$. Desiccant systems rely on thermal solar energy to drive the process.

AWH research and technology is just starting. Innovations to improve quantities of water collected in AWH could come from research into new types of absorbent and adsorbent materials and improvements in engineering design.

One example of a new atmospheric water harvesting technology is Majik Water. The machine harvests drinking water from the air using desiccant materials to absorb water, then solar thermal heat to release water for collection. The units come in different capacities, ranging from 25L for household use to 1000L per day for larger communities, such as schools. According to founder and CEO, Beth Koigi, at the moment the devices are mainly used in Kenya and East Africa, although some have been sent to South Africa and India.

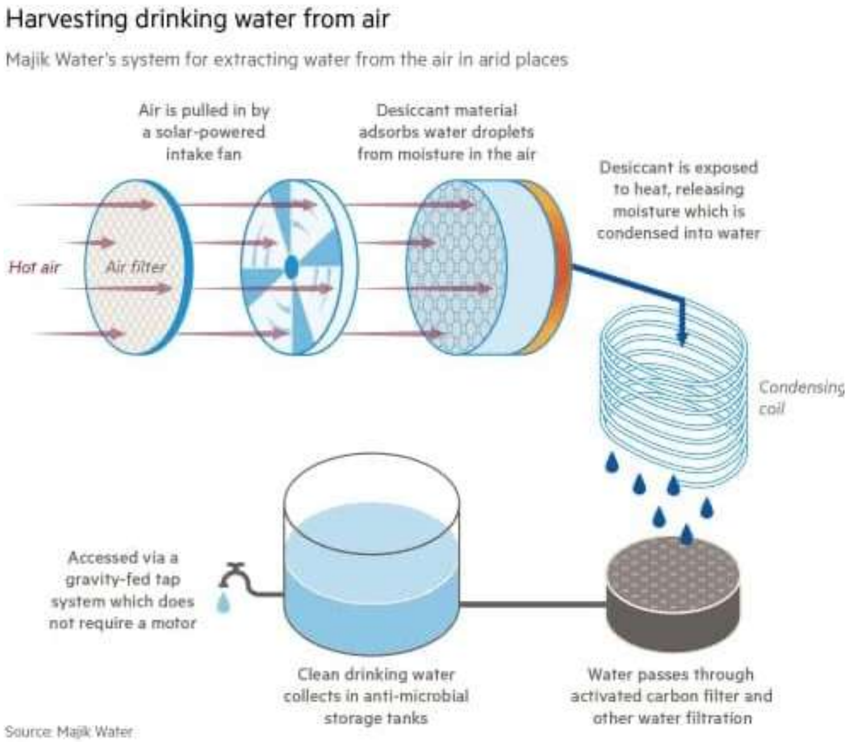


Image reprinted with permission from Majik Water, http://www.majikwater.co/

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.

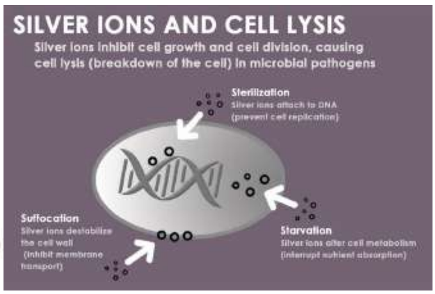
'Wrinkled' graphene, where a layer of the material has been scrunched up into a microscopic series of peaks and valleys creating nanochannels, is being studied in MIT and Brown University labs for their applications for water filtering. Current studies show water vapor has been able to pass through,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

Madidrop Ceramic Water Purification Tablets

The MadiDrop is a small micro porous and natural ceramic tablet, infused with silver nanoparticles, which kill microbes. When the tablet is put into water, the disk kills 99.9% of all pathogens. They are easy and relatively inexpensive to transport due to their small size. However, a disadvantage is their lack of sedimentation treatment, so water should go through a pre-filtering process first.

How the Madidrop Works



One unit, costing $14.95, can treat up to 20L of water each day and lasts for one year, treating 7,000 L of water in its lifetime. It is extremely simple to use; it must be placed into a drinking water storage container, and hence does not have any electricity requirement. There is no change to the taste of water, which is preferred to chlorine treatment.

As the tablet treats only 20L each day, this is a great application for household use or small communities.

How to Use MadiDrop

Images reprinted with permission from MadiDrop.com

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.

In developed countries, Droople may be more useful to help monitor their water appliances remotely for maintenance, improving efficiency through automation and helping in water-energy savings. In developing countries, on the other hand, Droople is more useful in managing water itself first. According to Mr. Bouzerda, CEO of Droople, for example, in some areas of Africa, Droople is used to monitor water usage from a common well so different farmers can know how much they each used and pay proportionately. Another usage is as a smart sanitation solution for remote shared restrooms to predict when maintenance or cleaning of the waste tanks is required, reducing incidence of diarrhea and diseases.

In response to the role of computer science in the future of solving the current water crisis, Mr. Bouzerda says, "Today, even though we have a water meter at the entry of all buildings in the developed world, we still don't know where it goes afterwards, if it is appropriately used or not, can we do better, what the data tells about the occupant's behavior, their health, their hygiene, etc. IoT combined with AI (Machine Learning, Deep Learning, etc.) will create a new transparency on how humanity behaves with water and what this behavior tells about us. We don't have to forget that water knows much more about us than we do about it. The more humanity is aware about its water relationship, the more it will help to understand, value, and manage water itself. Tomorrow, we will be able to design buildings that will understand those behaviors and adapt themselves to them to reduce and optimize water consumption, hot water production, heating demand and supply, and AC demand and supply."

SMS Reporting

U-Report, a UNICEF initiative, is a messaging tool aimed for young people to send messages when a natural disaster is incoming. For example, sending messages to summarize actions that should be taken in the event of flooding. In addition, U-Report can also gather information and opinions from its users, then the data and insights are shared back to the communities. The initiative is already active in 68 countries with 11 million users.
https://www.unicef.org/innovation/U-Report

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 Make Soapy Water of the Right Concentration as an Alternative to Bar Soap

Republished with permission of The American Journal of Tropical Medicine and Hygiene 99, 2; from Sultana F, Unicomb LE, Nizame FA, et al. Acceptability and Feasibility of Sharing a Soapy Water System for Handwashing in a Low-Income Urban Community in Dhaka, Bangladesh: A Qualitative Study. *Am J Trop Med Hyg*. 2018;99(2):502-512. doi:10.4269/ajtmh.17-0672; permission conveyed through Copyright Clearance Center, Inc.

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.

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- 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.

Sanitation

Sanitation is an equally important part of the clean water equation. Without improving sanitation, maintaining clean drinking water is difficult.
Safe disposal of feces is important, so everyone should always use a toilet where possible. Open defecation is not safe, as children can pick up pathogens by playing in the area, and the pathogens can also contaminate the drinking water supply.

Ideally, there should be one toilet for each gender at a minimum; the toilets should also provide privacy and be in a safe location. In a study in Nairobi, Kenya, 63% of women reported experiencing violence in public toilets. To better cater for women and girls, water, soap, hooks, shelves, mirrors, and access to an area to dispose of menstrual products is helpful. Arrangements for cleaning and maintenance of toilets are necessary to keep the area hygienic.

In countries where open defecation is still prevalent, Ms. Bostrom explains that community led total sanitation (CLTS) has led to good results. CLTS focuses on behavioral change, where community members analyze their sanitation behavior, which helps them become more aware of their actions, such as touching their mouths with fecal matter. Hopefully, this will lead to the community wanting change and encourage innovation.

However, Ms. Bostrom also notes this is a slightly controversial method, as some argue that the communities are being shamed for their behavior.

Ms. Bostrom is also hopeful that less developed countries can "leapfrog" over the current toilet system, which uses huge amounts of water to flush. Instead, she hopes a new method of discarding wastewater can be innovated without wasting so much water.

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, Costa Rica and Puerto Rica. The rainwater is collected and filtered for sediment, pollutants and any last traces of pathogens. As discussed in the

Rainwater Harvesting section, this is a great option that requires no-electricity or pumps, with gravity providing the pressure for filtration.

Charitywater.org

Along with implementing community-owned water projects, charity: water helps facilitate comprehensive water, sanitation, and hygiene (WASH) programming to protect everyone's long-term health. Founded in 2006, they have funded nearly 80,000 water projects benefitting 13 million people across 29 countries.

Thirstproject.org

The mission of the thirst project is simple: to build a socially conscious generation of young people to end the global water crisis. This is done through education and encouraging these young people to promote the clean water cause and build real projects globally. Donated funds are used to build freshwater wells.

Reboot2Kids.org

Reboot2Kids is my own charity that I founded to provide clean water solutions, computer labs and football boots to school communities. We work directly with each of our schools to identify the best way to improve their clean water situations, with solutions including education and involving students in decision making to give them self-agency and to feel invested in the projects, as well as providing physical solutions including wells, solar pumps, water filters, hand-wash stations, and rainwater collection systems. Computer labs are provided to teach digital literacy, but also for educating the school communities about water issues. All proceeds from the sales of this guide will be donated to Reboot2Kids and 100% of all donations go directly towards digital literacy or clean water solutions at our recipient schools.

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WATER WELL

A RESOURCE ON CLEAN WATER FOR LOCAL COMMUNITIES

Globally one in three people do not have access to safe drinking water, with 2.2 billion people not having safely managed drinking water services, according to UNICEF/WHO. This situation is not limited only to a few countries; problems finding safe drinking water exist on every continent, in rich and in poor countries.

This resource book offers ways that a community or household could self-implement access to clean drinking water, without needing to wait for big water infrastructure projects to be provided by governments or institutions. We offer an overview of the current drinking water situation in the world, why our bodies need water, what makes water unclean to drink, ways of filtering or treating water to be drinkable, and some new technologies on the horizon. There are concrete actions aimed at the communities and households who need clean drinking water, but also actions everyone can take to contribute to the issue of water scarcity.

It is our hope that the adding up of a lot of small gestures by a lot of individuals and communities can make big collective impacts.