Measures and technologies to address water shortages

Why do we have to deal with this problem?

Since 2010, the right to clean water and sanitation infrastructure has been an internationally recognized human right. However, there are still shortcomings in implementation. In 2015, around 2.4 billion people still lived without hygienic sanitary facilities and 663 million people still did not have access to clean drinking water (source: UNICEF/WHO 2015 according to “Wasserreport – Die Welt im Wasserstress” [Water report – The world in water stress]; 2017). This shortage of drinking water has negative consequences not only for the health of the global population, but also for food security. This trend is being further intensified by climate change and the growing world population.
Few people are aware that agriculture consumes the most fresh water worldwide, accounting for 70 percent of use. At the same time, intensive “industrial” agriculture has developed into one of the biggest water polluters. As the following examples show, this also affects people outside of developing countries. For instance, the groundwater in 27 percent of Germany’s land area is no longer suitable for drinking water production due to contamination from fertilizers and pesticides used in agriculture. In 70 percent of the cases in Germany, the nitrate content in drinking water now exceeds the 25 mg/l guide value recommended by the EU (source: German Federal Environment Agency and the Süddeutsche Zeitung dated 08/06/2017). In 2017, water resources became scarce in the United States, for example, in Los Angeles and Las Vegas, because the drinking water reserves were largely used to cover agricultural needs.

Therefore, water shortage is indeed a serious topic that can be addressed in class, whether in geography, biology, chemistry, or physics, and also on an interdisciplinary basis.

This information sheet can introduce potential measures and technologies to address water shortages only as short, concise solutions. However, it can serve as a starting point for students to explore the topic further in their own projects.

Measures to address water shortages

Many measures that can counteract water shortages apply not only to large agricultural or industrial companies; each and every individual can take small measures to help prevent water shortages.

Using water more sparingly in individual households

Using water sparingly should be a matter of course for most people, but unfortunately many still waste or contaminate precious drinking water, for example, by not repairing leaky or broken water pipes or by allowing wastewater to seep into the ground.
In addition, it should be noted that the sparing use of water must be implemented globally, since regional water-saving projects alone cannot solve the worldwide problem.
In 2014, the average German used approximately 127 liters of water per day, an American approximately 300 liters, a Dubai resident approximately 500 liters, but a person in India only approximately 25 liters per day (source: Food and Agriculture Organization of the United Nations, FAO). However, these values refer only to direct water consumption in a household, meaning cooking, washing laundry, bathing, flushing toilets, gardening, and filling swimming pools, etc. These values have barely changed since around 2007. Viewed globally, however, the savings potential is relatively low. That’s because for hygiene reasons alone, per capita water consumption urgently needs to increase in the poorest regions of the world. While it is true that household water consumption

has room for improvement in rich regions of the world through less watering of lawns, filling of fewer swimming pools, and less showering, this consumption is not the actual problem. Recent statistics on "per capita water consumption" from the FAO, UNESCO, etc., are therefore no longer indicated with reference to households, but rather as a "water footprint."

The water consumption "footprint" of every person is crucial

This footprint takes into account not only the direct consumption of individuals in their households (in Germany, for example, only 5.5 percent of total water consumption), but also indirect consumption in a country's agriculture and industry as well as the water used in imported industrial and agricultural products. Whether smartphone, T-shirt, French fries, hamburger, or tofu, all products used by end consumers were made using water locally and globally. For instance, the production of a single microchip uses approximately 32 liters of water, a T-shirt (from cotton cultivation to dyeing) approximately 4,100 liters, a hamburger (beef at 15,000 l/kg, wheat flour, lettuce garnish) approximately 2,400 liters, a portion of French fries approximately 180 liters, and even vegan tofu made from soybeans uses more than 900 liters of water per kilogram. Anyone enjoying a steak produced from locally raised beef must keep in mind that most of the fodder used (especially soy, with water consumption of approximately 1,800 l/kg) has been imported.
This also explains the extremely high value of per capita water consumption:
For the United States, this results in an annual water footprint of approximately 2,800 m³ per capita (7,800 liters per capita daily). In China, the value is approximately 1,100 m³ (2,900 liters daily). Germany has an annual water footprint of around 1,500 m³, which corresponds to approximately 4,000 liters per capita per day (source: German Federal Agency for Civic Education and waterfootprint.org).
People who want to prevent a global disaster caused by water shortages cannot be content with using the low-volume button on dual-flush toilets, but they must also reflect on people's consumption behavior and industrial and agricultural production processes.

Keeping sustainability in mind when using water

Sustainability means that people use resources such as water or other raw materials in a way that preserves them for future generations. In addition, the future viability of Planet Earth as a whole and thus also of the human habitat should be preserved.
For sustainable use of water, it is very important for each person to know how much water he or she uses and attempt to minimize the amount by using only as much water as is really needed, for example, to wash dishes. Viewed on a global level, people should make sure that agricultural activities are pursued only in places where they make sense to do so or in places using water-conserving plants or farming methods. An impressive example is the Aral Sea in Kazakhstan. During the era of Soviet government, the farmers in the region were compelled to cultivate cotton, which requires intensive irrigation and does not naturally occur in the arid Kazakh Steppe region. For the necessary irrigation to grow and harvest the required amount of cotton, the farmers extracted water from the tributaries of the Aral Sea, which subsequently shrank drastically and had lost 85 percent of its original water surface by 2006 (source: Michael Succow Foundation, 2009). In 2014, a particularly arid year, part of the Aral Sea completely dried up (source: Franz Mergenthaler, focus online, 2017). A small part of the Aral Sea, the North Aral Sea, has since been filled again to a depth of 3 m. This was possible thanks to the construction of a dam that prevented water from quickly flowing toward the southern part, where it would evaporate. However, all experts currently consider restoration of the entire Aral Sea impossible (source: Das Wunder vom kleinen Aralsee, Arte 2012).

Changing eating habits

Since fruit and vegetable production requires less water than meat production, some regions could benefit by switching from consuming large amounts of meat to a more vegetarian diet in order to save water. Of course, this applies only if crops are cultivated that do not require overly water-intensive production. Apart from that, the problem of high greenhouse gas emissions caused by factory farming would also be alleviated (methane from cattle farming and nitrous oxide from cattle, pig, and poultry manure). In addition, the slurry resulting from intensive livestock farming contributes significantly to groundwater pollution.

Controlled population growth and education

In order to reduce water shortages, population growth must be slowed. This reduction in growth can be achieved only through information and education, especially of women, in countries where birth rates are very high. This is particularly important because these countries are found in regions of the world, for example, large parts of Africa, where freshwater resources are very scarce due to the geographical and climatic conditions.

Technologies to address water shortages

In addition to a general change in thinking about the use of drinking water, technology can also make a contribution to improving the availability of drinking water, especially in regions where drinking water is rather scarce due to natural conditions.

Wastewater treatment is a prerequisite for clean drinking water

As late as the 19th century, it was also common in Central Europe to dig a well shaft for drinking water next to a cesspool for wastewater and feces (for example, in Munich). Or wastewater was discharged directly into the river from which drinking water was obtained, as in Hamburg. This resulted in recurring cholera and typhus epidemics. This situation did not improve until the first sewage systems and wastewater treatment plants were constructed (for example, in Munich by Max von Pettenkofer). The discharge of untreated wastewater into rivers is still a huge problem around the world today: According to UNESCO, in 2017 at least 80 to 90 percent of the world's wastewater flowed untreated into rivers, lakes, oceans and the groundwater (source: “2017 UN World Water Development Report, Wastewater: The Untapped Resource”).
Wastewater treatment is thus one of the most important methods for obtaining clean drinking water. There are several possibilities for this: physical, biological, chemical, and physical-chemical processes.
The first stage of wastewater treatment is a sieve (“screen”), which removes coarse solids. Next comes physical separation by density. Heavier particles in the water settle to the bottom of the tank (“sedimentation”) and are extracted as “sludge.” Lighter solids (for example, plastic or wood particles) float to the top and are skimmed from the surface.

The second stage involves the biological process, cleaning of the water using aerobic bacteria, which “eat” the organic suspended particles from the water. This means that the bacteria use oxygen to eventually break down the organic substances into water and carbon dioxide. If the organic substances in the water are from a natural source, they are broken down nearly 100 percent. Many synthetic substances, for example, solvents or medications, are not removed through this process. They must be removed subsequently through one or more of the following methods.

An additional chemical method for disinfection of wastewater already treated by means of microbial oxidation is carried out using chlorine or ozone, possibly also in combination with UV radiation. This combination has also proven successful for removing substances that cannot be broken down by microbes.
Purification through ion exchange, ultrafiltration using membranes, or adsorption using activated carbon is normally not carried out in wastewater treatment. (However, ultrafiltration and adsorption – for example, in Germany – are increasingly being used in the treatment of drinking water from surface and groundwater to compensate for agricultural contamination from pesticides and nitrates.
A physical-chemical process, the disinfection of the treated water using UV radiation, is also being increasingly used. As a result, for instance, the decades-long swimming ban for many rivers in Germany has now been lifted.

The first two purification processes are used in every modern water treatment plant. The other treatments are used as needed. After all, the wastewater is ultimately discharged into rivers, lakes, or oceans. Purification is therefore a precondition for the river or lake water to be used (in other places) as a source for drinking water production. If these standards were implemented globally, better wastewater treatment would be a good opportunity to take action against water shortages.

If all technical possibilities are fully exploited, wastewater can also be directly recycled into drinking water, such as in Singapore, where over 90 percent of the water is circulated.

Large seawater desalination plants for drinking water production

Water is actually not scarce, since two-thirds of Earth's surface is covered with water. However, nearly 98 percent of this water is unusable seawater. However, if people managed to figure out a way to use this salty seawater or saline groundwater under ecologically and economically favorable conditions, the water shortage could be eliminated worldwide.
Technologically, there are currently only two proven desalination methods for producing large volumes of water: thermally as a multistage flash evaporator system (a special distillation technique) and mechanically as reverse osmosis.
The thermal desalination plant in Abu Dhabi is currently the world's largest. In this plant, the seawater is heated, and then it evaporates and condenses. The salts remain in the seawater that has not evaporated. The water that evaporates is free from the sea salts and can be drunk. In detail, the plant works with 16 evaporation and condensation stages and a condensation stage in a countercurrent process. This means that the cold seawater is used as cooling water for the condensation process (= flash), heats up, and begins to evaporate. As a result, approximately 85 percent of the heat remains in the system and only about 15 percent must be added. Since the previously unused waste heat from gas turbine power plants in Dubai is used as the heat source, in this case the process also makes reasonable sense in ecological terms. Nevertheless, completely phasing out fossil energy sources would be even better for environmental reasons due to the high CO_2 emissions. However, due to the relatively high energy requirement in principle (approximately 12 kWh/m^3 of drinking water), this thermal process is poorly suited for conversion to renewable energies.
Another option for desalinating seawater is reverse osmosis. In addition to the thermal method, reverse osmosis is now also used on a large scale in the rich Arabian oil-producing countries and also on a larger scale in some regions of the United States and Spain. In this process, seawater is pressed through extremely fine membrane filters (the pores are just as large as a water molecule) using high-pressure pumps, thus producing clean drinking water. In terms of energy use, reverse

osmosis plants using 4 kWh/m^3 of drinking water are less expensive than thermal plants. If they could be operated 100 percent with solar electricity in sunny areas, they would be ecologically ideal.
The disadvantage of these two primary methods of seawater desalination is the relatively high investment costs. Populations in poorer regions of the world currently cannot afford the expensive water produced in this manner. Small plants that are fully operated using renewable energies, as described in the next section, would be good alternatives.
In the meantime, there have been a number of innovative improvements, especially in reverse osmosis, for example, the combination of reverse osmosis and a type of electrophoresis (ion migration in an electrical field). Unfortunately, so far none of the processes has proven successful on a larger scale.

Small water treatment plants fully operated using renewable energies

If it is assumed that in many regions of the world, 2 liters to 10 liters of inexpensive, clean drinking water per capita and day would be better than dirty or overpriced water, some solutions are available today.

Harvesting fog using net structures
In places that naturally have a lot of fog but extremely little to no rain (for example, in the Namib Desert or in parts of Ethiopia), the fine water droplets of the fog are captured in huge, fine-mesh nets. The droplets combine to form larger drops and then run downward, where the water is collected. In the “cloud forests” on Madeira, on La Gomera, and in regions of Costa Rica or the Philippines, plants and lichens have been performing this water-collecting trick for thousands of years. (Additional information about projects using this technology can be found online, for example, with the search terms “fog collector” or “CloudFisher.”)

Tapping into differences in humidity between day and night
In places where there is no fog but where temperatures fluctuate widely between day and night, often changing by more than 40 °C, there are also large differences in the relative humidity. In the heat of the day, a relatively large volume of water vapor is dispersed in the air. In the cold of the night, the water condenses on sand and rocks. If a transparent plastic dome (“Watercone”) is placed on the ground in the morning, the water evaporates until the air under the dome is oversaturated with water. Because the wall of the transparent plastic dome heats up less than the ground, the dew point of water is reached on the wall, and the water condenses on the plastic wall and trickles down, where it is collected in a trough. A Watercone with a diameter of approximately 90 cm can produce up to 1.5 liters of drinking water per day. That is enough to survive, but it is too little to subsist on permanently.

The SkyHydrant makes clean drinking water from dirty water using gravity
This mobile filtration system cleans dirty water using a membrane. The membrane filter consists of 10,000 ultrathin hollow fibers whose walls have tiny pores (diameter 0.1 µm). Contaminant particles and most bacteria do not pass through the pores. However, chemical contaminants dissolved in the water, such as salts, cannot be filtered out.
The SkyHydrant works without electricity and chemicals. The filtering process is “driven” purely mechanically using gravity (hydrostatic pressure resulting from the height difference between the tanks for dirty and clean water). The SkyHydrant is very light (12 kg), easy to use, and inexpensive: 1,000 people can be supplied with 10,000 liters of drinking water per day for 10 years for the equivalent of 30 eurocents per person annually. Launched in 2007, the device was used in 1,200

locations around the world in 2013 and is now distributed by a foundation (SkyJuice Foundation). At first glance, it is an ideal solution. The claim that no maintenance is required thanks to the applied technology must be questioned, however. Specifically, a maintenance-free, self-rinsing filter system requires electronic control of pressure and flow rate. At any rate, the membrane filters with a similar pore size used in European water plants require regular maintenance. The microbial water quality that can be achieved with this system is also considerably worse than the quality achieved with mobile high-tech water filters. However, the latter require a substantial amount of auxiliary energy.

Water desalination using the greenhouse trick

A more efficient, low-cost method that can be operated using 100 percent renewable energy is desalination according to the “greenhouse principle.” It can be used anywhere there is saline seawater or groundwater. A black, bottom-insulated tray made of plastic or metal is placed in a glass box similar to a greenhouse. Seawater is constantly added to this tray using a hand pump or an electric pump operated using photovoltaic power. The sunlight entering through the glass panes is absorbed almost entirely by the black tray and the seawater is intensely heated. The water evaporates and condenses on the glass panes like in the Watercone, runs down, and is collected. The concentrated seawater flows back to the ocean or is allowed to seep into the ground. With this method, up to 6 liters of drinking water can be produced daily per square meter of ground. Because the system is inexpensive and easy to scale in size, a greater number of people can be supplied with a sufficient volume of water.

The processes mentioned here are not the only desalination processes; a number of other similar methods and systems are not listed here.

Historical and modern water management

To prevent seasonal water shortages and to supply water as efficiently as possible to arid areas, people in many regions of the world have cleverly managed water distribution for centuries using reservoirs and aqueducts. Examples include the Incan Empire in South America, ancient Egyptians along the Nile River, the Roman aqueducts in Europe, underground conduits and cisterns in ancient Petra in Jordan, irrigation channels in Arabian Spain, and the modern levadas on Madeira. Today, water management can be improved further with the aid of modern measurement and data technology. Modern IT-based water management reduces water consumption and ensures fair water distribution. For example, meters distributed across the Indian subcontinent record the water extracted at important points of the existing irrigation system. These data are collected and evaluated using telemetry. This ensures that the water of the Indus River is equitably divided among the provinces despite large seasonal fluctuations. In this way, there is transparency for water distribution in one of the world's largest contiguous irrigation systems comprising an irrigation area of 10.2 million hectares (source: Diercke, 2013).

More groundwater is often used than is replenished

In most regions of the world, drinking water is produced from river water (known as “bank filtrate”) or from groundwater wells. When these water sources keep refilling due to sufficient precipitation, this is not a problem.

In many desert areas, the arid regions of the world, there is often still groundwater from prehistoric geological eras. For instance, the Sahara was still a rainy region approximately 5,000 years ago before it become a desert. However, in the Sahara and other arid regions of the world today, more water evaporates than falls as precipitation. This is why more and more wells were dug, for exam-

ple, in many regions of Arabia and Africa, and increasingly more groundwater was removed to supply agriculture and provide households with drinking water. This is nevertheless just a medium-term solution because the groundwater reserves will ultimately become depleted or salinized if insufficient rain falls locally.
Thanks to the U.S./German GRACE satellite project, we know from continuous gravity field measurements of various areas on Earth that in some desert areas such as the Sahara, the groundwater is “regenerated.” In some places, groundwater gradually flows underground across hundreds and thousands of kilometers from regions with abundant water to desert areas. However, this generally is insufficient to balance the water volume removed by people (source: Tagesspiegel 06/05/2013).

Mobile high-tech water filters are only a temporary solution

Ultimately, only very large and expensive water projects can improve the drinking water supply long term in developing countries’ densely populated areas. However, people living in more sparsely populated, remote regions can be connected to a central supply network only with difficulty, if at all possible, and therefore have only limited access to this vital commodity. Village communities in such regions obtain their water from nearby rivers, reservoirs, or other unsafe sources of water. Drinking untreated water frequently causes serious diarrheal diseases, cholera, or infection by worms. The mortality rate is particularly high among children and the elderly who become infected with diseases from drinking polluted water. The combination of many small, extensive water projects based on water purification systems operated with renewable energy could provide a remedy. In the meantime, there are small, reasonably priced solutions based on renewable energy (for example, the WaterCube), not only for water desalination but also for filtration and disinfection. Some companies active in the water treatment sector now offer mobile high-tech systems that turn dirty water into premium-quality drinking water in a compact, fully integrated system that performs coarse filtration to fine filtration by means of membrane technology and disinfection (using chlorination, ozone, or UV). Each system can provide thousands of liters of drinking water every day. Apart from the high price, the disadvantage of these systems is that they have a relatively high energy requirement and work, for example, using diesel-generator sets. In addition to the fuel consumption, they also require substantial maintenance; in most developing countries, these requirements cannot be met locally in the long run.
However, when large numbers of people need to be provided locally with drinking water due to flood or drought catastrophes, earthquakes, volcanic eruptions, or displacement to refugee camps, these high-tech devices are an ideal solution, at least temporarily. That is why they are often flown into disaster areas by aid organizations, as can be seen time and again in televised news.