The Water Module

Student resource

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Cover image: Cloudscape over the Phillipines, Astronaut photograph ISS048-E-10018 acquired on June 25, 2016 by the ISS Crew Earth Observations Facility and the Earth Science and Remote Sensing Unit, Johnson Space Center. M. Justin Wilkinson, Texas State University, Jacobs Contract at NASA-JSC.

Image Credit: NASA, Public domain. Other photos from the Gro for GooD project.

Note to educators

This booklet has been developed for use by Kenyan secondary school students. Schools in Kwale County, Kenya set up School Water Clubs in 2017 and tested out the information and activities that can be found in this booklet. The booklet can also be used to support classwork or projects in science or geography lessons. Students should note that there is a glossary at the back which explains all the technical terms used in this resource.

Each section includes background information and instructions for a variety of related learning activities.

Items in grey boxes such as this:

> The Water Module

are points for students to reflect on while working through the booklet.

The accompanying Educators' Guide provides additional guidance for teachers and activity leaders, for example materials required, time needed.

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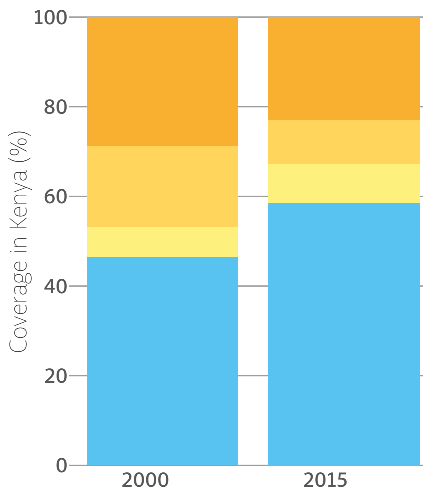
The Water Module

Student resource

Underwater photo (top) by Sime Basioli on Unsplash. Classroom activity with school water club. Photo by Saskia Nowicki.



SURFACE WATER
Drinking water directly from a river, dam, lake, pond, stream, canal or irrigation canal

UNIMPROVED
Drinking water from an unprotected dug well or unprotected spring

LIMITED
Drinking water from an improved source for which collection time exceeds 30 minutes for a roundtrip including queuing

BASIC
Drinking water from an improved source, provided collection time is not more than 30 minutes for a roundtrip including queueing

Data from WHO/UNICEF Joint Monitoring Programme.
https://washdata.org/data#!/ken

Why learn about water?

Improving access to well managed water is one of the global Sustainable Development Goals:

SDG target 6.1:
By 2030, achieve universal and equitable access to safe and affordable drinking water for all

It is also a key section in the Social Pillar of Kenya's Vision 2030 Development Strategy:

> "Kenya is a water-scarce country*. The economic and social developments anticipated by Vision 2030 will require more high quality water supplies than at present. The country, therefore, aims to conserve water sources and enhance ways of harvesting and using rain and underground water. The 2030 vision for Water and Sanitation is to ensure that improved water and sanitation are available and accessible to all. This will be realized through specific strategies, such as: (i) raising the standards of the country's overall water, resource management, storage and harvesting capability; (ii) rehabilitating the hydro-meteorological data gathering network; (iii) constructing multipurpose dams (e.g., on Nzoia and Nyando); and (iv) constructing water and sanitation facilities to support a growing urban and industrial population."
>
> Kenya Vision 2030 Development Strategy, Government of Kenya

Progress is being made, but there is still a lot of work to do. This booklet covers concepts and issues that are important for water management, preparing you to play a part in achieving the vision.

*Renewable internal freshwater resources per person in Kenya were estimated at 450 cubic metres per person per year in 2014 (FAO Aquastat data https://data.worldbank.org/indicator/ER.H2O.INTR.PC). When this value falls below 1,000 cubic metres per person per year a country is said to be experiencing water scarcity.

1. The water cycle

There has always been the same amount of water on Earth. It circulates continuously between the ocean, atmosphere and land in what is called 'the water cycle'. **Hydrology** is the branch of science that focuses on the occurrence, distribution and chemistry of water, so hydrological means "related to the movement of water". There are some important natural processes that create the water cycle. These are evaporation, transpiration, condensation, precipitation, infiltration, runoff and discharge – each one appears in the figure on page 6.

The main source of energy that drives the water cycle is the sun. Heat energy from the sun causes **evaporation** of water from the ocean and from surface water on land. Evaporation occurs when water molecules are heated enough that they have the energy to move from a liquid form into a gas. The water **vapour** produced by evaporation rises into the atmosphere. It is joined by more water vapour that comes from plant **evapotranspiration**. This term refers to a combination of two processes: 1) evaporation from the soil and 2) **transpiration** from plants. The vapour in the air is moved around by air currents and stays in the atmosphere until it becomes cold enough for **condensation** to occur.

When water vapour condenses, it produces clouds, which are made up entirely of tiny drops of water. If the temperature in the atmosphere rises, the drops can be evaporated and the cloud will disappear without producing any rain. If the temperature stays low enough, the drops move around within the clouds, colliding with one another and growing until they become heavy enough to fall as **precipitation** (rain, snow, sleet or hail).

"Between earth and earth's atmosphere, the amount of water remains constant; there is never a drop more, never a drop less. This is a story of circular infinity, of a planet birthing itself."

Linda Hogan, Northern Lights, 1990.

Clouds over Kitui County. Photo by Johanna Koehler.

Dry river bed in Kenya with farmers herding livestock.

Precipitation falls into the ocean or onto the land. When it falls onto the land it can fall directly into surface waterbodies like lakes or reservoirs; it can flow over the land surface as runoff forming channels and eventually rivers; or it can go into the ground (a process called infiltration). As you can see in the diagram on page 6, surface water also moves into the ground at the bottom of lakes and rivers. The zone where shallow groundwater and surface water mix beneath a river or stream is called the **hyporheic zone**. Unless it evaporates or transpires first, all surface water and groundwater eventually discharges to the ocean. Coastal groundwater can be saline (salty) due to seawater intrusion.

Seasonal and spatial variation

In Kenya, some months it rains a lot and in other months it does not rain at all. This is a seasonal pattern. Rainfall records also show that the distribution of precipitation changes a lot between months, years and decades. When the climate is unusually dry – when there is a lot less precipitation than normal – we call it a **drought**. Droughts often cause **water scarcity**, when there is not enough water to meet all the needs of people, animals and the environment.

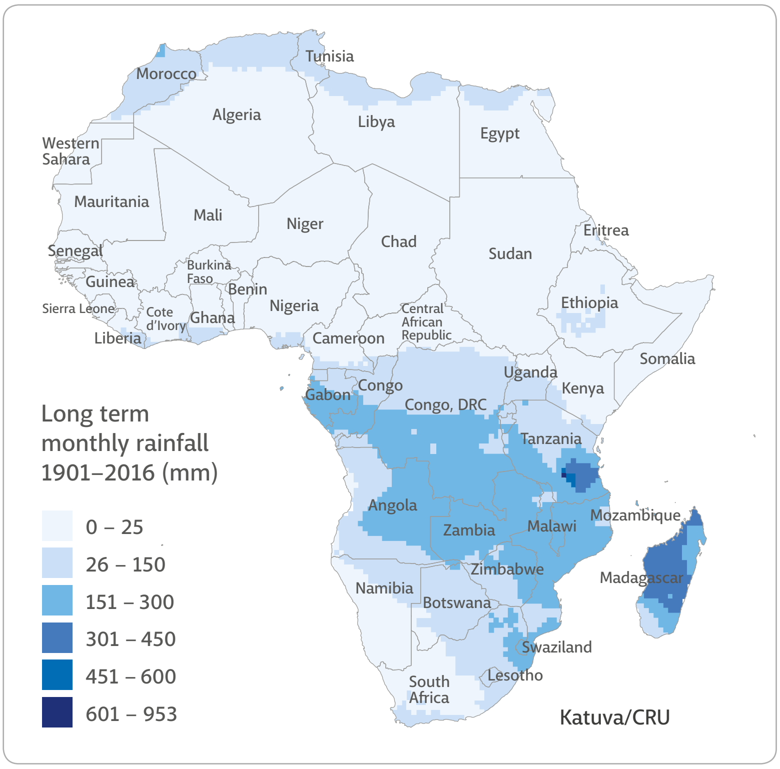
> How do we decide what is a normal amount of rain? How do we decide what is less than normal?

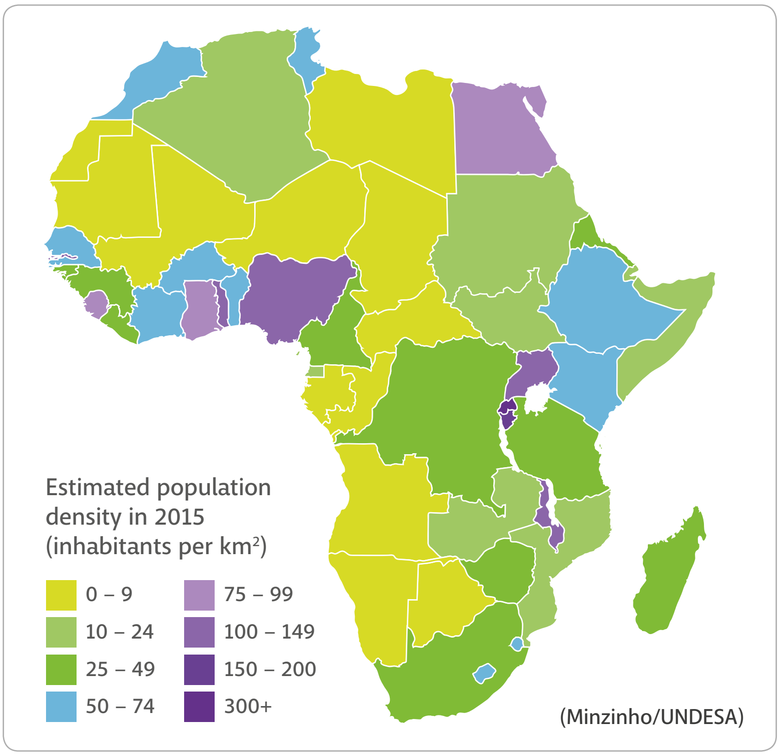
The hydrological cycle changes in intensity at different times and in different places. Sometimes it is raining in one village but not in the neighbouring village. Across the whole planet, the amount of precipitation is uneven and so are the numbers of people. This uneven distribution of water and people makes water management a challenge. Careful well-informed decision-making is needed, along with sufficient funding.

Humans impact the hydrological cycle in many ways, as page 7 shows. We change how water is stored and where it moves by building structures that affect water flow, for example, dams that form reservoirs or canals that irrigate fields. We take water from the natural cycle for **consumptive use** in agriculture, industry, and domestic activities. The way that we use and manage water and land can also affect water quality in both surface water and groundwater.

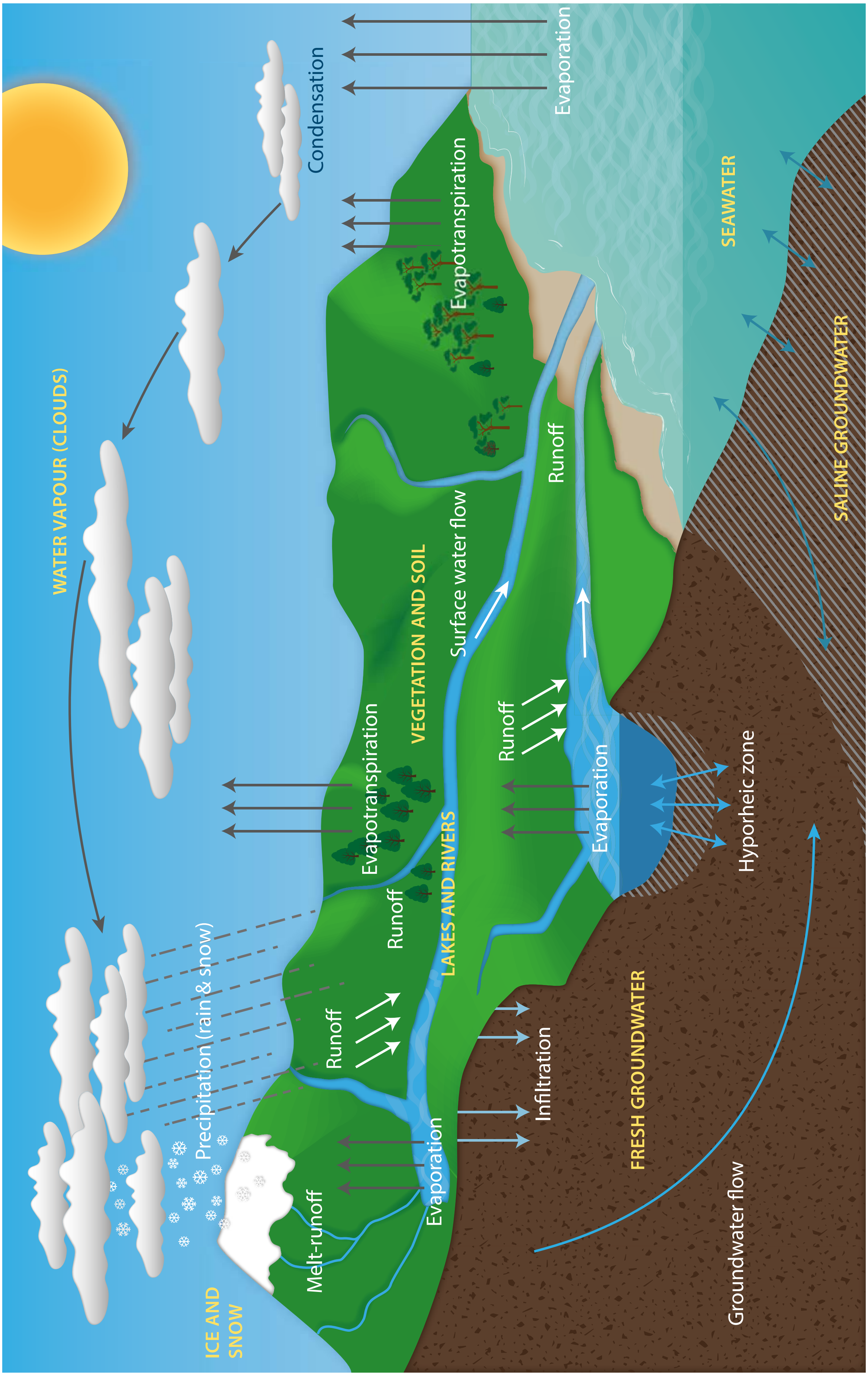
How long does the water cycle take?

For some water (especially water that ends up deep in the ground) the cycle back to the ocean or atmosphere takes a very long time, much longer than a human life. For other water, it takes almost no time at all – for example the rain that falls on the beach!



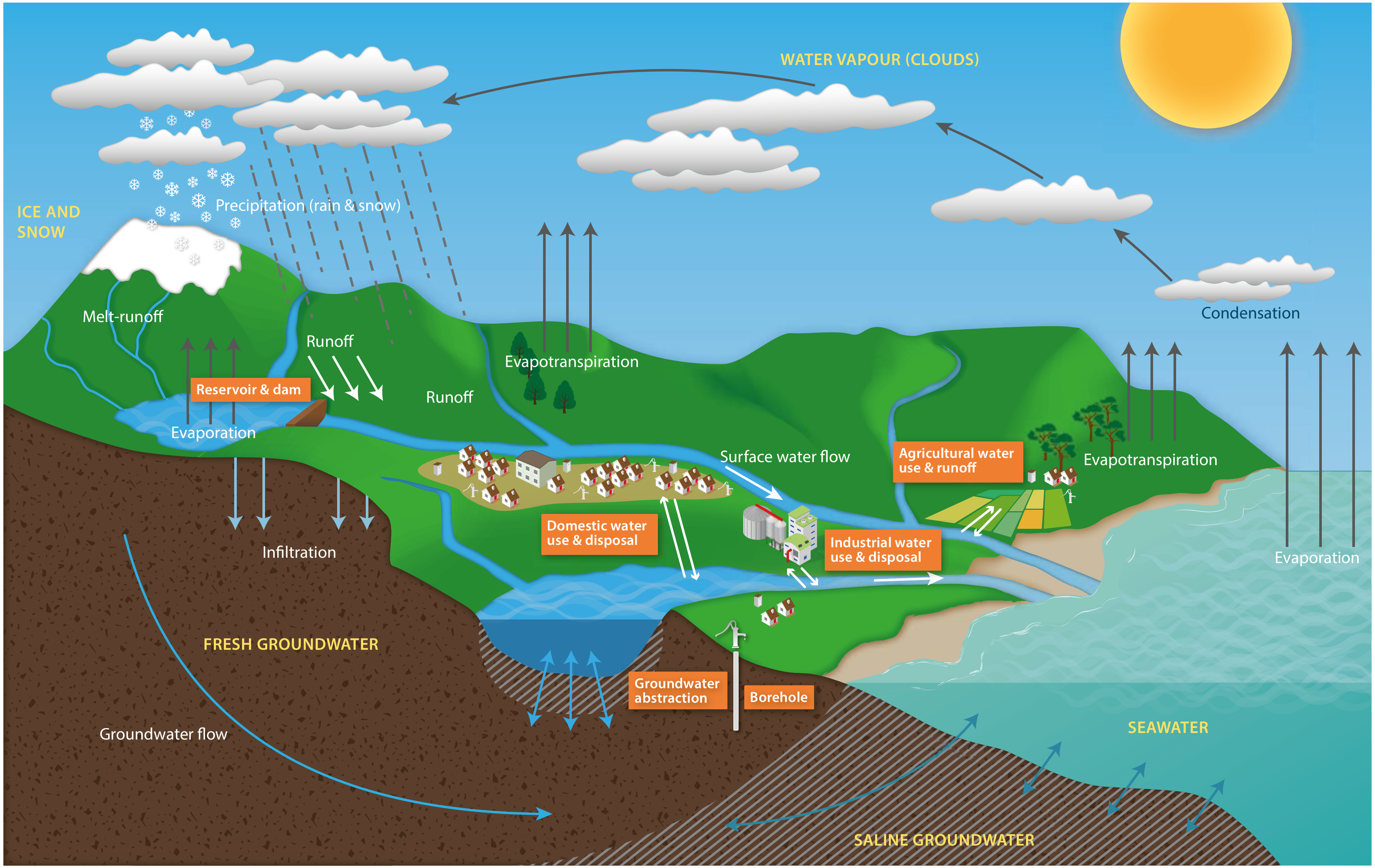


Look at the maps showing Sub-Saharan Africa. Where is Kenya? Do countries with more rain always have higher population density? What are some problems with getting too much rain or too little?



■ The water cycle – also known as the hydrological cycle

The water cycle including some human activity



The water cycle where I live

You could do this activity individually or in groups of 2–4. If you are working in groups, pause at each ✱ to get feedback from each group; if individually, turn to your neighbour and discuss. You can use what other people came up with to add to your lists and tables.

1 Make a list of ways people use water in your area during the rainy season.

2 Look at the diagram of the water cycle including human activity. Are the items on your first list included in the diagram? ✱

3 Make a list of places where people in your area get water from.

4 Look at the diagram of the water cycle including human activity. Are the items on your second list included in the diagram? ✱

5 Here are the labels from the water cycle diagram on page 7. Circle the labels which show the ways in which water moves around the cycle. (Clue: You should circle 13 of them).

Condensation
Precipitation
Borehole
Surface water flow
Groundwater abstraction
Evaporation
Saline groundwater
Groundwater flow
Infiltration
Runoff
Dam
Industrial water use and disposal
Reservoir
Evapotranspiration
Agricultural water use and runoff
Melt-runoff
Domestic water use and disposal

6 Copy out the table below and give it 13 rows after the title row. Add each of your circled words to the first column on table, and then fill in the other columns.

7 You can do this final step with everyone together, or continue to work in small groups. Put each of the words from your two lists, plus each of the circled words showing processes on to pieces of paper. Arrange them into a water cycle. Use a pen or more paper to make arrows to show the flow of water around your diagram.

8 Discuss as a group: How would your diagram change during the dry season when there is less rain? Does your diagram explain everything about where the water used in your area comes from and goes to? What else does your diagram make you want to find out?

Water cycle process	Have I ever seen it with my own eyes?	Description of an example of what can be seen of this process in my local area
Groundwater abstraction	Yes	Handpump that takes water from a borehole into the ground
Domestic water use and disposal	Yes	water taken from river, thrown onto ground

A small sip of hydrology

Hydrologists study the movement of water. They want to understand everything about water flow, including the rate at which water is passing through each process in the water cycle. These two activities show ways in which this can be measured for two of the water cycle processes.

1 Evapotranspiration

Equipment

- 1 small leafy plant growing in soil in a small pot or half plastic bottle
- 1 plastic bottle cut in half so that the bottom half is large enough to go over the top of the plants.
- Marker pen
- Accurate weighing scale
- Stopwatch or timer
- Litre of water in jug
- Calculator
- Pencil and ruler
- Drop of food colouring

Method

2 Use the food colouring to colour the water in the jug.

3 Water the plant with the coloured water. Record the weather and fill in your predictions.

4 Weigh the cut bottle and record its weight to the nearest 0.1 gram.

5 Place the half bottle over the plant.

6 Set the stopwatch or timer for 5 minutes.

7 When 5 minutes is up, carefully remove the bottles without letting any of the water inside it out.

8 Weigh the cut bottle and record its weight below.

9 Put the bottle back and time again for 5 minutes. Weigh again and record.

10 Put the bottle back and time again for 5 minutes. Weigh again and record.

11 Plot your results on a graph and draw a line of best fit.

12 Select two points from the best-fit line (x1, y1),(x2, y2) and determine the slope (y2–y1)/(x2–x1). The slope of the line is the rate of evapotranspiration, as it includes both transpiration by the plant and direct evaporation from the plant and the soil.

13 If other groups have conducted the same experiment using different species of plant, you could plot all your results on one graph using different colours for each plant. Did one plant species have a higher rate of transpiration than the other? If so, what were the physical differences in the plants? Why might this make a difference?

14 **Discussion**: What was the colour of the water that condensed on the inside of the bottle and why?

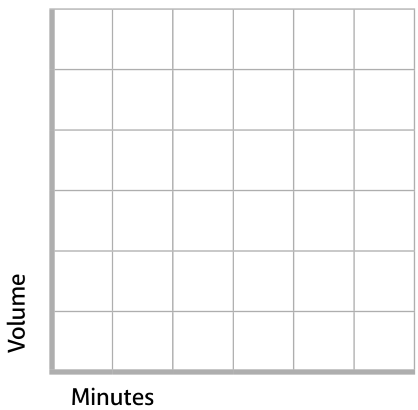
15 **Extension**: If you could find a dead plant of exactly the same size as your living plant, how would you design an experiment to measure evaporation and transpiration separately?

Evapotranspiration student worksheet

Time of Day		Weather conditions			
Predictions					
What do you predict that you will see accumulate on the bottle/bag?					
Results					
Plant ID #		Common name:			
Scientific name of plant (if known):					
Time (minutes)	Weight (g)	Observations (What do you see?)			
Determine the amount of transpiration:					
Trial 1 weight		Trial 2 weight		Trial 3 weight	
minus		minus		minus	
Initial weight		Initial weight		Initial weight	
equals		equals		equals	
Trial 1 transpiration mass (g)		Trial 2 transpiration mass (g)		Trial 3 transpiration mass (g)	
Trial 1 transpiration rate		Trial 2 transpiration rate		Trial 3 transpiration rate	
Average transpiration rate (1 g=1 ml)			ml/min		
Graph					

Plot the transpiration rate data as volume over time.

The slope of the line is the transpiration rate.



2 Precipitation

Hydrologists want to know the volume of rain that falls. Imagine if the rain fell and did not infiltrate into the ground or run downhill. Imagine if it just stuck where it landed – all the raindrops stacking on top of one another. If that happened, we could easily measure how deep the water was and multiply that by the area of land it was covering – then we would know the volume of rain that fell. Of course, in reality rain does infiltrate into the ground, run off over the land and evaporate back to the atmosphere so, to measure rainfall, hydrologists use an instrument called a rain gauge. The rain gauge captures the rain and makes it possible to measure the height of the water that accumulates over a specified period of time. That height can then be multiplied by the land area where the rain was falling and volume of rainfall can be estimated.

Rain gauge measurements are usually made in millimetres. If the rain falling on a square meter (m2) of land reaches a height of 1 millimetre (mm) in a rain gauge, a total of 1 litre (L) of rain will have fallen on that land. Here is the mathematical explanation for this:

height × area=volume
$1\text{mm} \times 1\text{m}^2 = 1\text{L}$
$1\text{m}^2 = 1\text{m} \times 1\text{m}$, and:
1m = 1000mm, therefore:
$1\text{m}^2 = 1\text{m} \times 1\text{m} = 1000\text{mm} \times 1000\text{mm}$.

This means that:

$1\text{mm} \times 1\text{m}^2 = 1\text{mm} \times 1000\text{mm} \times 1000\text{mm} = 1{,}000{,}000\text{mm}^3 = 1\text{L}$

So, when weather reports say that there has been 100mm of rain what they mean is that 100 L of rain has fallen per m^2:

height = 100mm
area = 1m^2

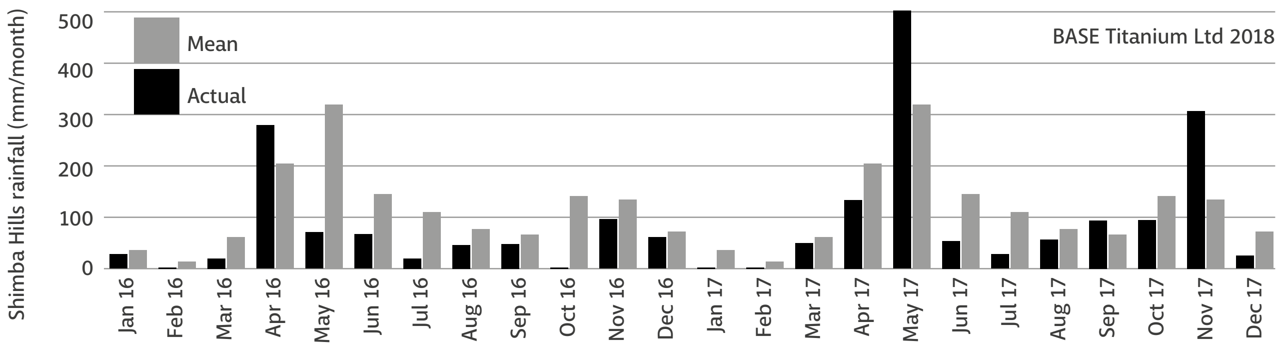
$100\text{mm} \times 1\text{m}^2 = 100\text{mm} \times 1000\text{mm} \times 1000\text{mm} = 100{,}000{,}000\text{mm}^3 = 100\text{L}$

Now, can you calculate how many litres of rain have fallen in one square metre if the height of rain was fifty millimetres? Can you estimate the area of your school roof? Now, can you calculate how many litres of rain would have fallen on it if the height of rain was two millimetres?

> Do you think 100mm rain would be a shower or a heavy storm? How often does it rain where you live? Does anyone collect rainwater from roofs?

Long term rainfall data can show us how the weather at a particular site changes through the seasons and how it compares to other years. This figure shows monthly rainfall measured in a rain gauge on Shimba Hills, South coast of Kenya in 2016 and 2017 (black) and the average rainfall over many years (grey). Which was the wettest month in 2016? Was it the same month in 2017? Which month is usually the wettest?

> Looking at this graph, do you think it is likely that Shimba Hills regularly receives more than 50mm rainfall a day?



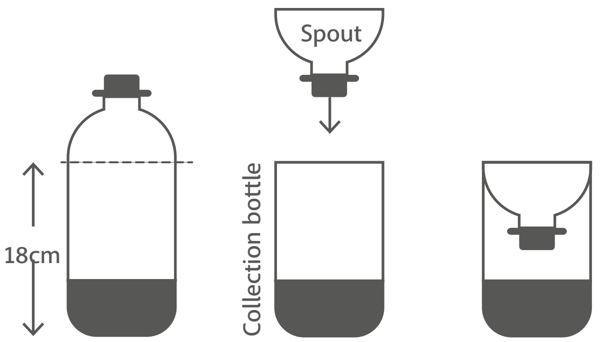
Commercially available standard rain gauges that measure the height of rainfall directly are designed with perfectly straight edges and a flat base. They are calibrated so you can read precipitation height directly from the scale. You can also purchase more expensive gauges that empty automatically using a tipping bucket design and produce a digital dataset that can be downloaded from the equipment.

Collect your own rainfall data

In this experiment, we are going to measure the volume of rainwater collected in a homemade rain gauge and use an equation to convert it into millimetres of precipitation.

Materials

- Plastic bottle (2 litre) with straight sides
- Paperclips or tape
- Sharp knife or scissors
- Sunflower oil or other non-toxic oil
- Plastic measuring cylinder
- Pencil
- Notepad



Method

1 Remove cap and lid from bottle and rinse out with water.

2 Use a marker pen or scratch to mark points straight around the top of the bottle, 18cm from the base, then carefully cut at this height all the way around.

3 Turn the top of the bottle upside-down and insert into the bottle to create a funnel. Fix with tape or paperclips. This is your rain gauge.

4 Choose the site for your rain gauge and fix it in place, keeping base horizontal.

5 Add a small drop of non-toxic oil to the bottle to reduce evaporation. (Oil is less dense than water so it floats on top, forming a layer that stops or slows evaporation.)

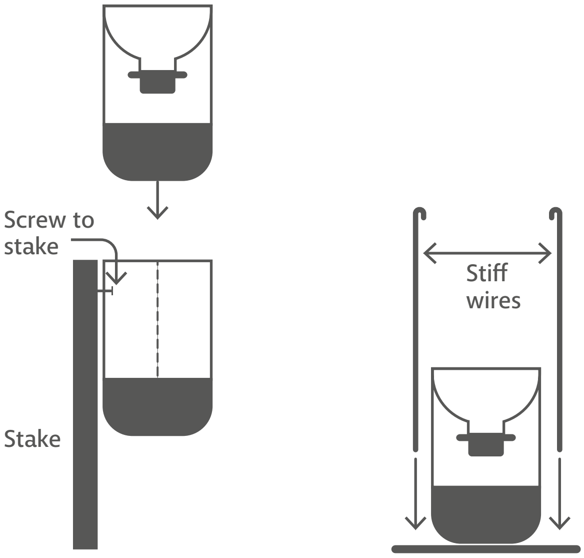
6 Each day, ideally at the same time, visit the gauge to take a reading. Tap the bottle to dislodge any droplets that have formed from evaporation on the inside bottle walls. Pour the water from the rain gauge into a measuring cylinder and record the volume in millilitres in your results table. When you read your measurement, read along the bottom of the liquid surface and not the meniscus which will be slightly higher up where the water touches the edge of the cylinder. Empty the gauge after each measurement and add a small drop of oil.

7 Repeat this over a month or for as long as possible until you have built up your own rainfall dataset.

8 Make a graph of rainfall (mm) over time to investigate seasonal changes and extremes where you live.

Fixing your rain gauge in place

- Ideally fix the gauge 90cm above ground level on a wooden post stuck into the ground. Suggested ways to do this include cutting the top off another plastic bottle and fixing it to the post with screws, then using this as a sleeve for the rain gauge. If it is on a grass or muddy surface, you could use 2 pieces of stiff wire bent into hooks to attach it to the ground.



Standard rain gauge. 4-inch plastic rain gauge, typical of those used by the CoCoRaHS program, photo by Famartin, CC BY 3.0, Wikimedia Commons.

Choose a good site for your rain gauge

- Away from any buildings or trees. If you estimate the height of any buildings or trees in the area, then the rain gauge should be at least 2 and ideally 4 times that distance away from the obstruction so that it does not influence the amount of rain that is captured in the gauge.
- Away from places where it will be disturbed by people or animals
- Fixing the rain gauge at about 90cm off the ground is a good idea if there is shrubby vegetation below this level or it is on a surface which could produce splashing. However, a rain gauge fixed too high up would be likely to be affected by the wind.

Rain gauge made by students. Photo by Fotokannan, CC BY 3.0. Wikimedia Commons.

Student rain gauge results

Copy into notebook

Time	Date	Volume (ml)	Precipitation (mm)

Use the following steps to convert the volume collected into the height of precipitation in mm to fill in the final column of the table.

Step 1: Convert volume in ml to volume in mm^3			
			(Volume in ml)
x 0.001 =			(Volume in mm^3)
Step 2: Measure the diameter across the top of the gauge and divide by 2 to get the radius.			
Diameter =			(mm)
Radius =			(mm)
Step 3: Use the radius to calculate the area of top of the funnel. $A = \pi r^2$ (π = 3.1416)			
π x	x	=	
radius (mm)	radius (mm)		area (mm^2)
Step 4: Work out the height of precipitation in mm using this equation and record.			
Volume	÷ area	= precipitation	
(mm^3)	(mm^2)	(mm)	

What are the advantages of the funnel design for the gauge? What might happen if you didn't include the funnel?

Maximum capacity will be reached when the water reaches the bottom of the funnel spout. What is the maximum rainfall that your rain gauge could measure? Is it regularly exceeded? How could you make the rain gauge bigger? What else could you do to keep accurate records during periods of high rainfall?

Can you find an official source of daily rainfall data from a meteorological station in your area? You might be able to download data from Internet sites such as https://en.tutiempo.net/ or www.wunderground.com. Plot your data next to this data and compare. How similar is it? Why might it be different?

Can you design an alternative homemade gauge where you can read precipitation height directly from a scale put on the side? You would need to find a suitable container with straight sides and flat base and a funnel with a collection area the same size as the container to avoid the need for calibration.

Water cycle crossword

Test your water cycle knowledge by using the clues to fill in this crossword puzzle.

ACROSS: Clues for horizontal words:

4 The process by which vapour becomes a liquid often due to cooling (12)

6 Water that flows over land to surface streams, rivers and lakes and eventually to the ocean/ sea (3-3)

9 Water falling out of the atmosphere in a liquid or solid state (13)

10 Movement of water vapour into the atmosphere due to both evaporation from soil and transpiration from plants (18)

DOWN: Clues for vertical words:

1 Water flowing out; the opposite of recharge (9)

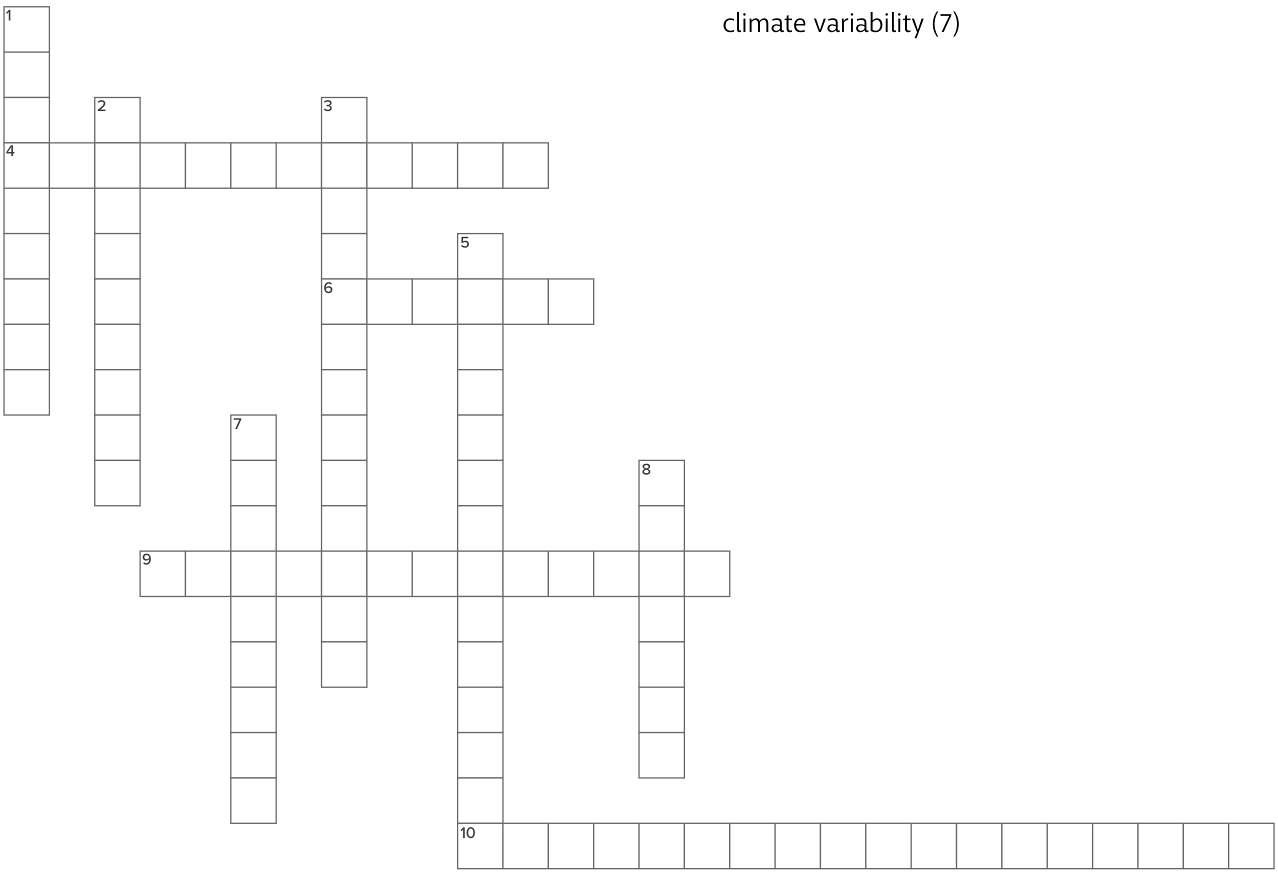
2 Water travelling horizontally through shallow ground during or soon after precipitation (Answer: interflow)

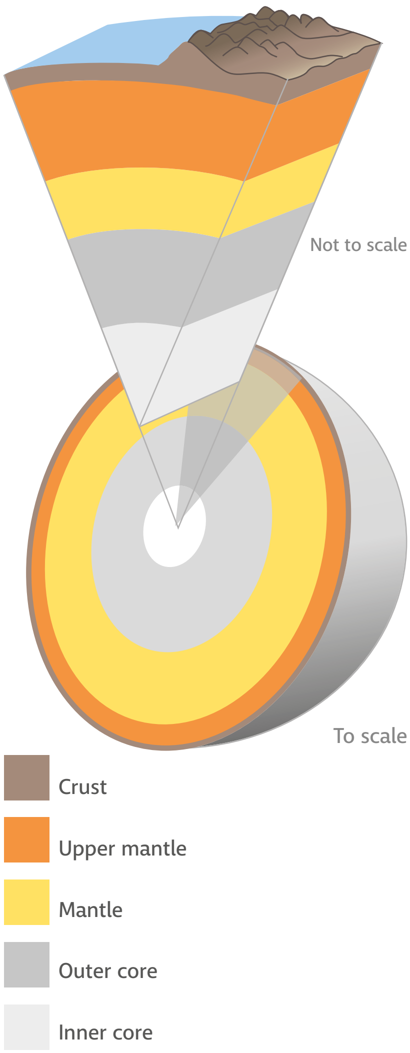
3 When there is not enough water to satisfy the needs of people, animals and the environment in a region (5, 8)

5 Use of a resource that reduces the supply, such as removing water from a river, lake or aquifer without returning the same amount (11, 3)

7 A body of water that forms behind a dam (9)

8 An extended period of less than normal precipitation that often affects availability of water supplies - a natural hazard caused by climate variability (7)





2. Geology

"Geo" means "earth" and "ology" means "a branch of knowledge" so geology is what we know about the Earth.

Layers of the Earth

Most of the Earth is made up of the inner core, outer core and the mantle and it is hot – hot enough for the rock to be melted (geologists call melted rock '**molten**', this word is used when a hard material like rock or metal is so hot that it becomes a thick liquid). When volcanoes erupt we see the molten material from the mantle come to the surface. There are three main reasons why it is so hot inside the Earth: 1) when the planet first formed it was very hot and some of this original heat remains in the deep Earth; 2) the molten material moves, and this movement creates heat due to **friction**; 3) there are chemical processes in the deep Earth that produce heat.

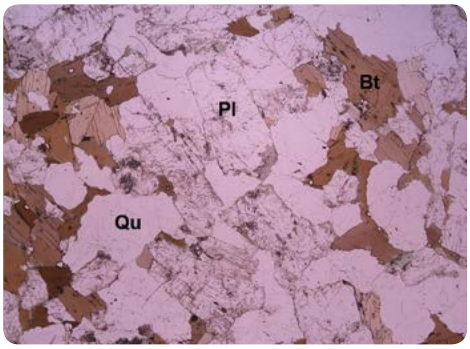
Groundwater does not come from the core or the mantle. All the groundwater that we use is stored in the crust – the outermost layer of Earth. If the Earth was a mango, the crust would be the skin, a thin layer compared to the mantle and the core. The crust layer is cool enough so that it is solid rock. Minerals are the building blocks of rocks in the crust. They are inorganic (meaning they are not created from living matter) and each have their own structure and combination of elements. A single rock can contain many different minerals.

Minerals and elements

Many of the elements in the periodic table are present in minerals that form the rocks in the Earth's crust. The common ones that make up most of the crust are **oxygen** (47%), **silicon** (28%), **aluminium** (8%), **iron** (5%) and **calcium** (4%). Elements form minerals; minerals form rocks; rocks form the Earth's crust.

Let us consider the rock in the top photo as an example. This is **granodiorite**, a type of rock found in many parts of the world including western Kenya. A coin is used to give an idea of size. **Granodiorite** is made up of three main minerals that interlock together. The interlocking mineral grains are very small and difficult to see. They are shown on the next image down, which is called a **photomicrograph**. This image was captured using a **microscope**, an important tool that geologists can use to magnify and study small, thin sections of rock.

The **granodiorite** minerals are **quartz** (Qu), **plagioclase feldspar** (Pl), and **biotite mica** (Bt). **Quartz** is formed by two elements: **silicon** and **oxygen**. **Plagioclase feldspar** is more complicated. It is formed from **silicon**, **oxygen** and **aluminium** as well as **calcium** or **sodium**. **Biotite** has even more elements including **potassium**, **magnesium**, **iron**, **aluminium**, **silicon**, **oxygen**, **fluorine** and **hydrogen**.

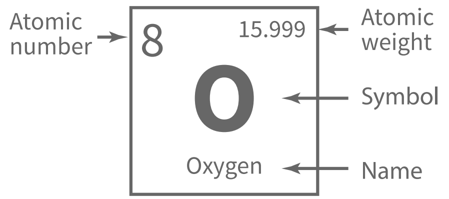


We are also interested in rocks that are made up of only one mineral. **Diamond**, for example, is a very unique mineral. It is formed from only one element: **carbon**. In some parts of Kenya, gemstones such as ruby are found. Ruby is also a single mineral; its scientific name is **corundum** and it is made up of **aluminium**, **oxygen** and **chromium**. Rubies are red and can be confused with garnets, which are less valuable but are also found in Kenya. Examples of garnets are shown in the photo on the right (the red stones). **Garnets** are complex minerals – they all contain **silicon** and **oxygen** and two other elements, which could be **calcium**, **magnesium**, **iron**, **manganese**, **aluminium** or **chromium**.

Photos by Tom Nowicki.

> 13 elements are listed above. Can you find them in the periodic table on the next page?

The Periodic Table



1 H 1.008 Hydrogen																	2 He 4.0026 Helium
3 Li 6.938 Lithium	4 Be 9.012 Beryllium											5 B 10.806 Boron	6 C 12.0096 Carbon	7 N 14.0064 Nitrogen	8 O 15.999 Oxygen	9 F 18.998 Fluorine	10 Ne 20.1797 Neon
11 Na 22.989 Sodium	12 Mg 24.304 Magnesium											13 Al 26.9815 Aluminium	14 Si 28.084 Silicon	15 P 30.974 Phosphorus	16 S 32.059 Sulfur	17 Cl 35.446 Chlorine	18 Ar 39.948 Argon
19 K 39.0983 Potassium	20 Ca 40.078 Calcium	21 Sc 44.9559 Scandium	22 Ti 47.867 Titanium	23 V 50.9415 Vanadium	24 Cr 51.9961 Chromium	25 Mn 54.938 Manganese	26 Fe 55.845 Iron	27 Co 58.933 Cobalt	28 Ni 58.6934 Nickel	29 Cu 63.546 Copper	30 Zn 65.38 Zinc	31 Ga 69.723 Gallium	32 Ge 72.630 Germanium	33 As 74.922 Arsenic	34 Se 78.971 Selenium	35 Br 79.901 Bromine	36 Kr 83.798 Krypton
37 Rb 85.4678 Rubidium	38 Sr 87.62 Strontium	39 Y 88.9058 Yttrium	40 Zr 91.224 Zirconium	41 Nb 92.906 Niobium	42 Mo 95.95 Molybdenum	43 Tc (98) Technetium	44 Ru 101.07 Ruthenium	45 Rh 102.9055 Rhodium	46 Pd 106.42 Palladium	47 Ag 107.8682 Silver	48 Cd 112.414 Cadmium	49 In 114.818 Indium	50 Sn 118.710 Tin	51 Sb 121.760 Antimony	52 Te 127.60 Tellurium	53 I 126.904 Iodine	54 Xe 131.293 Xenon
55 Cs 132.905 Caesium	56 Ba 137.327 Barium	57-71 Lanthanoids*	72 Hf 178.49 Hafnium	73 Ta 180.948 Tantalum	74 W 183.84 Tungsten	75 Re 186.207 Rhenium	76 Os 190.23 Osmium	77 Ir 192.217 Iridium	78 Pt 195.084 Platinum	79 Au 196.967 Gold	80 Hg 200.592 Mercury	81 Tl 204.382 Thallium	82 Pb 207.2 Lead	83 Bi 208.980 Bismuth	84 Po (209) Polonium	85 At (210) Astatine	86 Rn (222) Radon
87 Fr (223) Francium	88 Ra (226) Radium	89-103 Actinoids**	104 Rf (267) Rutherfordium	105 Db (268) Dubnium	106 Sg (269) Seaborgium	107 Bh (270) Bohrium	108 Hs (277) Hassium	109 Mt (278) Meitnerium	110 Ds (281) Darmstadtium	111 Rg (282) Roentgenium	112 Cn (285) Copernicium	113 Nh (286) Nihonium	114 Fl (289) Flerovium	115 Mc (290) Moscovium	116 Lv (293) Livermorium	117 Ts (294) Tennessine	118 Og (294) Oganesson

*Lanthanoids	57 La 138.905 Lanthanum	58 Ce 140.116 Cerium	59 Pr 140.908 Praseodymium	60 Nd 144.242 Neodymium	61 Pm (145) Promethium	62 Sm 150.36 Samarium	63 Eu 151.964 Europium	64 Gd 157.25 Gadolinium	65 Tb 158.925 Terbium	66 Dy 162.500 Dysprosium	67 Ho 164.930 Holmium	68 Er 167.259 Erbium	69 Tm 168.934 Thulium	70 Yb 173.045 Ytterbium	71 Lu 174.9668 Lutetium
**Actinoids	89 Ac (227) Actinium	90 Th 232.0377 Thorium	91 Pa 231.036 Protactinium	92 U 238.029 Uranium	93 Np (237) Neptunium	94 Pu (244) Plutonium	95 Am (243) Americium	96 Cm (247) Curium	97 Bk (247) Berkelium	98 Cf (251) Californium	99 Es (252) Einsteinium	100 Fm (257) Fermium	101 Md (258) Mendelevium	102 No (259) Nobelium	103 Lr (266) Lawrencium

Alkali metal | Alkaline earth metal | Lanthanide | Actinide | Transition metal | Post-transition metal

Metalloid | Polyatomic nonmetal | Diatomic nonmetal | Noble gas | Unknown chemical properties

The Three Categories of Rocks

There are more than 3000 different minerals and hundreds of kinds of rocks, but all rocks can be divided into three categories based on how they form:

Igneous rock is formed when molten rock, also known as magma, from the mantle cools down and solidifies. This cooling happens when magma is pushed into the crust or all the way through to the Earth's surface like in a volcano. The granodiorite rock discussed in the previous section is an example of an igneous rock.

Sedimentary rock is formed by a process that is like recycling. Existing rock is broken down by wind and water and the pieces become sand, mud and pebbles that can be blown by the wind or washed down rivers. Eventually these pieces stop moving and form a layer of material (often in deserts, lakes, at the end of rivers, or in the ocean). Over time more and more pieces settle forming more and more layers. After thousands or millions of years the weight of these layers creates enough pressure that the pieces are crushed together to form solid rock again. Sedimentary rock also forms in the same way from layers of coral and mollusc shell fragments and is called biogenic when it is formed from the remains of once living creatures.

Metamorphic rock is formed when existing rock in the crust is transformed by heating and crushing (high pressure). Because of the heating and crushing, the original rock undergoes chemical and physical changes that make the original minerals change into different minerals. A new kind of rock with different properties is formed.

It is possible to find groundwater in all three types of rock formation. In the next module you will learn more about how groundwater is stored in rocks and how we get it out of the ground so that we can use it.

> Look down at your feet and imagine drilling a deep hole right down into the ground. What would you find? Would someone standing in Nairobi find the same materials as you do if they drilled under their feet? What about someone in another part of the world, for example France or Canada?

Pahoehoe lava in Hawaii, USA. Photo by Hawaii Volcano Observatory (DAS).

Colourful layers of sedimentary rock in Makhtesh Ramon, Israel. Photo by Rhododendrites, Own Work, CC BY-SA 4.0 Wikimedia Commons.

Metamorphic rock cliff at Black Canyon of the Gunnison Park, Colorado USA. Photo by National Parks Services, Lisa Lynch.

Geology News

2018

GEOLOGISTS MAP ANCIENT RIVERBEDS IN KWALE COUNTY

Geological study of Kenya reveals new groundwater resources

Millions of years ago, a network of rivers and their tributaries flowed across the land that is now known as Kwale County, Kenya. The water in the rivers carried particles of clay and sand washed down as eroded materials from the hills and mountains. As the rivers came closer to the ocean the land became less steep and the water spread out and slowed down. Near the coast the water flowed slowly enough for the clay and sand in the river water to settle, sinking down to rest on the bottom of the river, layer upon layer, year after year. These coastal rivers flowed for millions of years, but about 5 million years ago sea level increased and the coastal plain with its river channels was buried by more sediments, including rubble from the coral reefs which fringed the coast. As sea level fell again, gradually the landscape came to look as it does today.

How did geologists figure out what took place on the coast of Kenya over the course of millions of years? By studying the rock beneath the ground, geologists are able to piece together the processes by which the rocks and landforms of an area were formed. In 2017, geologists from the University of Nairobi used a variety of techniques to map some of Kwale County's ancient riverbeds, giving us more information on their evolution in the distant past. Their findings are very interesting and lead on to many more questions: For example, what did these rivers look like? What creatures lived in and around them? More importantly perhaps, this new geological research may have practical significance for the county...

continued on page 26

Learning activities

Read the Geology News article on page 20. Note that this is real information but from a pretend magazine. Would the rocks formed from the clay and sand carried by the rivers be classified as igneous, metamorphic or sedimentary?

Is rock or stone seen on the surface of the land in your area? What colour is it? What texture does it have?

Is there a mine or quarry in your area? Can you find out what mineral or rock they are extracting and what is the material used for?

Geology crossword

ACROSS: Clues for horizontal words:

5 The scientific mineral name for ruby (8)

7 A mineral found in granodiorite rock that is formed of only two elements (6)

9 The most common element in the Earth's crust (6)

10 The name for rocks that form from the remains of once living creatures (8)

11 The name for an image captured by a microscope (15)

DOWN: Clues for vertical words:

1 The category of rocks that form directly from cooled magma (7)

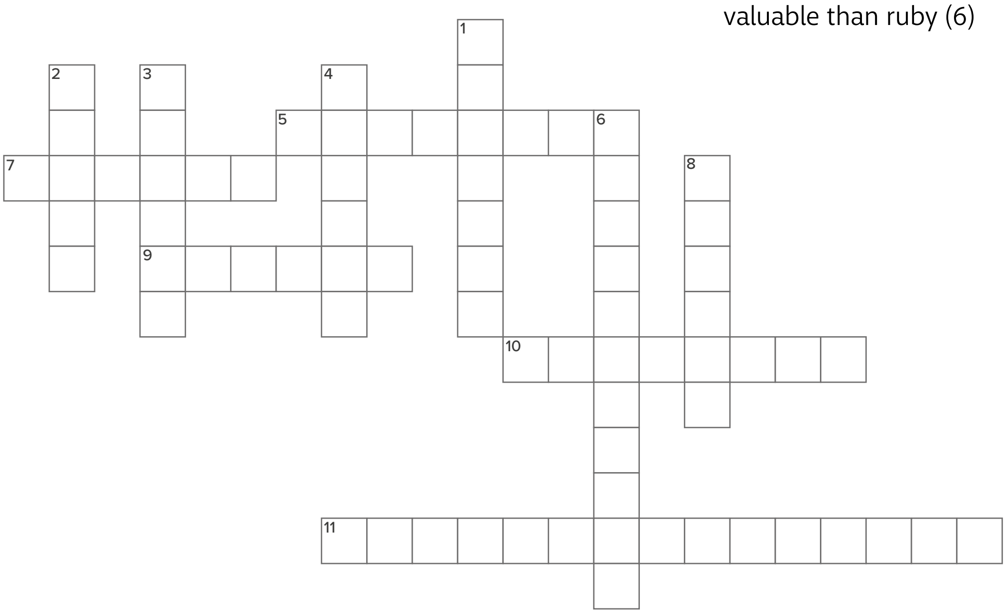
2 The outermost layer of the Earth (5)

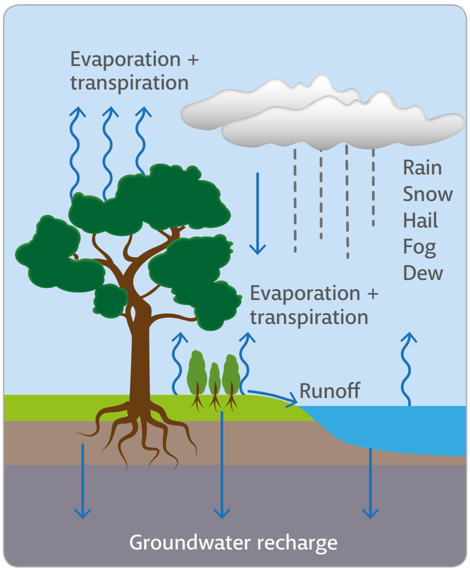
3 The element that forms diamonds (6)

4 The name for rock that is so hot it has become liquid (6)

6 The category of rocks that form from heating and crushing of existing rock (11)

8 A red mineral found in Kenya that is less valuable than ruby (6)





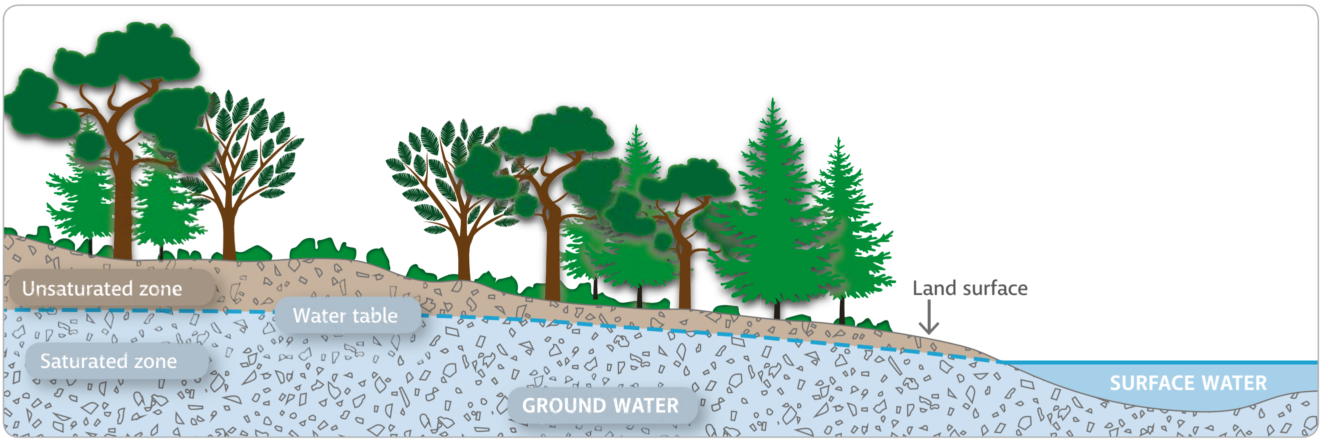
3. Groundwater

How does water get into the ground?

In many places the first layer of the ground is **soil** – a layer of decomposing organic material and rock material in which plants can grow. Below the soil layer there are different types of rock materials. The ground can be thought of as two zones – the **unsaturated zone** and the **saturated zone**. The unsaturated zone does contain some water but it also has air in the open spaces between rock materials. Below it, deeper in the ground, is the saturated zone. Saturated means full up – all the open spaces (the pores) are filled with water and the ground is holding as much water as it can. The top of the saturated zone is called the **water table**. This can be thought of as the boundary between the saturated and unsaturated zones.

When precipitation falls on land, some of it goes into the ground. In other words, it infiltrates into the ground. When water infiltrates into the ground, some of it clings to the soil or to roots of plants. This is called **soil moisture** and it can be used by plants to grow. However, not all infiltrated water is used by plants. Some of it flows horizontally through the shallow ground until it ends up in a stream or other surface **waterbody** (this is called **interflow**). Other water flows downwards into the saturated zone below the water table and becomes groundwater (this is called **recharge**). Groundwater is recharged from rainwater and snowmelt and from **seepage** from the bottom of reservoirs, lakes and rivers. Groundwater can also be recharged when water supply systems (e.g. pipes, canals or sewers) leak and when crops are irrigated with more water than the plants can use.

Cross-section showing unsaturated and saturvated zones above and below the water table. Based on USGS 2016.



What is porosity?

Even though it looks completely solid, there is actually a lot of void (empty) space in the ground. Water in the ground is stored in this space, which is made up of a) small voids (called **pore spaces**) between the particles that make up rocks or soil, b) the space created by rock **fractures** and c) **solution channels** – the spaces created in carbonate rocks by the dissolving action of underground water. Depending on the geology, some types of ground have more space than others. We measure this using a ratio called **porosity**:

$$\text{porosity} = \frac{\text{volume of void space in rock or sediment}}{\text{total volume of rock or sediment}}$$

Ground that has high porosity can store more water than ground that has low porosity.

Globally, at least 2 billion people depend on groundwater and in rural areas of Africa and Asia it is a particularly important resource for drinking water as well as agriculture and other livelihood uses. It is a very important resource for humans, but only if we can get it out. Removing water from the ground is called **abstraction**. Abstraction is only possible if the water can flow through the ground.

What is permeability?

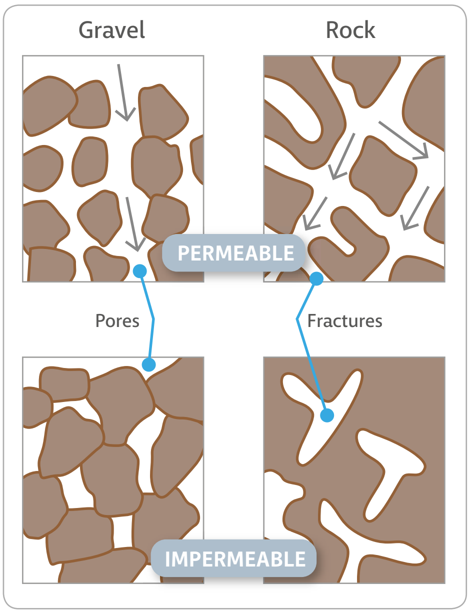
Water can move through the ground when the pore spaces and fractures are connected. If they are connected, water can find a path to flow through the space.

Permeability is a measure of how well the spaces are connected. As an example, some of the rocks which make up the coastal area of Kwale County are formed from old coral reef and are very **permeable** – water can flow through them very quickly. You can see in the photograph from Kisite Island that it has many small holes and passages.

If a material does not have connected pores, the permeability is low and the water cannot move easily. These materials are said to be impermeable. Geological materials such as clay or shale are made of fine particles and have many small pores, but the pores are not well connected. These types of materials usually stop the flow of groundwater (or slow it down a lot).

Rock formed from coral reef, Kisite Island, Kwale County. Photo by www.yakari-travel.de; Flickr; CC BY 2.0

Sample of shale by Amcyrus2012. Own work, CC BY-SA 4.0 via Wikimedia Commons.



Flowing artesian borehole in Kilimambogo, NE. of Nairobi. Photo by Rotary Clubs of Nairobi, (Kenya), Carlisle, PA and Indianapolis (USA), Edgbaston Convention and Stratford-Upon-Avon, (UK), and Hanau (Germany).

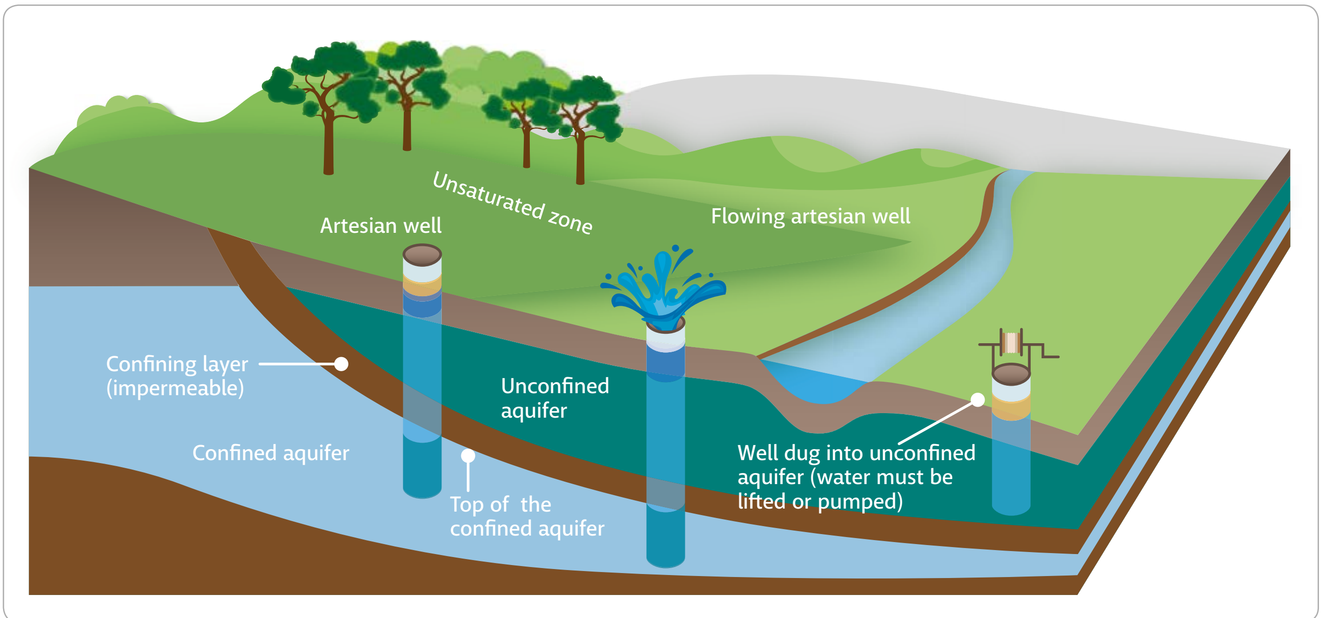
What is an aquifer?

When groundwater in the saturated zone (below the water table) can flow through interconnected spaces we call this zone an aquifer. Aquifers are groundwater resources that people can take water out of. In other words, aquifers are able to yield (provide) water. The layout and properties of different geological materials control how groundwater moves. This means that there are different types of aquifers. The two main types to know about are shown in the figure below.

Unconfined aquifers: The top of an unconfined aquifer is the water table, usually not far below the ground surface. Water at the ground surface infiltrates through the unsaturated zone to recharge the aquifer. The lower boundary of the aquifer is a confining layer of less permeable material (an **aquitard** or **aquiclude**). An aquitard is a layer of material that slows the flow of water whilst a completely impermeable layer that stops water movement is known as an aquiclude. The water in an unconfined aquifer is at atmospheric pressure so to get it to the surface it must be pumped out or pulled out (for example with a handpump or a bucket in an open well).

Confined aquifers: Both the upper and lower boundaries of confined aquifers are rock layers of low or no permeability (i.e. they form an aquitard or aquiclude). These are usually deeper than unconfined aquifers. In a confined aquifer, the water is under pressure from the rocks above and/or from the water flowing into it. If a borehole is drilled into a confined aquifer, water will rise inside the borehole due to the pressure on it, and it may even

Representation of unconfined and confined aquifers. Although the aquifers look like big caves full of water, remember that they are full of sediment and rock and the water is stored in the spaces between this material. Based on USGS 2016.



flow out at the top. A borehole drilled into a pressurized aquifer is called "artesian". The name artesian comes from the first recorded example of a naturally flowing well which was drilled by monks in the province of Artois in France in 1126.

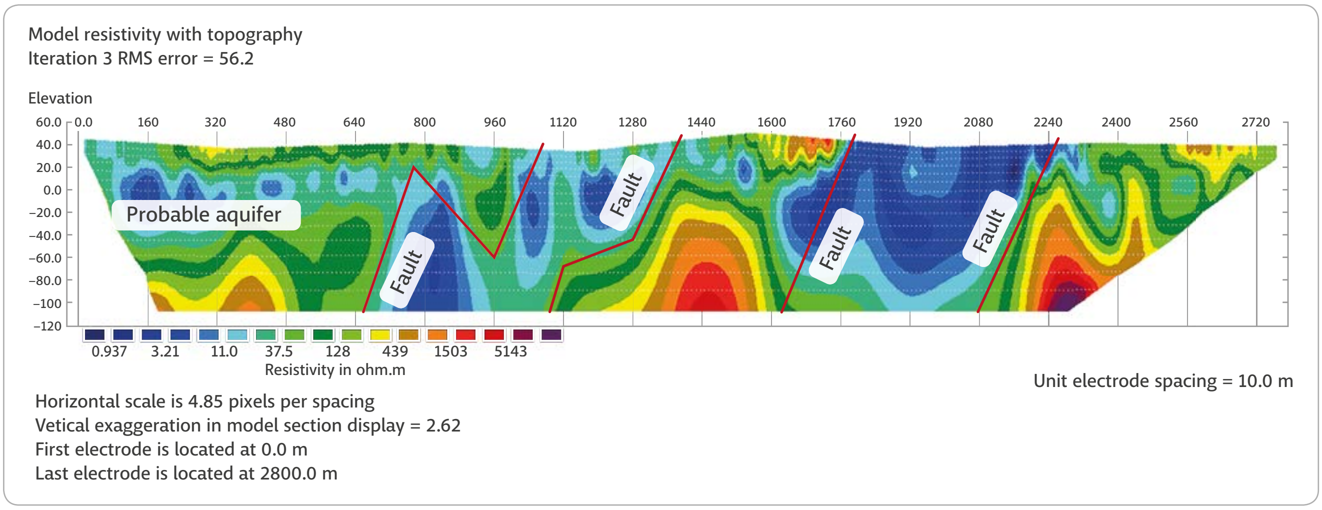
See the 'flowing artesian well' in the figure and photo on page 24? Water is coming out of it without pumping. Can you explain why in your own words?

How is groundwater detected and assessed?

Hydrogeology is the study of groundwater and the geological and non-geological materials that it interacts with. Hydrogeologists study aquifers to predict what will happen to them when water is pumped out (abstracted) for human use, or when changes to the climate reduce or increase rates of groundwater recharge. Knowing where water goes and how fast it moves underground can also help prevent or limit groundwater contamination.

It is challenging to detect groundwater because you cannot see through the ground. Hydrogeologists can use geological maps and cross-sections showing local rock types to assess if groundwater is likely to be found in a particular area. They also use "geophysical methods" to measure physical properties of rocks below the surface and map out where water will be found and how it will move underground. Geophysical methods help us understand the geology of an area better. Understanding the geology helps us know how much water may be stored. When the geology indicates that there may be a lot of groundwater, boreholes can be used for further studies to learn how much of the water we can abstract and use.

Example of results from a geophysical transect using electrical methods (Gro for GooD project, coastal Kenya). The labels show the geophysicists' initial interpretation of the results. The identification of faults (breaks in the rocks where the rocks on either side have moved in relation to each other) is important because fissures, cracks and faults in the rock affect how groundwater will flow through it.



Geophysicists from the University of Nairobi. Photo by Rural Focus Ltd.

There are different ways to do geophysical studies – some general approaches are given in the table below.

Geophysical methods used to "see" below ground	
What is measured?	
Gravity / magnetics	Variations in the Earth's gravitational and magnetic fields – this gives clues to the density of the rocks and what they are made of.
Vibrations (Seismic)	How fast vibrations move through the ground – this gives clues about the geology because the vibrations move at different speeds in different types of rock.
Electrical current	How easily electrical currents move through the ground – this gives clues about the porosity and permeability of the rock.

Boreholes can also be used to take samples to assess water quality. Hydrogeologists do a lot of work to understand the chemical and biological quality of groundwater. We will learn more about that in Section 4.

Geology News 2018

Geological study of Kenya reveals new groundwater resources. . . *continued from page 20*

The geologists working in Kwale County used geophysical methods, fieldwork mapping of rocks, and studies of rock samples from boreholes drilled into the ground to build up a picture of the geological structures and rock types which lie beneath Kwale County and find out where groundwater is stored. Many of the sandstone and coral rock formations found in the area are great sources of groundwater, supplying thousands of people for their daily needs. However, surveys suggest that the ancient river-beds located by the University of Nairobi geologists have the potential to form another useful groundwater resource. The ancient sediments found in the palaeo-channels (palaeo = ancient) store groundwater in their interconnected pores – small spaces between the particles forming the rocks.

Professor Dan Olago, University of Nairobi.

Boreholes drilled into the channels are providing a new source of water for people, industry and agriculture in the county.

How do people access groundwater?

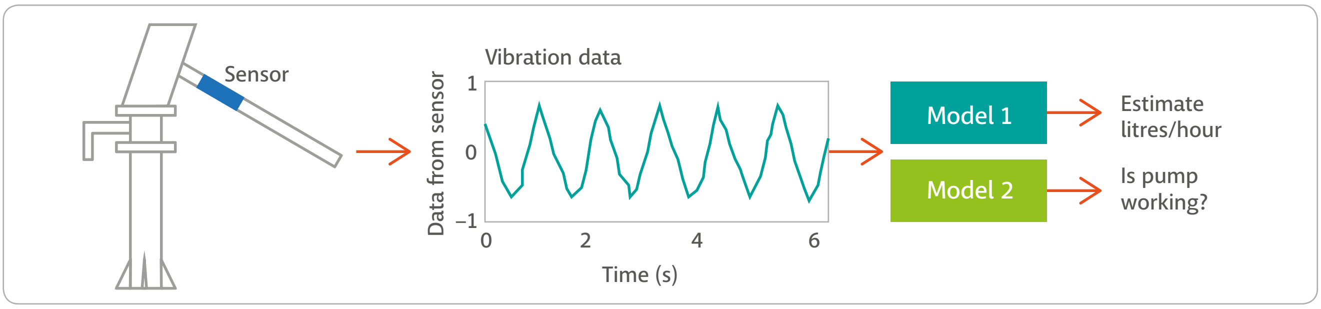
Shallow groundwater can be accessed by digging a well that goes deeper than the water table (into the aquifer/saturated zone) and then drawing water out. Groundwater can also be accessed by drilling a borehole down into the aquifer and pumping the water out. There are many kinds of pumps including electric pumps, solar pumps, diesel pumps, and handpumps. In much of Kenya, handpumps are used. The Afridev is the most common handpump in all of Africa.

Handpump in Kwale County. Photo by Saskia Nowicki.

> How do Afridev pumps work? How do they compare to other types of pumps? What is needed to keep them working?

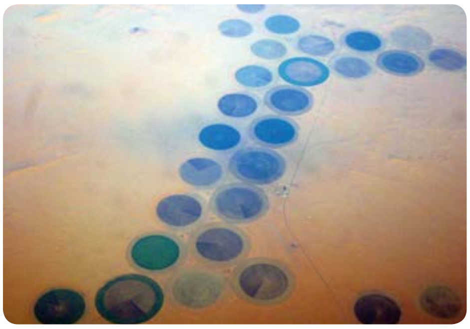
Handpumps have been used for a long time but new research and technology is making them better. Sensors can now be added to handpumps to make them 'smart pumps' (see the figure below). The sensors make it possible to gather data on how much a handpump is being used and from this it is possible to estimate how much water is being pumped out of the aquifer. Monitoring of smart pumps may also help make repair times faster by predicting when a handpump is about to break. This technology was first tested in Zambia and is being used in several countries including Kenya and Bangladesh.

Schematic showing how sensors are attached to the handle of handpumps. These sensors transmit vibration data from the handle. This data can be analysed to estimate the amount of water being pumped (litres/hr) and can indicate how well the pump is working. Image by Achut Manandhar.



Is groundwater a sustainable resource?

Groundwater is important for many people. If it is accessed carefully and well protected, it can be much cleaner than surface water. It can be available when rain water collection is not enough or when surface water sources have dried up or are polluted. Whether it can be used sustainably depends on how much is being used and how quickly it is being recharged. If recharge is reliable and the amount abstracted is less than the amount recharged, we can treat the groundwater as a renewable resource. However, if abstraction and outflow is greater than recharge, this is called over-abstraction and the aquifer will eventually be pumped dry.



Aerial photo from a plane of pivot irrigation in the Sahara desert. Photo CC by 2.0 on Flickr.

Close-up photo of a pivot irrigator in use. Photo by Patrick Thomson.

When should groundwater be treated as a non-renewable resource?

When groundwater is taken out of an aquifer in a dry area where there is hardly any rain, no new water will replace it. Groundwater that is not being recharged should be managed as a non-renewable resource - once it is gone, it is gone. If we want it to last for as long as possible we must use it carefully, and we need to have plans for what to do when we must get water in a different way.

How can you grow crops in a desert?

In many dry areas, groundwater recharge from rainfall is very low, but there is still plentiful groundwater to be found. How can this be? As an example, there are large groundwater reserves under the Sahara Desert in North Africa. Studies of this water have shown that it has been trapped deep in the ground for a million years – it infiltrated into the ground when the climate in northern Africa was very different and there was a lot of precipitation. As the aquifers in this area are not linked to the oceans, or to rivers or lakes, this groundwater has been sitting there all this time. Ancient water like this is known as fossil water.

In the case of the Sahara Desert in North Africa, a recent study has shown that the massive aquifer beneath the desert is in fact being recharged. Rainwater and runoff bring an average of 1.4 km^3 of water into the aquifer per year. However, water is being abstracted from the aquifer at a rate of 2.75 km^3 per year for use in crop irrigation, industry, tourism and households.

Based on the rates of abstraction and recharge in the Sahara given above, is the groundwater in the aquifer being used sustainably?

You could say that using renewable groundwater is like spending some of the money you earn every month, whereas over-abstraction is like using up your savings until eventually you have none left. Can you think of another analogy that could be used to explain sustainable versus unsustainable rates of groundwater abstraction?

Learning activities

1 Groundwater where I live

Are there boreholes, wells or handpumps accessing groundwater near to your school? Ask your teacher if you can arrange one of the following activities to find out more about a groundwater source:

- Arrange to interview some of the people using the groundwater source – What do they use the water for? How often do they visit to collect water? Are there any problems with the water source? What other sources of water do they use?
- Can you find out who drilled the borehole or well and/or who installed the handpump?

2 Read and respond

Read the article on pages 20 and 26.

1. What methods did geologists use to find out about the geological structures and rock types of Kwale County?
2. How is groundwater stored in rocks?
3. How is the groundwater stored in the palaeochannels being accessed?
4. If you had the opportunity to meet one of the geologists involved in this research, what questions would you ask?

3 Infiltration experiment

If you dig into the ground where you live, what do you find? Soil? Sand? Pieces of gravel? Rock? Does this vary depending on exactly where you dig? This experiment aims to show how the rate of infiltration (how fast rainwater soaks into the ground) varies depending on the material at the surface. It will also demonstrate the porosity and permeability of different materials.

Materials

- Gravel
- Sand
- Soil
- 3 plastic bottles
- Measuring jug or bottle
- Stopwatch
- Scissors/knife
- String or wire
- Small circle of fine cloth or window screen
- Tape
- Water

Method

1. Make 4 holes at the base of each plastic bottle 3 cm from the base.
2. Cut off the bottom of the bottle 1-2 cm from the base.
3. Thread 4 pieces of string through the holes so that the bottles can be suspended upside down.
4. Take the lid off the bottles and tape a piece of fine cloth over the opening.
5. Hang the bottles up in a row.
6. Fill the first with soil, the second with sand, the third with pebbles or gravel.
7. Draw a picture of the set up. Can you see any pores in the material?
8. Make a prediction – which material do you think will allow fastest infiltration of water?
9. Place the empty measuring jug underneath one of the bottles and get your stopwatch ready.
10. One person starts the timer whilst another person pours 250ml of water into the top of the first bottle (slowly so it doesn't overflow).
11. Observe and record the volume of water in the measuring jug after 30 seconds, 1 minute, 5 minutes, 10 minutes, 30 mins.
12. Repeat timed experiment for the other bottles (If in groups, compare your results with the groups with other materials in the bottles). What did you observe? Make a graph of your results.

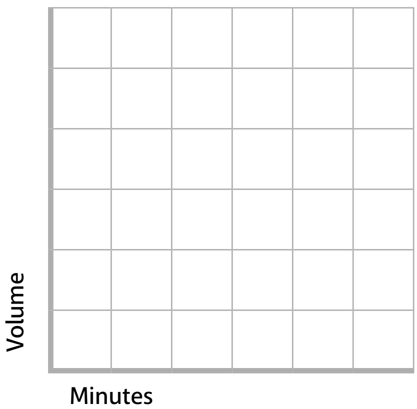
Infiltration experiment worksheet

Draw a picture or diagram to show how the experiment is set up:	
Make a prediction: Which material do you think will have the fastest infiltration rate and why?	

Soil		Sand		Gravel	
Time (mins)	Volume (ml)	Time (mins)	Volume (ml)	Time (mins)	Volume (ml)
1		1		1	
5		5		5	
10		10		10	
30		30		30	

Graph

Plot soil, sand and gravel data in different colours. The slope of the graph shows the infiltration rate.



Conclusion

Which material allows water to infiltrate the fastest?	

4 Saturation experiment

After 30 minutes put the lids back on each of the bottles. Had all 250ml been filtered through the bottle into the measuring jug?

Fill the measuring jug with 1 litre of water and pour slowly into each bottle, slow enough so that it soaks in and doesn't overflow over the sides straight away. What is the maximum volume each bottle can hold?

Saturation experiment worksheet

	Soil	Sand	Gravel
Volume left in bottle after 30 mins (ml) [A] (250ml minus volume recorded in previous table)			
Volume poured into the bottle before it cannot hold any more (ml) [B] (1000ml minus what is left in measuring jug)			
Maximum saturated volume (A+B)			
Which material holds the most water?			

Using your results, how would you rank the different materials in terms of porosity and permeability? • Soil • Gravel • Sand	↑ Most porous Least porous	Most permeable ↑ Least permeable

If you wanted to make an impermeable layer in one of the bottles, what material could you use?	

Groundwater crossword

Test your groundwater knowledge by using the clues to fill in this crossword puzzle.

ACROSS: Clues for horizontal words:

2 The zone between the land surface and the water table where pore space contains both water and air (11, 4)

4 A separation in a rock that divides it into two or more pieces (8)

5 The study of groundwater and the geological materials that it interacts with (12)

6 Groundwater that has been stored in an aquifer for thousands of years (10 US spelling)

7 What we call material that has connected void spaces so water can flow within it (9)

8 A layer of geological material that is impermeable, it stops the flow of water (9)

10 What we call material that is holding as much water as possible (9)

11 A deep, narrow hole made in the ground, usually to locate water or oil (8)

12 Movement of water a) into the ground from a surface waterbody or b) out of the ground into the ocean or onto land (7 Find the definition on page 55)

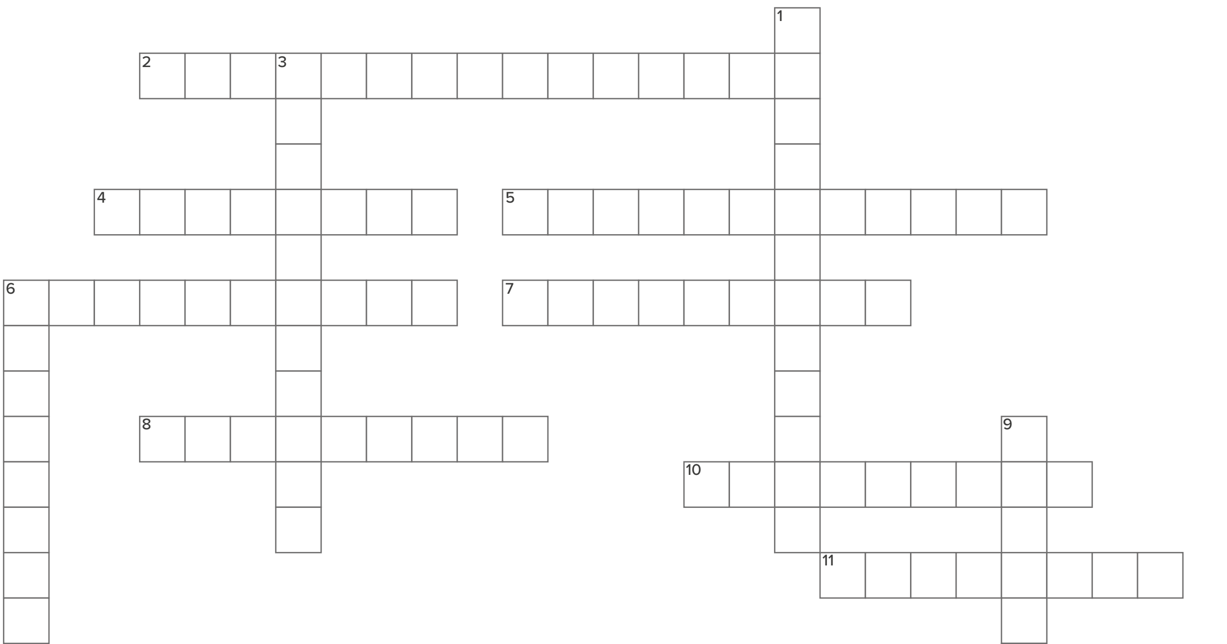
DOWN: Clues for vertical words:

1 A measure of the connectivity of void spaces in the ground (12)

3 The process of taking water out of the ground temporarily or for permanent use (11)

6 The ratio of the volume of void spaces in a rock/sediment to the total volume of the rock/ sediment (8)

9 Water that is added to an aquifer (e.g. when rain infiltrates into the ground) (8)



4. Water quality

Water is a natural habitat for many living things and it is a powerful **solvent**, so as it moves through the hydrological cycle it picks up and carries many things with it. Because of this, **water quality** will naturally be different in different places and at different times of year.

When thinking about what affects water quality, there are three main considerations:

- Biological quality – bacteria, viruses, protozoa and worms
- Chemical quality – dissolved metals and other elements and chemicals
- Physical quality – temperature, colour, smell, taste, **turbidity**

Most of the things that are dissolved or living in water are harmless or even beneficial. However, it is possible for water to be *naturally* contaminated with substances that can cause illness and/or make the water taste bad. Water can contain biological **pathogens** that are spread by wildlife. This is more common for surface water than for groundwater because wildlife are more likely to make contact with surface water. Groundwater is naturally better protected from pathogens, but that doesn't mean it is always safe. For example, water can dissolve fluoride from rocks and high levels of fluoride can cause a disease called fluorosis in humans. Water can also dissolve other elements from rocks that can make it taste salty. This is one reason why groundwater can be naturally salty, even when it is far away from the ocean. Often, there is not much that can be done to protect water from natural contamination. In cases when natural contamination is a problem, water will have to be treated.

There is a lot that can be done to protect against **pollution** by human activities. Water can be polluted by humans in many ways. Some examples include:

- Improper management of **wastewater** and solid waste (including open defecation, livestock waste, or building latrines too close to water sources)
- Improper use of fertilizers and pesticides in agriculture
- Swimming and bathing in water sources

An open well in Kwale County, Kenya. Photo by Saskia Nowicki.

Water treatment

Not all pollutants are visible, so even though water may look clear it could still be unsafe to drink. The best way to have safe drinking water is to use a multi-barrier approach. This is the approach that is recommended by the World Health Organisation and it involves five different steps:

- Source protection
- Sedimentation
- Filtration
- Disinfection
- Safe storage

1 Source protection

Water needs to be protected so that it is safe to drink. Protecting water can lead to improved water quality and health. Protecting water means keeping pollutants away from it. Usually, **surface water** is more difficult to protect than groundwater because it is more difficult to prevent humans and animals (and their waste!) coming in contact with the water when it is open to the air. Protecting surface water as much as possible can help to improve water quality, but usually treatment will still be needed to make the water safe to drink.

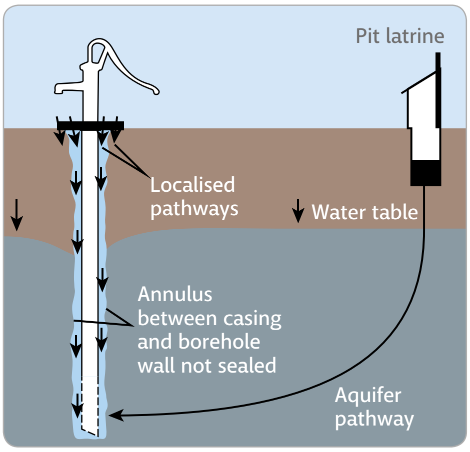
Remember that pollution in rivers will flow downstream, so if possible, it is better to collect water upstream of where pollution is happening. For example, if you know there is an area of the river where people usually go to wash or animals usually go to drink, you should collect water upstream from that place.

Groundwater is often cleaner and less accessible than surface water, and water naturally filters through layers of ground material before it enters aquifers, this process can remove some pollutants. However, aquifers are vulnerable to pollution when:

- The water table is close to the surface. For example, when you can see the water in an open well it is close to the surface
- The ground above the aquifer is permeable. The more permeable the ground is, the more easily pollutants can get into the aquifer

Different pathways to groundwater pollution

In the coastal county of Kwale, Kenya, villages rely on shallow groundwater pumped out by handpumps from an unconfined aquifer. The ground is permeable above unconfined aquifers, which means that the groundwater can be polluted from latrines and other waste sources on the surface (for example animal faeces inside livestock pens). When pollutants are washed down through the ground into an aquifer, the pollution has arrived in the groundwater through the '**aquifer pathway**'. Pollution of groundwater can also come from '**localised pathways**'. This is when pollutants enter the water through wells/boreholes themselves (or the ground immediately surrounding them). This happens if wells/boreholes are not well protected or properly constructed. The figure shows an aquifer pathway by which pollution has entered to groundwater from a latrine as well as localised pathways directly around the borehole.



Two pathways to groundwater pollution. Note: The 'casing' is the pipe that is installed into the borehole which has holes at the bottom to let the water in; the 'annulus' is a ring-shaped hole that forms between the sides of the drilled hole and the pipe/casing. The annulus is supposed to be blocked up with special material to stop water from travelling down it, but sometimes this is not done properly (Lawrence et al. 2001).

> What factors might affect how far away a pit latrine needs to be from a borehole to avoid the risk of pollution?
>
> Have you heard of composting toilets? Would they be useful in your area?
>
> If you know of a well or handpump that needs improving, who should be informed of the problem?

Protecting groundwater from pollution

Protecting groundwater requires consideration of both aquifer and localised pathways. To be effective, water protection requires communities to work together. The first thing to do is identify all the possible sources of pollution in the area and then try to keep the pollutants away from the water. These are some important steps that communities can take:

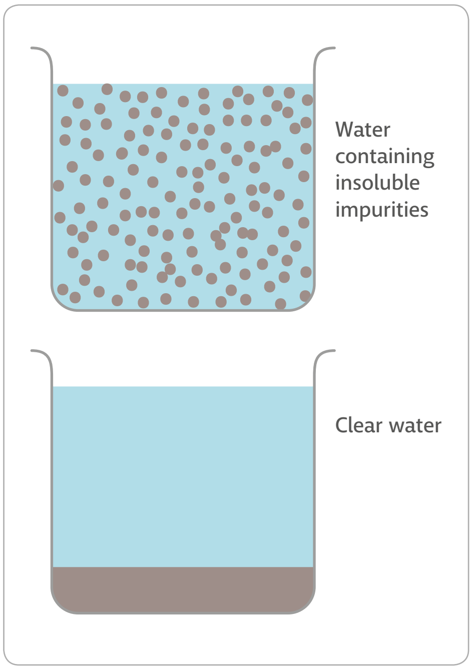
- Keep the area around the water source as clean as possible (remove garbage, faeces and other types of pollutants so that they cannot be washed into the well/borehole)
- Build latrines away from and downhill of water sources
- Use latrines and avoid open defecation especially near water sources
- Build fences to prevent large animals from going near water sources

The Llobregat water treatment facility in Barcelona, Spain. Photo by Saskia Nowicki.

- Build animal pens away from water sources
- Build good drainage channels around taps and pumps so that water does not form pools in which pathogens can collect and then infiltrate into the groundwater
- Use concrete to cover the area around handpumps and wells so that surface water cannot flow directly into the well through the surrounding ground
- Use clean buckets to collect water

It is important to remember that this is an ongoing task. To protect water, communities need to always be aware of any potential pollutants and be careful to keep them away from the water. The most common and harmful pollutant is often human and animal faeces.

After you have protected your water the best that you can, the next steps are **sedimentation**, **filtration** and **disinfection**. These are all types of water treatment. This treatment can be done at a very big scale. For example, the pictures below show a water treatment facility in Spain that can treat 200,000 cubic metres of water in a day (that is 10 million jerry cans!). In places that do not have large centralised treatment facilities, and most **rural** places do not have them, the same three treatment steps can be used at the household level to make water safer for drinking. The next three sections talk about **sedimentation**, **filtration** and **disinfection** at the household level.



2 Sedimentation

Even if you have done your best to protect your water, it may still contain contaminants that could make you sick. You can do sedimentation for another layer of safety. This is a very simple step; it just takes time. Sedimentation happens when you let water sit in a container and the particles that are suspended (floating) in the water slowly fall/settle out to the bottom because they are heavier than the water. Large particles will settle to the bottom of the container more quickly but small particles will take more time.

It is possible to add chemicals to the water to make the particles group together into clumps. This involves two processes: 1) coagulation and 2) flocculation. The clumps are heavier so they settle out faster. These chemicals are used in large water treatment facilities and sometimes households will also use them in small amounts. Seeds from the Moringa plant are a natural product that is available in Kenya and can be used to speed up the sedimentation process. In the activities section you will learn how to do this.

If you do not have access to coagulants or flocculants, you can still let sedimentation happen – it will just take longer. Put the water in a clean container, cover it so that no additional pollutants can enter, and wait. After some time, the water will become clearer and you can take it out of the container. Be careful not to disturb the particles (sediment) at the bottom of the container otherwise it will mix back into the water and the water will be turbid again.

When water has high turbidity it is good to do sedimentation before filtering because the filter will then last longer; it will not clog up as fast.

An example of a ceramic bucket filter being tested by a school water club in Kwale County. In this example the water slowly passes through the ceramic layer that has been inserted inside the bucket. This ceramic has been specially treated to make it more effective at removing pathogens. When the water passes through the ceramic it collects at the bottom of the plastic bucked and can be poured out using the small tap. Photo by Kingwede School Club.

3 Filtration

After sedimentation, the next step is filtration to further remove contaminants. When you do not have time to wait for sedimentation or when water does not have high turbidity, you can skip directly to filtration. Filtration is a physical process that involves passing water through a filter – a material that catches contaminants, which are larger than water particles, and holds them back while clean water drains through. Some filters are also designed to grow a biological layer that kills or inactivates pathogens and makes their removal more effective. There are many kinds of filters. Some work better than others and different filters can remove different types of pollutants. Ceramic, for example, is often used as a filter material.

Other common types of filters are **membranes** and sand. Membranes are flexible sheet-like material that acts as a boundary to block pollutants from passing through. There are many kinds of membranes but they are often expensive and can be difficult to acquire. Sand is a less technical solution and it can be very effective. Sand filtration can be done to treat water for a whole community if the community builds a *good slow sand filtration* system. Such a system is made up of different parts including water storage tanks, an aerator, pre filters, and slow sand filters.

It is important to remember that all filters will eventually get clogged up by the pollutants that they have removed from the water. When this happens, they must either be cleaned or replaced. Different filters can last for different lengths of time and have different procedures for cleaning / replacing.

UV Radiation using clear plastic bottles. Photo by SODIS Eawag, CC BY 3.0, Wikimedia Commons.

What are the advantages and challenges of each disinfection method? Which do you prefer?

4 Disinfection

After filtration, there is another very important treatment step to make water safe for drinking: It must be disinfected. Disinfection will kill pathogens that remain in the water after the first two treatment steps. There are different ways to disinfect but the most common are:

- **Chlorine** – The effectiveness of chlorine disinfection is impacted by the chemistry and temperature of the water, but guidelines are available to know how much chlorine should be used for different volumes of water.
- **Boiling** – Boiling will kill pathogens regardless of the chemistry of the water. Boiling should be done for at least 1 to 3 minutes to be safe. Of course, boiling requires fuel to heat up the water and this is sometimes difficult or expensive to obtain.
- **Ultraviolet radiation exposure** – Ultraviolet (UV) radiation comes from the sun. Water that is left in the direct sun can be disinfected by UV radiation. Water does not have to reach boiling temperatures (because in this case it is not the temperature that is killing the pathogens) but it needs to be exposed to the sun in a clear container. Some companies make special containers for this purpose but it is also possible to use plastic water bottles (see picture on this page). If using this method, it is particularly important to do sedimentation and filtration first because otherwise pathogens can 'hide' behind turbidity in the water to survive the UV exposure.

  When relying on UV exposure to disinfect water, it is important to leave the water in the sun for long enough. The length of time that is needed depends on how strong the sun is. When the sun is very strong, less time is needed. There is a company that manufactures a device called a WADI which measures the strength of UV radiation and tells you when the water has been exposed for long enough.
- **Solar distillation** – Another disinfection method that uses energy from the sun is solar distillation. Distillation purifies water through evaporation and condensation. First water is heated using solar energy until it evaporates. The water vapour is then captured in a separate container and cooled down so that it condenses back to liquid form. When water evaporates, it leaves behind anything that it was carrying so all pollutants are removed. This method can even remove salt from saltwater. Of course, you must get rid of what is left behind (which is called 'residual brine'). If there are pollutants in the brine that may be harmful to the environment, you must be careful how you manage it.

5 Safe storage

After all the work of protection, sedimentation, filtering and disinfection has been done, the final step is to store the water safely. It is possible for water to be polluted again after it has been cleaned – safe storage makes sure this does not happen. Of course, keeping clean water stored safely means storing it away from possible sources of pollution. The most important thing is to *keep hands out of the water!* Here are some other tips:

- Keep water in a clean and covered container (it should be a special container that is only for treated water)
- Remove water from the container using a tap or by pouring it through a narrow opening in a way that will not let anything get into the container and prevents hands from touching the water
- Make sure the container has a stable base so it does not tip over and if possible, keep it elevated off the ground
- When the container is empty of water, clean it carefully with soap (if no soap is available, use clean water to rinse the container but avoid putting your hands in it)

It is best to drink water soon after it has been treated. The longer it is left in storage the more likely it will become dirty again.

How is water stored at your home or school? Could this be improved based on the information above?

Water supply in Kyuso County. Photo by Water Programme, Smith School of Enterprise and the Environment.

Learning activities

1 Protecting a water source

Think about one water source used by people near your home or school.

Make a list of all the possible ways that this water source may be at risk from pollution. Next, make a list of ways to protect the water source from the risks that you have noted.

When you are finished with your lists, discuss your ideas with a partner or a small group and see if you can identify any other risks or protective actions that could be made.

What are some of the challenges you would face if you tried to protect the water source better?

2 Comparing methods to speed up sedimentation

Sedimentation is an important step in water purification, particularly if the water is turbid and full of floating solid particles. Sedimentation occurs as gravity causes these particles to settle at the bottom of a container. Various substances known as coagulants can be added to water to speed up the process of sedimentation, by making the particles group together into clumps. In this experiment, you will compare two different coagulants to see how they affect the rate of sedimentation. Remember to follow any safety instructions from your teacher when doing experiments.

Materials

- 2 litre sample of murky water from a muddy place or a water sample made by mixing dirt and water
- 3 x 2 litre plastic bottles cut in half
- 1 tablespoon of Alum (potassium aluminum sulfate)
- Small pestle and mortar
- Moringa seed (1 seed per litre of water, choose good quality seed)
- 2 x Tablespoon
- 3 x Metal spoon or stirrer
- Funnel

Method

1. Grind moringa seed into a powder.
2. Put lid on original sample and shake.
3. Use a funnel to pour the same amount of water into each bottle.
4. Add ground moringa seed to one bottle and a tablespoon of alum powder to another; Stir all three bottles for 5 minutes.
5. Record your observations of the appearance of each bottle at the start, and then at 5 minute intervals.

Student observations

Water appearance	No treatment	Alum	Moringa seed
Appearance and smell before the start of treatment			
Appearance 5 minutes after adding coagulant			
10 minutes after adding coagulant			
15 minutes after adding coagulant			
20 minutes after adding coagulant			
30 minutes after adding coagulant			
Which treatment worked fastest?			

Extension: Investigate how turbidity is measured

Materials

- A flashlight
- Four flat-bottomed drinking glass
- Samples of 1) unfiltered water (the original untreated water), 2) water after sedimentation with alum, 3) water after sedimentation with moringa, and 4) clear drinking water

Method

1 Pour equal volumes of unfiltered, filtered and home drinking water into the flat-bottomed transparent drinking glasses.

2 Move the glasses of water into a dark room and place them on a flat surface.

3 Place the flashlight against the side of each container and shine a beam of light through each of the samples. Look at the path of the flashlight beam.

4 How does the path of the flashlight beam through filtered water compare to that through unfiltered water? How does the filtered water compare to tap water?

5 Now pour half of the unfiltered water out and replace it with clear drinking water. Examine the effect by shining the flashlight through the glass. How many times must you repeat this dilution before you can see no difference between the filtered water and the tap water?

Why does the path of the flashlight tell us anything about the turbidity? The reason is that the particles in the water scatter the light from the flashlight. Scientists studying water quality often use turbidity meters called nephelometers which measure how much light is scattered at different angles. As more particles cause more scattering of the light, the nephelometer is designed to provide a precise measurement of turbidity, which is given in Nephelometric Turbidity Units (NTU). (Nephele = Greek for cloud; Metric = Greek for measure)

This activity has been adapted from the Global Experiment that was conducted during the International Year of Chemistry, 2011.

3 Solar still design challenge

In this activity you will build a solar still and find out how it can purify water. You will be challenged to use your knowledge to build a more efficient solar still.

The solar still is a device that that uses solar energy to purify water. Different versions of solar stills are used to desalinate seawater and in desert survival kits. Solar stills are also available for home water purification.

Part A: Build a simple solar still

Materials

- Large metal or plastic bowl/basin
- Small, shallow glass or cup (washed in soapy water, rinsed with clean water and dried)
- Measuring jug or cylinder
- Cling film (wider than the bowl)
- Small stone (pebble)
- Hot water (recently boiled and cooled)
- Food colouring
- Salt

Method

1 Add a measured volume of recently boiled and cooled water (about 1 cm) to the bowl. (Record the volume of water added)

2 Add some food colouring and about a teaspoonful of salt to the water in the bowl.

3 Take all the equipment out to a sunny, level place.

4 Place the glass or cup in the middle of the bowl making sure no water splashes into it.

5 Cover the bowl loosely with cling film, sealing the film to the rim of the bowl. Use tape or string if necessary.

6 Place the stone in the middle of the film above the cup.

7 Leave the still for at least an hour (the longer the better) and then check that there is some water in the cup.

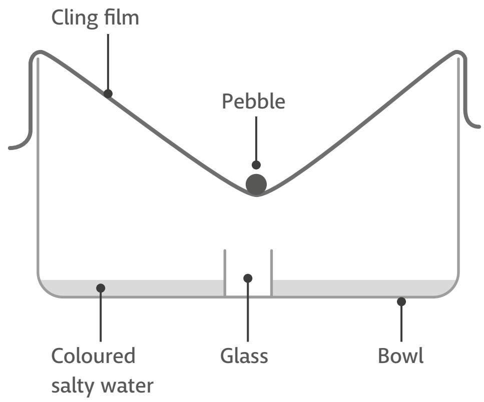
8 Take the still back indoors, remove the cling film and take out the cup without splashing any water into or out of the cup.

9 Measure the amount of water in the cup.

10 Observe the colour of the water in the cup and test it for salt (ask your teacher if you can use taste to test).

11 Calculate the percentage of the water that was purified:

$$\% \text{ water purified} = \frac{100 \times \text{volume collected}}{\text{volume added to still}}$$



Part B: The design challenge

Your challenge is to modify or make a more efficient solar still than the one that you made in Part A.

12 Write down some ideas about how you might improve the still. For example you might try using different coloured containers to find out which absorbs the sunlight most efficiently.

13 Discuss your ideas with your teacher and get his/her permission to carry out the experiment.

14 Carry out the experiment recording the volume of water you start with and the volume you purify.

15 Calculate the % water purified and record it on the Results Table.

16 If you have time, you can develop your design further. Make sure you get permission from your teacher for each experiment you carry out.

17 Draw a diagram of your most efficient still showing why it is more efficient than your first still.

Results

Copy this results sheet into your notebook or use one provided by your teacher.

Trial	Volume of water added	Volume of water collected	% water purified

Part A: First still

1 Explain in your own words how the still works.

Part B: Design challenge

2 Write down one way in which you could make your still work better.

3 Draw a diagram or explanation of your design for a still that will work better and then discuss the ideas with your teacher before building it.

4 Try the new still and record results in the table.

This activity has been adapted from the Solar Stills Challenge Activity part of the Global Experiment that was conducted during the International Year of Chemistry, 2011.

Part B: Improved still design trials

Trial	Volume of water added	Volume of water collected	% water purified

Water quality crossword

Test your water protection and treatment knowledge by using the clues to fill in this crossword puzzle.

ACROSS – Clues for horizontal words:

3. Changing the physical, chemical or biological properties of water by introducing any substance that makes the water harmful to use (9)

4. Radiation that comes from the sun and has a wavelength shorter than visible light (11)

7. Controlled application of water to agricultural fields (10 Hint: look back to the end of section 3)

8. Wastewater from household use (9 See page 47 for an extra clue)

9. The action of passing water through a device / material to remove unwanted substances (10)

10. Water that contains unwanted materials from homes, businesses and industries (10)

11. Something that can dissolve other substances (7 Starts with an 's', check the glossary for an extra clue)

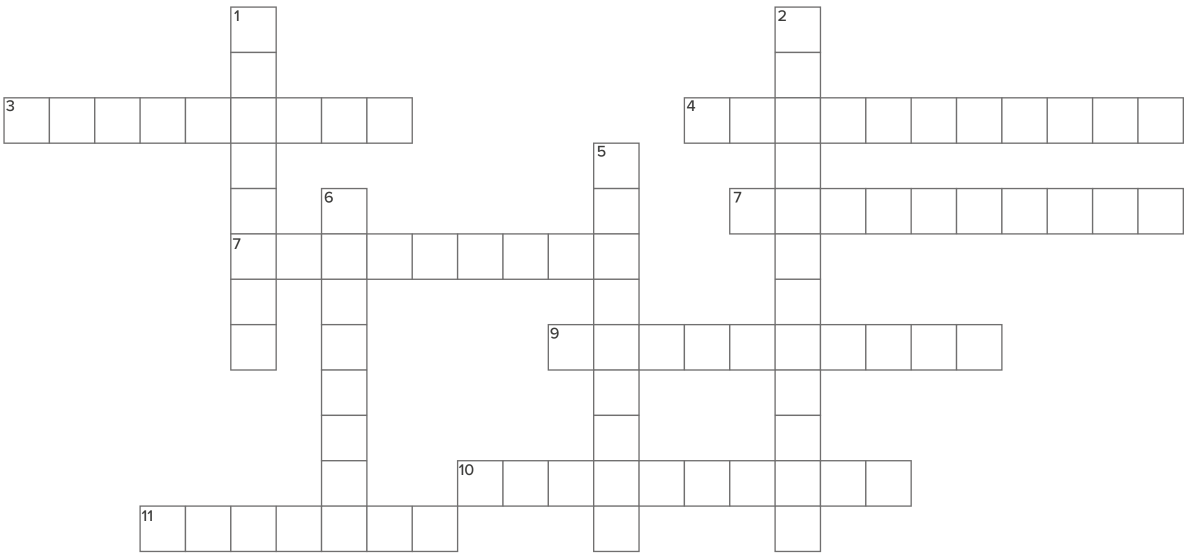
DOWN – Clues for vertical words:

1. A biological organism (often bacteria or viruses) that causes disease (8)

2. The chemical, physical and biological characteristics of water with respect to its suitability for a particular use (5, 7)

5. A measure of the cloudiness/haziness of water due to suspended particles (9)

6. A flexible sheet-like material that acts as a boundary so that some substances are blocked from moving through it (8)



5. Water conservation

What is your water footprint?

A “water footprint” has nothing to do with feet! It is a term that we have to talk about all of the water that is used when something is produced. Every item you can imagine has its own water footprint – that is the amount of water required to create that item and transport it to where it is used. You have a water footprint too. If you could add up the amount of water that is required to produce and transport everything you eat and use every day, you could calculate your own water footprint. A water footprint can be divided into blue, green and grey water.

The average water footprint of Kenyan citizens is 1100 m^3 each year (that is 55,000 large jerry cans) – 95% of this is water used in producing the food we eat, the rest for washing, drinking, clothes, etc. The global average water footprint is higher, 1240 m^3 per person each year.

BLUE water footprint

The water taken and used from rivers, lakes or aquifers e.g. for farming or use in a factory

GREEN water footprint

The rainwater used by plants that are then consumed by people or livestock

WASTE water footprint

The freshwater that is needed to dilute pollutants from households, farms or factories enough to meet specific water quality standards

waterfootprint.org

> What are some possible reasons why the global average water footprint is bigger than the average footprint for a Kenyan citizen?
>
> Within Kenya, how do you think the water footprint of a person living in Nairobi would compare to the water footprint of a person living in a small village? How do you think it would compare with your own footprint? What would be some reasons for the differences?
>
> Is a big water footprint good or bad? Why?

Water conservation in farms and gardens

Water use for growing crops and raising livestock is the largest part of a person’s water footprint but there are ways to save water. There are many techniques that make agriculture more sustainable by saving water and reducing loss to run-off or evaporation.

Some examples are:

- Experimenting with different farming methods e.g. The System of Rice Intensification developed in Kenya by Professor Bancy Mati and colleagues
- Harvesting rainwater and runoff as an alternative source of water – as in, for example, terracing techniques such as Fanya Juu and Fanya Chini that started in Eastern Province of Kenya and are spreading through East Africa
- Building cut-off drains and ditches to retain water in the soil (popular practices in dryland counties of Kenya such as Machakos and Makueni)
- Planting drought-resistant indigenous plants adapted to the local climate and/or varieties of crops that need less water
- Composting and mulching – Organic matter can be used as a surface mulch layer or rotted down to compost and mixed into the soil. These practices improve soil structure which results in better drainage: Water does not pool on the surface and evaporate or sit in the soil and cause rotten roots, but rather seeps gradually into and through the soil at a rate which allows plants to make good use of it
- Using targeted "drip" irrigation systems that transport water to crops through pipes and release water as needed may avoid wasting water to evaporation. Systems are available for small farms and even some schools use them. It is important to monitor how effective they are.

Taita, Kenya, Terraced Farmland, Upland. Photo by Peter R Steward, CC by NC 2.0, Flickr.com.

Drip irrigation at a primary school in Kwale County, Kenya. Photo by Saskia Nowicki.

Using greywater in your garden

Another possibility for water conservation is to use **greywater** – wastewater from household use – on crops or ornamental plants. In this way, greywater can become **recycled water**. Professionally-designed greywater systems can be installed to filter, treat and store the water to make it safer and easier to re-use, but it is important to get expert advice on the costs and benefits of installing such a system.

Most simply, greywater can be collected in a bucket or other large container and transferred to the garden directly, but it is important to pay attention to the safety guidelines overleaf.

Watering crops in a greywater tower, Ethiopia. Photo by Sustainable sanitation, CC BY 2.0 Flickr.com.

Safety guidelines for greywater use

- Water from toilets or washing soiled nappies is not safe for re-use due to faecal contamination
- Residential gardens close to streams or shallow water tables should not be irrigated with laundry water: There is a risk of ground and surface water contamination from salts and other non-biodegradable substances found in washing powder or other laundry products. Long-term use at one site may pose a risk to soil quality
- Shower and bath water or water from a bathroom hand basin is most appropriate for use in the garden because the residues from soap/cleaning products are small
- Kitchen sink water can be used if it does not contain oil/grease or blood
- Filter the water before use so that any lint, hair and food particles are removed to reduce bad odours and avoid attracting pests. A filter could be a sock over the end of the pipe/hose, a simple sand/gravel filter, or something professionally-designed. The filter will need to be cleaned regularly

Important safety points for using greywater

- To avoid bacteria growth, do not store greywater for more than 24 hours before using it
- Greywater should be used on crops in combination with freshwater to avoid build-up of salts that are bad for plants. To address this issue, pour freshwater on the crops/soil at least once a month if it has not been raining
- Don’t use greywater on vegetables where you eat the leaves or on crops that will be eaten uncooked
- Don’t pour greywater directly onto leaves or spray it into the air, pour it directly onto the ground – this reduces the health risk from bacteria
- Ideally, pour the greywater onto a mulch (a surface layer of organic matter used in gardening; learn more in the next section!) rather than bare soil so that it filters slowly into the soil below; Alternatively, find out more about the construction of greywater towers which filter water before and supplying it to crops
- *Wash with clean water and/or cook crops before eating them*

Learning activities

Extract from Guardian newspaper article from World Water Day 2015

The cost of cotton in water-challenged India

Stephen Leahy
Friday 20 March 2015 14.12 GMT

Severe water scarcity in India is exacerbated by the cotton industry. Concerns are high, but are businesses,consumers and government doing enough?

You might not realise it, but India exports enormous amounts of water when it exports raw materials such as cotton and products such as automobiles.

The water consumed to grow India's cotton exports in 2013 would be enough to supply 85% of the country's 1.24 billion people with 100 litres of water every day for a year. Meanwhile, more than 100 million people in India do not have access to safe water.

Virtual water

Cotton is by no means India's largest export commodity – petroleum products followed by gems and jewellery follow closely behind. All of these exports require water to produce, and the quantities needed are staggering. Not only does it take water to grow anything, it also takes water to make anything: cars, furniture, books, electronics, buildings, jewellery, toys and even electricity. This water that goes largely unseen is called virtual water.

What's easy to forget is that virtual water is as real as the water you drink. Producing 1kg of cotton in India consumes 22,500 litres of water, on average, according to research done by the Water Footprint Network. In other words, this 22,500 litres of water cannot be used for anything else because it has either evaporated or is too contaminated for reuse.

By exporting more than 7.5m bales of cotton in 2013, India also exported about 38bn cubic metres of virtual water. Those 38bn cubic metres consumed in production of all that cotton weren't used for anything else. Yet, this amount of water would more than meet the daily needs of 85% of India's vast population for a year.

Doing things differently

Cotton doesn't usually consume this much water. The global average water footprint for 1kg of cotton is 10,000 litres. Even with irrigation, US cotton uses just 8,000 litres per kg. The far higher water footprint for India's cotton is due to inefficient water use and high rates of water pollution — about 50% of all pesticides used in the country are in cotton production.

Most of India's cotton is grown in drier regions and the government subsidises the costs of farmers' electric pumps, placing no limits on the volumes of groundwater extracted at little or no cost. This has created a widespread pattern of unsustainable water use and strained electrical grids.

Recent reports show that India's water consumption is far too high. In 54% of the country 40 to 80% of annually available surface water is used. To be sustainable, consumption should be no more than 20% in humid zones and 5% in dry areas, to maintain the ecological function of rivers and wetlands, experts say.

India's extensive groundwater resources are also rapidly being depleted, with 58% of wells in the drier north-west India experiencing declining water levels.

1 Water use in your school

Design a research plan to find out how much greywater is produced at your school per week.

Research techniques you could use:

- Survey forms for staff and students
- Observation at waterpoints – taps, pumps, etc.
- Direct measurements of your own use – e.g. Collect and measure water used when washing clothes, washing hands and brushing teeth

Present your findings as a poster.

> How is the greywater at your school or home used or thrown away? Within the safety guidelines in this booklet, can you design a simple greywater reuse system that would work at your school?

2 Can a t-shirt have a footprint?

T-shirts are often made of cotton, which is a crop grown in many countries around the world. You can read about cotton production in India in the newspaper article on page 49. "Blue" and "Green" water (see diagram on page 46) is used for irrigation and also in the process of preparing and dying the final cotton textile used to make the t-shirt. The WASTEwater footprint of a t-shirt depends on how much pollution was caused by its production from the pesticides, dyes and any other chemicals used in the process. All these elements can be put together to estimate the total water footprint of a t-shirt.

If you can find a t-shirt with a label showing where the cotton was grown, you can use the information below to calculate the water footprint of that t-shirt. You will also need a weighing machine or use the average t-shirt weight of 0.25kg.

Where was it made? (Check the label)

Country	Water footprint to produce 1 kilogram (kg) of cotton
USA	8,100 litres (L) of water
China	6000 L
Pakistan	9,600 L
Uzbekistan	9200 L
India	22,500 L
Global Average	10,000 L

Weight of one t-shirt:	↓
Remember 1 kilogram = 1,000 grams	(kg)

Calculate the water footprint of the t-shirt		
Water footprint of cotton (in L per kg)	T-shirt weight (in kg)	Water footprint of t-shirt (in L)
x	=	

Figures from The Water Footprint of Modern Consumer Society by Arjen Y. Hoekstra, Routledge, 2013.

Cotton harvest. Photo by Kimberly Varden; CC BY 2.0; Flickr.com.

Why do the water footprints for cotton produced in different countries vary so much? If you can watch videos in school, ask your teacher about a video called Cotton and Water to find out about ways to reduce water use in cotton production.

3 Conservation agriculture project

Which food crop plants growing in your area use the most water and which ones use the least? Is there a gardener or farmer that you could ask about this or can you think of a way to measure it directly?

Can you find out about some of the water-saving techniques that are used by farmers in your area? Are there any water-saving techniques could be used in the gardens at your school?

Use your water knowledge

Choose two questions from the list on the right of the page and discuss in pairs or small groups to get your ideas flowing.

Make a poster, write a school newsletter, or create an awareness campaign on the theme of OUR VISION FOR WATER to share what you have learned in this module with others.

Discussion points

- Who is responsible for making water safe to drink?
- Who is responsible for making sure there is enough water for everyone?
- How much water is enough water for drinking and household activities?
- How much water do people in your school use every day? Do you think the water footprint of your school should be reduced or increased? If so, how would you do that?
- How can commercial users of water like agriculture, factories or mines conserve water and protect supplies?
- What are the main risks of drinking unsafe water and what can be done to reduce the risks?
- Why is groundwater from a handpump usually safer to drink than water collected from a lake, river or open well?
- What do you think everyone should know about water?
- What are the best ways to share important messages about water?

Glossary

abstraction	the process of taking water out of the ground for use
Afridev	a handpump design that was created based on research in Africa and is commonly used throughout the continent
aquiclude	a layer of geological material that is **impermeable**; it blocks water and does not allow it to flow through
aquifer	an underground geological formation that stores and yields water
aquifer pathway	a route that solutes (substances dissolved in water) and microorganisms (bacteria, protozoa, viruses) can travel where they move down through the ground into an aquifer and then flow with the groundwater into an abstraction point like a well or borehole
aquitard	a layer of geological material that has low **permeability**; it slows down the flow of water
blackwater	wastewater that contains faeces
borehole	a deep, narrow hole made in the ground, often to locate/pump out water or oil
climate	the weather conditions in an area in general or over a long period of time
coagulation	the process of changing a liquid into a solid or gel
condensation	the process by which a vapour becomes a liquid often due to cooling
consumptive use	use of a resource that reduces the supply: such as removing water from a river, lake or aquifer without returning the same amount (e.g. consumption of water by plants, humans, and animals and the incorporation of water into the products of industry or food)
discharge	water flowing out (e.g. out of a stream, pipe, or aquifer); the opposite of recharge
disinfection	cleaning something by killing the microorganisms (bacteria, protozoans, viruses) that are in it (e.g. water) or on it (e.g. a table)
drought	an extended period of less than normal precipitation that often affects availability of water supplies, it is a natural hazard caused by climate variability
evaporation	conversion of a liquid (water) into a vapour (a gas) usually through application of heat energy
evapotranspiration	movement of water vapour into the atmosphere due to both evaporation from soil and transpiration from plants

filtration	the process of passing water through a device/material to remove unwanted substances
flocculation	to form clumps of material within a liquid
fracture	a break/crack in a rock that divides it into two or more pieces
friction	the resistance that material encounters when moving against another material – it generates heat (for example when you rub your hands together you can feel friction and after a short time your hands will get warmer)
greywater	wastewater from household use
hydrogeology	the study of groundwater and the geological and non-geological materials that it interacts with
hydrology	the study of the occurrence, distribution, and chemistry of water
hyporheic zone	zone beneath and alongside streambed where shallow groundwater and surface water mix
impermeable	what we call material that water cannot flow through; it does not have connected void spaces so it blocks the flow of water
infiltration	movement of water from the land surface into the subsurface/ground
interflow	water travelling horizontally through shallow ground during or soon after precipitation (it discharges quickly into a stream or other waterbody but does not move down below the water table)
irrigation	controlled application of water to agricultural fields to supplement the water that is supplied by precipitation
localised pathway	a route that solutes (substances dissolved in water) and microorganisms (bacteria, protozoa, viruses) can travel to get into a well or borehole by moving through the ground very nearby or falling directly into the well/borehole
membrane	a flexible sheet-like material that acts as a boundary, lining, or partition so that some substances are blocked from moving through it
microscope	an instrument used for viewing very small objects like mineral grains or animal or plant cells by making the objects appear larger than they are, thereby allowing the viewer to see them in detail
molten	adjective used to describe a material in a liquid state due to high temperature (e.g. glass or metal)
non-renewable	non-renewable resources are finite – e.g. a goldmine – once the gold deposits are finished, no more will be made.
over-abstraction	withdrawal (removal) of groundwater over a period that exceeds the amount of water recharged to the aquifer

palaeowater	groundwater that has been stored in an aquifer for thousands to millions of years (US Spelling: paleowater)
pathogen	a biological organism (often bacteria or viruses) that causes disease
permeability	a measure of the connectivity of void spaces in the ground
permeable	what we call material that has connected void spaces so water can flow through it
photomicrograph	a photograph of something very small that is taken using a microscope
pollutant	any substance that when added to water (or another substance) makes it impure and unfit for consumption or an intended use
pollution	changing the physical, chemical, or biological properties of water by introducing any substance that makes the water harmful to use
pore spaces	void spaces between geological material
porosity	the ratio of the volume of void or air spaces in a rock or sediment to the total volume of the rock or sediment
precipitation	water falling out of the atmosphere in a liquid or solid state
recharge	water that is added to an aquifer (e.g. when rain infiltrates into the ground)
recycled water	water that is used more than one time before it passes back into the natural hydrological system
reservoir	a body of water that forms behind a dam
runoff	water that flows over land to surface streams, rivers, and lakes and eventually to the ocean/sea
rural	adjective referring to the countryside rather than the town
saturated	what we call material (like soil or a sponge) that is holding as much water as possible
saturated zone	the area below the water table where the ground is saturated with water (all the void spaces are filled with water)
sedimentation	the process of suspended material settling or 'falling' out of water, being deposited as a sediment
seepage	when water moves into the ground from a surface waterbody (e.g. some water from lakes and rivers moves down into the ground) or out of the ground into the ocean or onto land
soil	the top layer of the Earth's surface, containing unconsolidated rock and mineral particles mixed with organic material
soil moisture	water clinging to soil in the unsaturated zone
solvent	something that can dissolve other substances

surface water	Water in rivers, lakes and streams on the land surface
sustainable	something that can continue indefinitely at the same rate or level, with the same inputs, and without leading to depletion of resources
transpiration	the process by which water absorbed by plants, usually through their roots, is released into the atmosphere, mostly through the leaves of the plant, due to photosynthesis (photosynthesis is the process that plants use to transform sunlight into energy that they can use - the process produces oxygen and water in gaseous form)
turbidity	a measure of the cloudiness/haziness of water due to suspended particles (often silt or organic matter)
ultraviolet	radiation that comes from the sun and has a wavelength shorter than visible light
unsaturated zone	the zone between the land surface and the water table where pore space contains both water and air (plant roots can capture the moisture passing through this zone, but it is not enough water to fill wells)
vapour	the state of water in which individual molecules are highly energized and move about freely; also known as gas/gaseous
wastewater	water that contains unwanted materials from homes, businesses, and industries; a mixture of water and dissolved or suspended substances
water quality	the chemical, physical, and biological characteristics of water with respect to its suitability for a particular use
water scarcity	when there is not enough water to satisfy the needs of people, animals and the environment in a region (when water demand is greater than water supply)
water table	the level in the ground below which the soil and rock are fully saturated with water (all the spaces are filled with water); this is the name for the top of an unconfined aquifer
waterbody	any significant accumulation of water such as a lake, sea or river

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