Drinking Water

Grandma – I'm not sure our drinking water is safe since it comes from dirty places like rivers, lakes, or underground. Wouldn't it be safer to drink bottled water?

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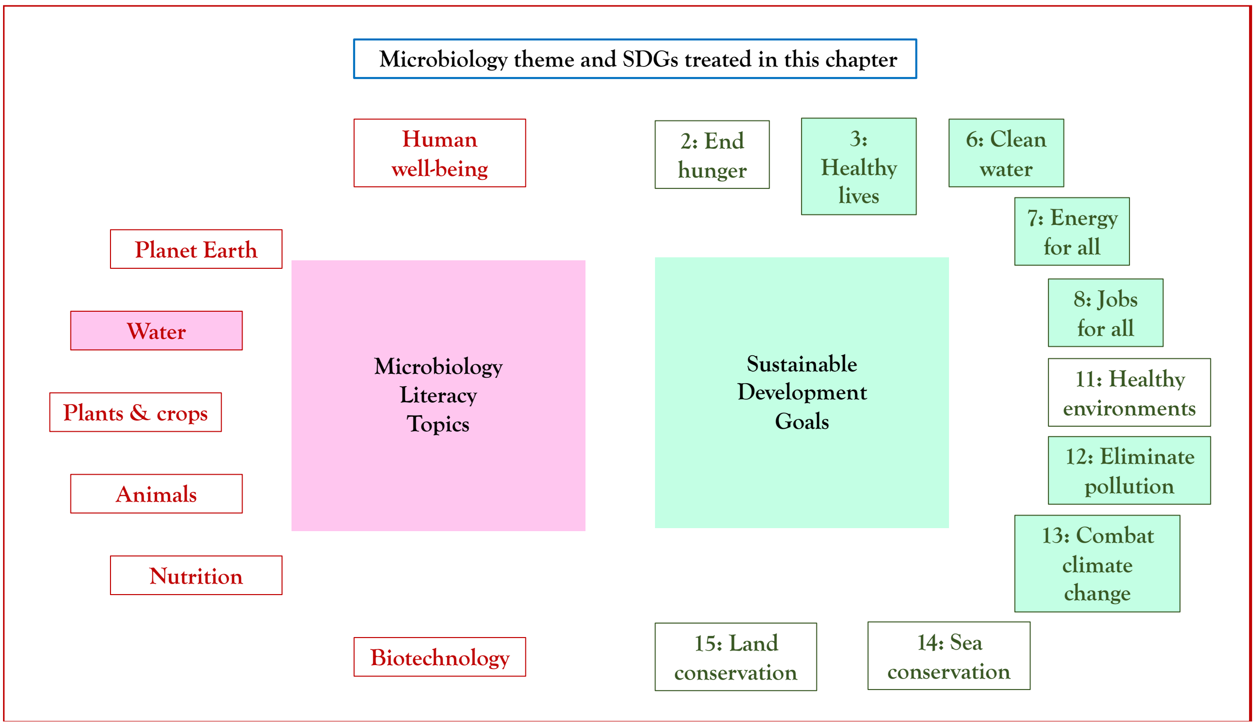
Drinking Water

Storyline

Most children in developed countries have no idea where their water comes from. Children turn on the tap, and clean, safe water flows out. Getting a drink of water to them feels as natural as breathing air. The difference is that oxygen occurs naturally in the air we breathe, but water in its natural state is not necessarily clean or safe. By studying the processes used to process raw water into drinking water, students in developed countries can begin to understand and appreciate the water-cleaning and water-distribution engineering feats they take for granted. In addition, students learn how valuable and precious our water resources are, sparking a desire to protect them through good stewardship.

Children in developing countries may not have the luxury of wondering where their water came from. They may have walked miles roundtrip to collect enough water for one day. Clean, safe water does not magically flow from a tap for them. Although the United Nations General Assembly recognized the Human Right to Water and Sanitation (HRWS) as a basic human right in 2010, approximately 10% of the world's population does not have access to clean drinking water. Polluted water can transmit waterborne diseases like diarrhea, cholera, dysentery, typhoid, and polio. The World Health Organization estimates that 485,000 people – mostly children – die each year because of drinking water that contained diarrhea-causing pathogens. That is more than 1,000 deaths every day, usually children and the elderly.

Because waterborne pathogens can be debilitating or deadly, is it better to drink bottled water? The answer will depend upon the circumstances of water procurement, treatment, distribution, and storage in your community.



The Microbiology and Societal Context

The microbiology: because water-borne pathogens are microscopic, nobody can tell by looking at water if it is safe to drink or not.

Pollution:

- bacteria, archaea, protists (including algae), and fungi play many important roles in the biochemical processes of freshwater ecosystems;
- human and animal waste can introduce pathogens that cause diarrhea, cholera, dysentery, typhoid, and polio;
- other pollutants include pharmaceuticals from human waste, personal care products, pesticides, and heavy metals;
- groundwater in wells may become polluted by leaky storage tanks or septic systems, as well as by flooding or by runoff over contaminated ground;
- pollution from one site (point source pollution) vs pollution from many sites (nonpoint source pollution);

Cleaning Water:

- treatment plants in urban areas utilize pretreatment, coagulation, flocculation, sedimentation, filtration, disinfection.
- in undeveloped nations long term solutions are cleaning water sources and providing wastewater treatment systems;
- undeveloped nations need short term solutions like economical point-of-use water cleaning/sterilization systems.

Sustainability issues: healthy lives, clean water, energy for all, jobs for all, healthy environments, eliminate pollution, combat climate change.

Drinking Water: the Microbiology

1. We cannot drink saltwater, and it is 97.5% of all the water on earth. Most of earth's freshwater is inaccessible. Less than 1% of all the water on earth is liquid and accessible, i.e. water that we could potentially drink. But before we drink, water needs to be tested and/or treated to make sure it's safe. Microorganisms that could make us ill, pathogens, might be living in the water, and they're invisible. You can't tell by looking if the water is clean enough to drink.

Our drinking water predominantly comes from two places. Just over half of the people on earth get their drinking from surface sources like rivers, lakes, or streams. Rivers, lakes, or streams are home to animals like fish and frogs. Microbes live there too.

Just under half of the people on earth bring their water up from underground, using wells. The groundwater in these wells is held in underground layers of porous rocks and sand that hold water in the pores (holes in the rocks) or in the spaces between the rocks or particles. The poster below (download at https://water.usgs.gov/outreach/OutReach.html) shows an aquifer that is connected to a river and a pond.

In addition to drinking water, a few (very few) communities worldwide convert salt water into fresh water. It takes a great deal of energy currently, to remove the salt from ocean water or brackish lakes or brackish aquifers. As technologies evolve it may become feasible for more communities to use salty water sources.

Lastly, some drinking water comes from cleaned wastewater, cleaned sewer water. These systems are rare now, but will become more widespread as our fresh drinking water sources dwindle due to increased population and climate change.

No matter where your drinking water comes from it will inevitably have microbes in it. We've known about microbes in water since the mid 1670's, when Antonie van Leeuwenhoek described very little "animalcules" living in rainwater, pond water, and well water. Using a single high-quality lens that he produced himself, van Leeuwenhoek saw and described protists and bacteria in the water. His drawings and analysis opened up a new microscopic world that had been invisible. Although most microorganisms do not cause illness, surface water and groundwater may harbor pathogens that can cause illness. Just because water looks clean, doesn't mean that it is safe to drink.

Since water is home to microbes, some of which cause illness, we want to make sure those pathogens cannot hurt us. We can act proactively to keep pathogens out of our water by making sure that sources of human or animal waste are not near our drinking water sources. We also need to reactively get rid of pathogens already in the water. The three predominant strategies we use are:

- We can kill them with chemicals like chlorine or ozone (O_3).
- We can use ultraviolet light to damage their DNA, rendering them harmless to us.
- Or we can use other microorganisms in soils, filters or water to kill or inhibit their growth.

2. Pollution is introduced in many ways. The poster below (download at https://water.usgs.gov/outreach/OutReach.html) shows how water can become polluted.

At the top of the poster, we see a wastewater treatment plant that cleans sewer water from an upstream city. Often, Wastewater Treatment Plants discharge the cleaned sewer water into a nearby river. In developed countries, governments monitor the water released from treatment plants. They set limits for microbes, as well as pharmaceuticals and personal care products. In undeveloped countries, wastewater is often untreated and flows freely near drinking water sources.

Other potential contamination sources included in this poster are:

- agricultural pesticides and fertilizers,
- industrial waste from factories,
- heavy metals from mining or construction sites,
- improperly contained landfill or garbage dump,
- leach fields from septic tanks (private wastewater treatment sites) or outhouses, and
- storm drains that carry rainwater runoff, often oil from parking lots and dog poop or trash that wasn't disposed of properly.

Although most microbes in surface water do not cause illness, some do. Some examples are:

- the protists that can give us giardia or dysentery,
- the bacteria that can give us cholera,
- and the viruses that cause hepatitis A or diarrhea.

3. Rivers and lakes are home to microbes. Some may cause illness. Surface water must be cleaned before we drink it. Microorganisms like bacteria, archaea, fungi and protists play important roles in freshwater ecosystems. They fix nitrogen and produce oxygen. Microbial decomposers break down detritus (dead and decomposing plants and animals), returning the nutrients to the water for new life to use. In the process, these beneficial microbes in the water actually clean the water in rivers, streams, and lakes.

Microbes also produce food in fresh water ecosystems. In the presence of sunlight, protists known as algae, and cyanobacteria, produce simple sugars from carbon dioxide (CO_2) and water (H_2O) through photosynthesis. The sugars they produce, and indeed the microorganisms themselves, become the bottom level of the food chain. Photosynthesis produces a waste product, oxygen, that is needed by fish and other oxygen-breathing organisms.

Everything in rivers and lake water is not helpful or harmless. Pathogens, pharmaceuticals, pesticides, just to name a few pollutants, can hurt us. "Point Source Pollution" comes from one place, like a factory, feedlot, or leaky storage tank. "Non Point Source Pollution" can come from many places at the same time, e.g. excess pesticides in agricultural lands or residential areas. Dog feces are a good example of nonpoint source pollution. Pet feces left on the sidewalk or in parks can be carried off by rain and washed into a river or lake that is a drinking water source. The river is polluted by many dogs' feces coming from many places.

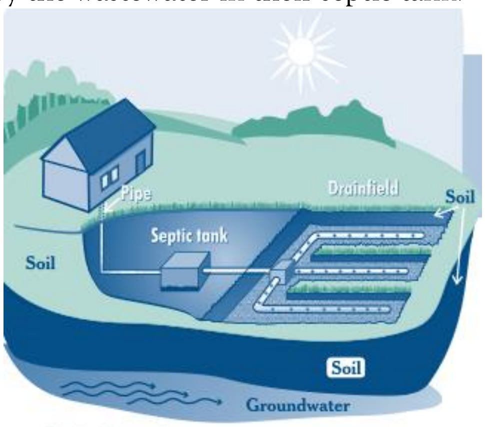
4. Water in wells can also be polluted. The water held in aquifers started out as precipitation (rain, snow, sleet, or hail). Some rain or melted snow evaporates, some is taken up by plants or animals, and some seeps into the ground. The seeping water is pulled deeper into the ground by gravity. As the water travels through the soil layers, pollutants are filtered out. Deep aquifers are usually cleaner than shallow aquifers since the water has traveled through more soil.

Microorganisms living throughout the soil work independently or in biofilms to break apart and digest any organics, including other microbes and pieces of plants or animals. As soil microbes work, they carry out beneficial processes: decomposition, nutrient recycling and cleaning the water that is infiltrating into the aquifer.

Although groundwater is usually clean, it can become polluted. In London, England in 1854 a cholera epidemic broke out in the Soho area. At the time, it was believed that "miasma," what they called "unhealthy air," caused diseases including cholera. The air did smell foul because sewage and rotting food that flowed through the streets. Modern plumbing had not been invented yet. John Snow, a physician, mapped the locations of deaths and determined that they clustered around one well in the Soho area. Looking at the water in the well, he saw white, flocculent particles that were not in the nearby wells. These were probably *Vibrio cholerae*, bacteria that cause cholera, which manifests as severe diarrhea, vomiting, and leg cramps. Snow persuaded authorities to disable the pump by taking off the handle and the outbreak rapidly declined.

Feces are not the only thing stored in tanks underground that can contaminate groundwater. Gas stations store fuel underground. Airports and military bases can store fuel for their planes and jets underground too. If these tanks leak, the fuels move into the underground water and pollute drinking water sources.

In rural areas, private wells are often the source of drinking water. People who pump drinking water from their own wells usually must take care of their own wastewater from toilets, showers, and sinks. Often a private well owner uses a septic system to process their sewage. Well owners must make sure that the water they pump from their aquifer has not been contaminated by the wastewater in their septic tank.



Typical septic system

https://www3.epa.gov/npdes/pubs/homeowner_guide_long.pdf

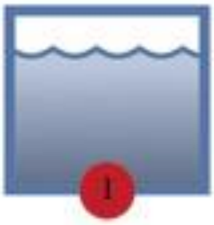
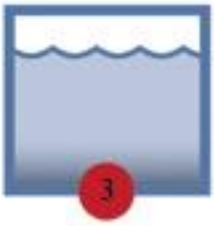
A typical septic system has four main components:

- a pipe from the home that drains wastewater from toilets, showers, sinks, or washing machines,
- a septic tank,
- a drainfield, and
- the soil.

Private septic systems are like large-scale wastewater treatment plants in that they rely on naturally-occurring microorganisms to clean the wastewater by ingesting pathogens in it.

5. In cities, drinking water treatment plants clean our drinking water. Raw water, especially from rivers and lakes or aquifers, may contain dirt, nitrates, heavy metals, radionuclides, pesticides, pharmaceuticals, hormones (from medications in insufficiently cleaned wastewater), as well as microbial pathogens and parasites. Drinking water plants must also consider color, taste, and odor of drinking water.

Note: Groundwater from wells may need only disinfection, but unless it comes from a protected aquifer, it may also require some or all of the steps below.

Step	Description of Step
 Pre-treatment	Pretreatment steps settle muddy water in basins. They may include screening the raw water to remove twigs, leaves, trash, or algae. Some water treatment plants may aerate the water by bubbling air into it in order to remove iron and manganese compounds that can cause peculiar tastes or coloring of the water. Pre-chlorination may be necessary to kill algae if it is abundant.
Coagulation  Flocculation	Coagulation and flocculation are used to get rid of suspended solids like silt, clay, plankton, algae, and other particulates. Many particles suspended in raw water have a negative charge, hence they repel each other. Treatment plants can add coagulants like iron salts, aluminum salts or polymers to neutralize the particles. Flocculation is the process of slowly mixing the raw water and coagulant, so that the neutralized particles will clump together.
 Sedimentation	These flocs or globs will settle to the bottom. Some microbial pathogens will be caught up in the flocs, but coagulation-flocculation will not remove them all.
 Filtration	Filtration removes smaller particles and pathogens. Granular filters can be made of a single medium (e.g. sand), or of two media (e.g. anthracite coal and sand), or three media (e.g. coal, sand, and powdered garnet). Activated carbon filters or granular activated carbon filters are made of natural materials that are treated to create highly porous surfaces. Microbe biofilms may grow on these filters. The microbes in the biofilms can aid filtration by killing or outcompeting pathogens. Reverse osmosis filters can also be used, but they are expensive. Pressure forces water through a semipermeable membrane to remove metals, organics, and microorganisms.
	Water purification either kills pathogens or renders them harmless. Chlorine gas or hypochlorite solutions are cheap and effective methods to kill pathogens. Ozone (O_3) is a more expensive disinfection step, but it also breaks down industrial chemicals and pharmaceuticals. Ultraviolet (UV) light render bacteria harmless, because UV light damages the cell's DNA. It cannot reproduce, therefore cannot cause illness. If UV light or O_3 are used, a small chlorination step is added to protect the water as it travels through distribution pipes.

Disinfection	
 Water Distribution	The clean, disinfected water is pumped through pipes to homes, businesses, and industry. Water is tested often to assure high quality standards.

6. Drinking water in undeveloped countries. Globally, at least 2 billion people use a drinking water source contaminated with feces, causing 485,000 deaths each year, predominantly among children or elderly. Primitive cleaning and disinfection methods do not always make the water safe. In addition, pathogens may also be introduced by unsanitary hands during storage or distribution. Inadequate sanitation often goes hand in hand with inadequate access to safe drinking water.

Currently, water may be treated at home with one of more these methods: boiling, filtration, solar disinfection, chlorination. Many new ideas and technologies are being developed to make point of use water purification systems more economical and easier to use.

7. Biofilms may form on pipes and pumps in Water Distribution System. As water is pumped to customers, it could come into contact with microorganisms in the soil that entered pipes through cracked pipes, faulty connections, or storage reservoirs. These microbes can grow into biofilms, a collection of one or more types of microorganisms that collect on surfaces.

Biofilms are not necessarily harmful. The biofilm that coats our intestines helps us digest our food. Biofilms in the soil help clean contaminated water as it travels into the aquifer.

But biofilms can harbor pathogens. They may lead to rotten egg odor or cause pipe corrosion in iron pipes. In order to control biofilm growth in drinking water distribution pipes, water utility companies must make sure to filter out any organics (food sources for microorganisms) and/or use chlorine as a final step to kill microbes the water may contact during its journey.

Biofilms do not only grow in pipes. They may also grow in water bodies that are drinking water sources. When fertilizers are carried off with rains and deposited in water bodies or when septic systems flow into water bodies, the excess phosphorus and nitrogen can cause a “bloom” of algae or cyanobacteria (sometimes called blue-green algae). The process, called eutrophication, starts with excess nutrients in the water, then leads to a growth of algae called a bloom, which blocks sunlight. Plants die. Eventually the nutrients are used up and the bloom dies. Bacteria digest it all, using up oxygen, which may lead to fish deaths. Cyanobacteria blooms are even more dangerous because theyproduce toxins that can poison people and animals. We must protect our water sources in order to protect our drinking water.

8. Many consumers believe that bottled water has more stringent quality standards than the water from their tap, but this is a misconception. Bottled water often has fewer oversights than tap water, and it is a hundred times more expensive. Customers must decide about purchasing bottled water based upon the quality and availability of drinking water in their home.

It is important to remember that when purchasing bottled water, customers are purchasing the water and the plastic bottle. Plastic water bottles are resistant to biodegradation and often become a source of pollution on land and in our oceans. The cost of making, transporting, and disposing of the bottles leaves a large carbon footprint.

However, where water treatment is ineffective or has broken down (e.g. Haiti earthquake) the emergency bottled water (which may be tap water from elsewhere) is a sensible option.

Relevance for Sustainable Development Goals and Grand Challenges

Visit the Koshland Science Museum's virtual drinking water exhibit and watch the introductory video to get a broad understanding the global issues and challenges involved in procuring and distributing clean, safe drinking water globally. Microorganisms in drinking water relates directly to several Sustainable Development Goals (SDGs) with microbial factors in italics, as set out by the United Nations, including:

- **Goal 3: Ensure healthy lives and promote well-being for all at all ages** (*improve health, reduce preventable disease and premature deaths).*

  1 million deaths each year are associated with unclean births. Infections account for 26% of neonatal deaths and 11% of maternal mortality. (WHO/UNICEF 2019).

  Some 297 000 children – more than 800 every day – under age five die annually from diarrheal diseases due to poor sanitation, poor hygiene, or unsafe drinking water. (WHO 2019)

  2 out of 5 people or 3 billion people around the world lack basic handwashing facilities at home. (WHO/UNICEF 2019)

  Unsafe drinking water can cause disease and death by introducing pathogens into our bodies. But clean, purified drinking water is also necessary for washing our hands and our produce before eating. Without clean water, disease can spread more easily through a community. Clean, safe drinking water and sanitation are closely related. Both are necessary to promote healthy minds and bodies.

- **Goal 6: Ensure availability and sustainable management of water and sanitation for all** *(assure safe drinking water, improve water quality, reduce pollution, protect water-related ecosystems, improve water and sanitation management).*

  A third of the world's biggest groundwater systems are already in distress (Richey et al., 2015).

  Over 2 billion people live in countries experiencing high water stress. (UN, 2018)

  700 million people worldwide could be displaced by intense water scarcity by 2030. (Global Water Institute, 2013)

  In July 2010 the United Nations General Assembly declared that access to water and sanitation was a human right. Each person has the right to 50 – 100 liters of water per day and that the water must be safe, acceptable, and affordable. It should not cost more than 3 per cent of household income. The water source should be within one kilometer of the home and collection should not exceed 30 minutes.

As population numbers increase, so does water scarcity. Governments everywhere need to align their water allocations with the needs and uses of different users, while respecting the environment.

- **Goal 7: Ensure access to affordable, reliable, sustainable, and modern energy for all** *(ensure access to clean, renewable and sustainable energy, and increase energy use efficiency).*

    Although some electricity sources like wind are not water intensive, 90% of global power generation is water-intensive. (UNESCO, 2014)

    Agriculture (including irrigation, livestock and aquaculture) is by far the largest water consumer, accounting for 69% of annual water withdrawals globally. Industry (including power generation) accounts for 19% and households for 12%. (FAO, AQUASTAT)

    Roughly 75% of all industrial water withdrawals are used for energy production. (UNESCO, 2014)

Fresh water is a critical ingredient for power plants that use turbines. The rotating shaft of the turbine drives the generator where an electromagnet rotates inside a copper coil cylinder and makes electricity. Hydroelectric power relies on the water turbines built into the dams. Thermo-electric power plants also use turbines. Fossil fuels, nuclear rods, or the sun's rays are used to heat water, converting it into high pressure steam that rotates the shaft of a turbine. These water-dependent power plants are currently the most predominant source of electricity globally.

- **Goal 8: Promote sustained, inclusive, and sustainable economic growth, full and productive employment and decent work for all** *(promote economic growth, productivity and innovation, enterprise, and employment creation).*

    A study of time and water poverty in 25 Sub-Saharan African countries estimated that women spend at least 16 million hours a day collecting drinking water, while men spend 6 million hours, and children 4 million hours on the task. (WHO/UNICEF, 2012)

    Reducing the time it takes to fetch water from 30 to 15 minutes increased girls' school attendance by 12% according to a study in Tanzania. (UNICEF)

In developing nations, carrying water is done daily and mostly by women and children. It is dangerous and time-intensive. By ensuring access to clean drinking water, people could spend less time and effort in the pursuit of fetching, cleaning and storing water. They could spend more time in school and with families and contribute to the community.

https://www.who.int/news-room/fact-sheets/detail/drinking-water

- **Goal 12. Ensure sustainable consumption and production patterns** *(Achieve sustainable production and use/consumption practices, reduce waste production/pollutant release into the environment, attain zero waste lifecycles, inform people about sustainable development practices.)*

> Global water demand (in terms of water withdrawals) is projected to increase by 55% by 2050, mainly because of growing demands from manufacturing (400% increase). More than 40% of the global population is projected to be living in areas of severe water stress by 2050. (OECD, 2012)
>
> While almost 800 million people are currently hungry, by 2050 global food production would need to increase by 50% to feed the more than 9 billion people projected who live on our planet (FAO/IFAD/UNICEF/WFP/WHO, 2017).

As human populations grow, so do our water needs. In the future we will need even more water for drinking, more water for sanitation, more water for health care, more water for farming, more water for energy, and more water for industry. We will have to all become vigilant water stewards in order to assure there is enough drinkable water for everyone. For more information about how much water it takes to make some common household items, visit https://waterfootprint.org/en/resources/interactive-tools/product-gallery/

- **Goal 13. Take urgent action to combat climate change and its impacts** *(reduce greenhouse gas emissions, mitigate consequences of global warming, develop early warning systems for global warming consequences, improve education about greenhouse gas production and global climate change).*

> Climate change will have its most direct impact on child survival through three direct channels: changing disease environments, greater food insecurity, and threats to water and sanitation. (UNICEF, 2019).

Violent weather events caused by climate change can cause communities to receive too much water which can scour the land as it runs off and empties into rivers, often carrying pollutants with it. Flooding can pick up pollutants on the land, then carry them back to river when the flood recedes. Polluted water is more expensive and energy-intensive to clean, no matter who is cleaning it. When more energy is required from fossil fuel burning power plants, more carbon dioxide will be released into the atmosphere, causing more climate change. This creates a loop of increasing energy needs that make violent weather events more likely that requires more energy to clean up, etc.

Water scarcity or water stress are other outcomes of climate change. Drought is deadly and not just because people are thirsty. Drought kills crops and food animals. As both food and water become scarce, families must leave their homes, immigrating to more suitable lands in order to survive.

Potential Implications for Decisions

1. Individual implications

a) Is there anything you dislike about your drinking water?
b) What circumstances make you or people you know reach for bottled water?
c) Why do you or people you know trust bottled water to be cleaner or safer?
d) Nonmicrobial aspects of bottled water:
   i) How often do you drink bottled water in a week? A month? A year?
   ii) Using the number above, how much did you spend on bottled water last year?
   iii) How many plastic bottles of water did you put in a recycle bin?

2. Community aspects

a) Does your community provide clean, safe drinking water? If not, what are the sources of the pollutants in your drinking water source?

b) Does your community have enough water to provide to everyone?
c) What kinds of agriculture or industry in your community might compete for domestic water uses?

3. National aspects

a) What organization in your country is responsible for setting water quality standards?
b) How are your countries water quality standards enforced?

Pupil Participation

1. Class discussion of the issues associated with drinking bottled water vs water from the tap.

2. Pupil stakeholder awareness

a) What are the most important qualities you want your drinking water to have? Put them in order from most important to least important.
b) Choosing to drink bottled water or tap water has consequences which affect the SDGs. Which of the Sustainable Development Goals (SDGs) mentioned above are most import to you individually? As a class?
c) Water is not just for drinking. What are all the ways that drinking water is used in your home. In what ways do businesses and health facilities in your city (or a nearby city) use drinking water? Are your toilets flushed with drinking water? Are your clothes washed in drinking water? Are gardens watered with drinking water?
d) What can you do as an individual to reduce your water footprint?

3.) Exercises

Elementary

a) Find out where your drinking water comes from. Is it surface water or underground water?
b) Imagine you are a drop of water in the river, lake or aquifer that supplies your drinking water. As a class or individually, draw a map showing your journey from the water source to your mouth. Be sure to draw in microorganisms (show them in a magnified circle because otherwise they'd be invisible). Most of the microorganisms help clean your water, but draw in some that might make you sick.
c) Read the label on one or several bottles of drinking water. Where does the water come from? Where is it bottled? Find those places on a map. Draw the journey of the water it is transported to you. Why might it be good to get water from far away? Why might it be bad to get water from far away?

Secondary

a) Your drinking water
    - Who sets your drinking water quality standards? How they are enforced?
    - Find out where your drinking water comes from.
    - Determine the processes your drinking water goes through before you drink it.
    - How much does a liter of your tap drinking water cost?
b) Your bottled water

- Research the bottled drinking water you or your classmates have purchased or been given. What did the water in the bottle come from? Where was it bottled?
- Find out who sets the water quality standards for your bottled water and how those standards are enforced.
- How much does a liter of this water cost? How much did you spend last year on bottled water?

c) The plastic bottle *(nonmicrobial factors)*

- Investigate the production of the plastic bottles used to bottle water to determine its carbon footprint as well as its water footprint.
- What types of transportation is necessary to deliver the bottle from the factory to you?
- How much energy does it take to make the bottle? How much water was used to make that electricity?
- How much clean, fresh water was used to make the electricity that was used in the bottle's manufacturing.
- Research the efficacy of plastic bottle recycling.

The Evidence Base, Further Reading and Teaching Aids

Drinking water – microbiology

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Drinking water – Sustainability

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Glossary

Aerate
Algae
Algal bloom
Aquifer
Archaea
Archaea
Bacteria
Biofilms
Cholera
Coagulation
Cyanobacteria
Diarrhea
Direct potable reuse
Disinfection
Dysentery
Eutrophication
Filtration
Fix nitrogen
Flocculation
Fungi
Indirect potable reuse
Nonpoint source pollution
Organics
Plankton
Point source pollution
Polio
Pretreatment
Protists
Sedimentation
Septic tank
Typhoid
Water-borne pathogens