A-LEVEL GEOGRAPHY TOPIC MASTER

THE WATER AND CARBON CYCLES

Series editor
Simon Oakes

Andrew Davis
Garrett Nagle

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CHAPTER 3

Water security and sustainable water management

Water security is essential for human wellbeing: 'Thousands have lived without love, not one without water' (W.H. Auden). However, water security varies spatially as well as temporally, and human activities are making water scarcity more intense than ever before. This chapter:

- investigates the water budget and the causes of water deficits
- explores the reasons for water scarcity and water insecurity
- analyses sustainable water management strategies
- evaluates the extent to which water security can ever be fully guaranteed.

KEY CONCEPTS

Water budget The relationship between the inputs and outputs of a drainage basin.

Water security Having access to sufficient amounts of safe drinking water.

Water stress When per capita water supply is less than 1700 cubic metres per year.

1 The water budget and water deficits

▶ *What is meant by the water budget and how much does it vary spatially and temporally?*

The water budget (or balance) shows the relationship between the inputs and outputs of a drainage basin. It is normally expressed as:

precipitation = Q (discharge) = E (evapotranspiration) +/– changes in storage (such as on the surface, in the soil and in the groundwater).

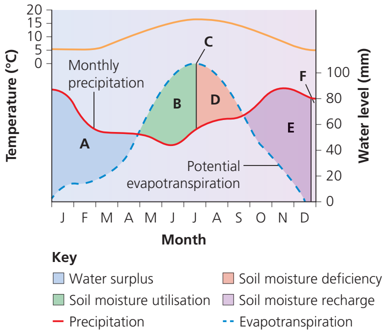
Figure 3.1 shows the water balance for a location in southern England, and how this affects availability of water in soils.

- Precipitation exceeds evapotranspiration between October and April, whereas evapotranspiration exceeds precipitation for the rest of the year.

- There are sufficient stores of water in the soil to be evaporated between May and June, whereas between July and September there is a water deficit. During this period, it may be important for farmers to irrigate their crops.

Figure 3.1 also illustrates how geographers recognise four distinct system states when analysing seasonal variations in soil water storage:

- **Soil moisture deficit** is the degree to which soil moisture falls below field capacity. In temperate areas, during late winter and early spring, soil moisture deficit is usually very low, due to high levels of antecedent precipitation and limited evapotranspiration in prior months.
- **Soil moisture recharge** occurs in autumn when precipitation exceeds potential evapotranspiration – there is some refilling of water in the dried-up pores of the soil.
- **Soil moisture surplus** is the period (typically the first few months of the calendar year in temperate regions) when soil is saturated and water cannot enter, and so flows over the surface.
- **Soil moisture utilisation** is the process operating in summer by which water is drawn to the surface through capillary action.



A Precipitation > potential evapotranspiration. Soil water store is full and there is a soil moisture surplus for plant use. Runoff and groundwater recharge.

B Potential evapotranspiration > precipitation. Water store is being used up by plants or lost by evaporation (soil moisture utilisation).

C Soil moisture is used up gradually during this period. Any new precipitation is likely to be absorbed by the soil rather than produce runoff. River levels fall or rivers dry up completely.

D There is a deficiency of soil water (soil moisture deficit) as the store is used up and potential evapotranspiration > precipitation. Plants must adapt to survive, crops must be irrigated.

E Precipitation > potential evapotranspiration. Soil water store starts to fill again (soil moisture recharge).

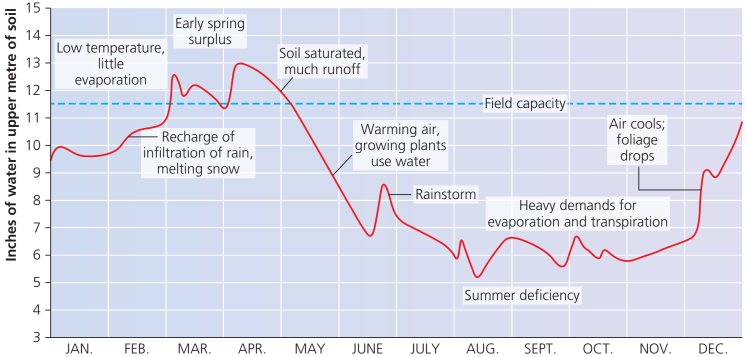
F Soil water store is full, field capacity has been reached. Additional rainfall will percolate down to the water table and groundwater stores will be recharged.

▲ **Figure 3.1** Soil moisture status

Figure 3.2 provides another view of seasonal variability in catchment water storage. It shows the annual cycle of soil moisture in an agricultural region in Coshocton, Ohio. The cycle is generally representative of conditions in a humid, mid-latitude climate, in which there is a strong temperature contrast between summer and winter. In spring (March), the evaporation rate is low due to the low rates of energy input (reflected in low temperatures). Snowmelt and rainfall restores the soil moisture store to a surplus system state: for two months, the amount of water percolating through the soil and entering the groundwater keeps the soil pores fully occupied with water.

By May, increasing solar radiation leads to increased evaporation and vegetation growth leads to increased transpiration. This reduces the soil moisture to below field capacity, although it may be restored temporarily by occasional rainstorms. By the middle of summer, a moisture deficiency exists.

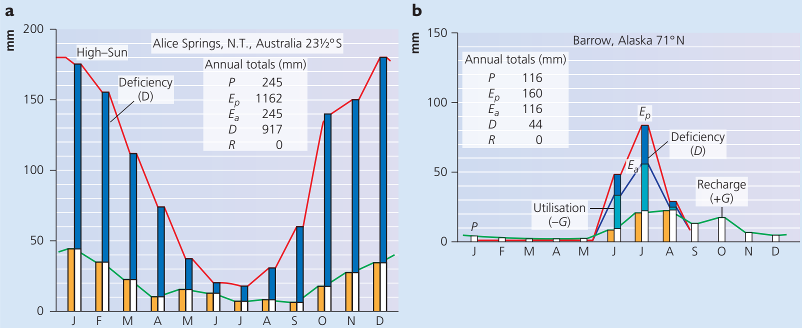
During the autumn, soil moisture begins to increase, due to reduced temperatures and less vegetation cover. At some stage during the winter/early spring, field capacity is again reached. This pattern of change is repeated each year: a good example of steady state equilibrium within a system.

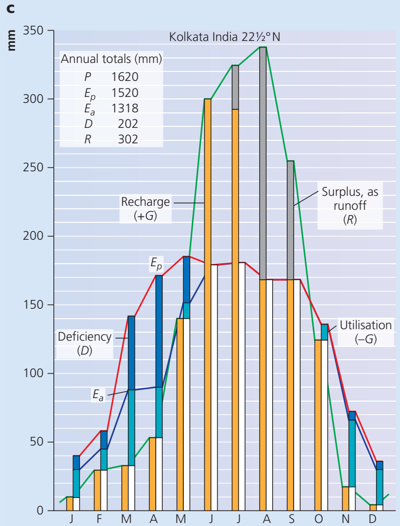


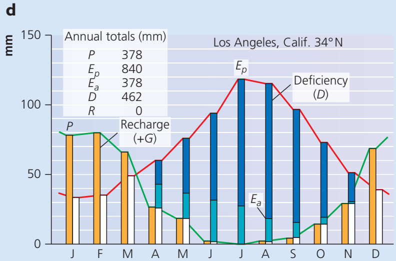
▲ **Figure 3.2** Annual cycle of soil moisture at Coshocton, Ohio, USA

In addition to the seasonal changes shown here, there are longer-term changes to consider for places where a state of dynamic (changing) equilibrium may exist (see page 11). For example, the water balance in southern England would have been very different during the last glacial period, and we would expect it to change in the next century as global warming leads to an increase in the UK's mean surface temperature and changing rainfall patterns.

Geologists and botanists have analysed old pollen samples extracted from soil and gravel deposits to show long-term climate changes. The results show conditions in the British Isles were much colder and wetter around 11,000–10,000 years ago (thereby favouring the growth of plant species whose pollen can still be found in soil deposits laid down at this time). Conditions became much warmer between 10,000 and 5000 years ago, with a warmer, drier climate. Evidence for this includes pollen extracted from the lake bed in Lough Neagh (Northern Ireland), along with hazel, oak, alder and elm pollen found in many bogs. In contrast, colder and wetter conditions are suggested by the birch and pine pollen found in earlier deposits. However, some of the changes in vegetation over time may also have been due to diseases, such as a fungus that attacked elm (similar to Dutch elm disease), and early human activities, notably farming, which replaced some species of trees with grasses. It is not always the case that pollen analysis invites a straightforward interpretation.







Key

E_a = Actual evaporation
E_p = Potential evapotranspiration
P = Precipitation
$+G$ = Recharge
$-G$ = Soil moisture utilisation
D Soil moisture deficit/deficiency

▲ **Figure 3.3** Soil moisture budgets for contrasting locations: **a** Alice Springs, Australia, **b** Barrow, Alaska, **c** Kolkata, India, **d** Los Angeles, USA

▲ **Figure 3.4** World map showing the location of Alice Springs, Barrow, Kolkata and Los Angeles

ANALYSIS AND INTERPRETATION

Study Figure 3.3, which shows soil moisture budgets for four contrasting places which vary greatly in their climatic characteristics. Figure 3.4 shows the site locations.

(a) Distinguish between soil moisture deficiency and soil moisture utilisation.

GUIDANCE

This is a straightforward question essentially asking for two definitions, e.g. soil moisture deficiency occurs when the store of available water in the soil has been used up and when potential evapotranspiration is greater than precipitation. In contrast, soil moisture utilisation occurs when there is a store of water in the soil and it is available for use by plants or to be used in evaporation.

(b) Contrast the soil moisture budget for Alice Springs, Australia, and Barrow, Alaska.

GUIDANCE

This question asks us to contrast the differences in the soil moisture budget for two areas (but we are not asked to suggest reasons for the differences). It is sometimes easier to describe one station first, and then draw explicit contrasts when describing the second station.

For example:

- Alice Springs receives just 245 mm of rain annually, making it an arid location, but has a potential evapotranspiration of over 1100 mm. It has a year-round water deficiency totalling over 900 mm. The deficiency is greatest during December to January (summer in Australia), when it is approximately 125 mm/month. Whereas, during the winter, it is less than 10 mm/month.
- In contrast, Barrow has a more varied soil moisture budget. It is even more arid than Alice Springs. It receives just 116 mm of rain, making it a hyper-arid location. Monthly rainfall varies from a maximum of about 80 mm in July to less than 5 mm in the winter months. The period of soil moisture deficit is shorter than in Alice Springs, lasting about three months between June and August (summer). There is some soil moisture utilisation between July and August. Overall, there is a slight deficit of soil moisture (44 mm) and a slight recharge in October (in Alice Springs there was none).

(c) Suggest reasons for the differences in the soil moisture budget of Kolkata and that of Los Angeles.

GUIDANCE

In this answer you need to suggest reasons why the graphs differ. You may not have any prior knowledge of these places; instead, you are expected to make use of the resources provided and to apply your knowledge and understanding of geography to this novel situation. For example, possible points to make include the following:

- Kolkata has a very seasonal pattern to its soil moisture budget; so too does Los Angeles.
- Kolkata appears to have a monsoonal climate (the graph shows very high runoff and most likely flooding in summer, but dry in winter). There is soil moisture recharge each summer and sufficient soil moisture remains to allow for utilisation by plants (along with evaporation losses) throughout the autumn.
- Whereas Los Angeles is dry in summer but experiences rainfall in winter. In summer, a soil moisture deficit results from the lack of rainfall and high potential evaporation rates; but there is some recharge in winter due to the higher rains and lower evaporation rates.

2 Drought, aridity, water scarcity and water insecurity

▶ *How do the causes of water scarcity and water insecurity vary?*

According to the seventh World Water Forum (2015), water stress and **water scarcity** are global challenges with far-reaching economic and social implications.

- Driven by increasing population, growing urbanisation, changing lifestyles and economic development, the total demand for water is rising. Urban centres, agriculture and industry all make increasing demands.
- World Water Forum experts hope in future to see greater evidence of **nexus thinking** in relation to water management. This means improved governance of water resources in ways which challenge traditional distinctions between competing economic sectors (such as agriculture or tourism) in order to help tackle water scarcity and insecurity issues. Co-operation is necessary not only between sectors or industries, but also between players at different hierarchical levels and scales (for example, from those working on the ground to the decision-makers, along with those working in different sectors, such as water, food and energy and different research fields).

Physical water scarcity and economic water scarcity

The level of water scarcity in a country depends on precipitation and water availability, population growth and affluence, demand for water,

▲ **Figure 3.5** The impact of drought on soils

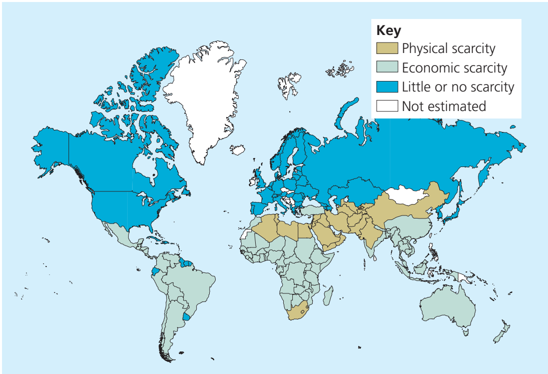
KEY TERMS

Water scarcity A lack of water due to either physical or economic reasons.

Nexus thinking Consideration of the complex and dynamic interrelationships between water, energy and food resource systems. Understanding of these interrelationships is essential if water and other natural resources are to be used and managed sustainably.

affordability of supplies and infrastructure. Where water supplies are inadequate, two types of water scarcity exist:

1 **Physical water scarcity**: where water consumption exceeds 60 per cent of the useable supply. To help meet water needs some countries, such as Saudi Arabia and Kuwait, have to import much of their food and invest in desalinisation plants.
2 **Economic water scarcity**: where a country physically has sufficient water to meet its needs, but requires additional storage and transport facilities. This means having to embark on large and expensive water-development projects, as in many sub-Saharan countries (Figure 3.5).



▲ **Figure 3.6** Physical and economic water scarcity

Drought and aridity

A drought is an extended period of unusually dry weather. The precise definition of drought varies from place to place, however.

- In the UK, for example, drought is defined as a 50 per cent deficit over three months, or a 15 per cent shortfall over two years (measured in relation to normal expectations for precipitation).
- In contrast, UNEP defines a drought as two or more years with rainfall substantially below the mean.

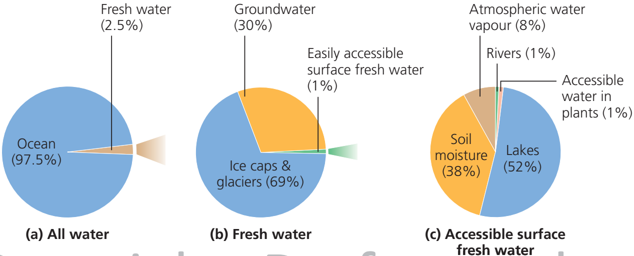
For example, the seasonal rains that usually fall between June and September in north-eastern, central and southern Ethiopia did not arrive in 2015. According to the UN, this was Ethiopia's worst drought in 30 years. Around 90 per cent of cereal production is harvested in autumn, after the summer-long rainy season, and the rest at the end of spring after the end of the short rainy season. The onset of this drought was linked to the El Niño weather system (see page 16), and resulted in a 90 per cent reduction in crop yields.

▲ **Figure 3.7** Drought in Ethiopia began in 2015, leading many people to rely on emergency food assistance.

A large proportion of the world's surface naturally experiences dry or arid conditions. This is not the same as drought because low precipitation levels are a natural feature of the climate.

- Semi-arid areas are commonly defined as having rainfall of less than 500 millimetres per annum, while arid areas have less than 250 millimetres and in extremely arid areas the figure falls below 125 millimetres.
- In addition to low rainfall, dry areas typically have *variable* rainfall. As rainfall total decreases, variability usually increases. For example, areas with an annual rainfall of 500 millimetres have annual variability of about 33 per cent. This means that in such areas rainfall will typically range from 330 to 670 millimetres each year. This variability has important implications for vegetation cover, farming and the risk of flooding.

Water quantity and water quality issues



▲ **Figure 3.8** Availability of freshwater supplies

Less than 1 per cent of all freshwater is available for people to use; the remainder is locked up in ice sheets and glaciers (see page 29). Globally, around 12,500 cubic kilometres of water are considered available for human use on an annual basis. This amounts to about 6600 cubic metres per person per year. If current trends continue, only 4800 cubic metres will be available in 2025.

The world's available freshwater supply is not distributed evenly around the globe. Variations in annual supply may also be subject to marked seasonal differences in availability.

- About three-quarters of annual rainfall occurs in areas containing less than a third of the world's population.
- Two-thirds of the world's population live in the areas receiving only a quarter of the world's annual rainfall. This is one reason which helps explain the enormous variability in per capita **water footprints** shown in Table 3.1. What other factors might help explain the range of values shown?

KEY TERM

Water footprint A measure of the use of water by individual humans, nations and the amount needed to grow or manufacture products such as meat, textiles or steel.

The global challenge of water stress

When per capita water supply is less than 1700 cubic metres per year, an area suffers from water stress and is subject to frequent water shortages. In many such areas, per capita water supply is actually less than 1000 cubic metres per capita, which can create challenges for food production and economic development. In 2016, a total of 2.3 billion people lived in water-stressed areas. If current demographic and economic trends continue, water stress will affect 3.5 billion people – 48 per cent of the world's projected population – by 2025.

In many developing countries and emerging economies, access to adequate water supplies is increasingly threatened by the permanent loss or exhaustion of traditional sources, such as wells and seasonal rivers, for multiple reasons including conflict, dam building and climate change. Access may be worsened too by inefficient irrigation practices and lack of resources to invest in improvements. At present, 34 countries in Africa, Asia and the Middle East are classified as water-stressed. All but two of them, Syria and South Africa, are, as a result, net importers of grain. These countries collectively buy about 50 million tonnes of grain each year, about one-quarter of the total global trade volume.

Global patterns and trends in water use

The world's population has tripled since 1922. Humanity's water use has increased six-fold, however (Figure 3.9). Some rivers that once reached the sea, such as the Colorado in the USA, no longer do so. Moreover:

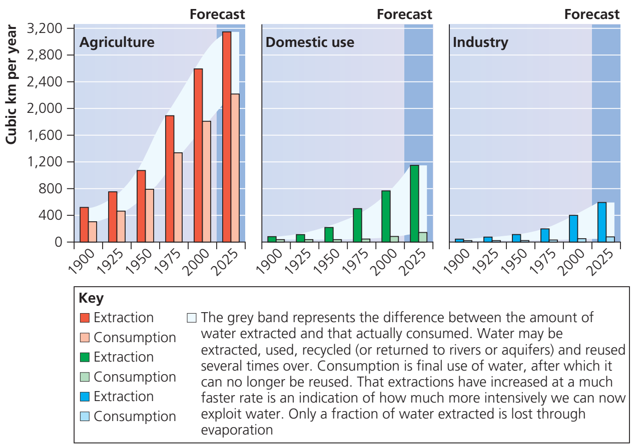
- half the world's wetlands have disappeared in the same period and 20 per cent of freshwater species are endangered or extinct

- water tables in many parts of the world are falling at an alarming rate and many important aquifers are being depleted.

Withdrawals of water for irrigation are nearly 70 per cent of the total demands placed on the water cycle by human activity, amounting to 2500 of 3800 cubic kilometres. Withdrawals for industry represent about 20 per cent; those for municipal use (drinking water and sewerage) account for the remaining 10 per cent.

Globally, human activity only makes use of around 10 per cent of renewable water resources. This is because of the highly uneven pattern of population distribution, however. Vast stores of water in high latitudes and continental interiors may go largely untouched; whereas concentration of population in warmer and drier regions – including the Mediterranean, North Africa, the Middle East and southern states of the USA – place very high demands on local water stores.

Currently, about 1.1 billion people lack access to safe water, 2.6 billion are without adequate sanitation and more than 4 billion do not have their wastewater treated to any degree. These numbers are likely to get worse in the coming decades. According to current predictions, by 2025, 4 billion people – half the world's population – will live under conditions of severe water stress. They will be disproportionately located in drier parts of Africa, the Middle East and South Asia. Disputes over scarce water resources could lead to an increase in armed conflicts.



▲ **Figure 3.9** Trends in water use

Country	National water footprint (m³/year/per capita)
Brazil	2027
China	1071
Ethiopia	1167
India	1089
South Africa	1255
UAE	1000
UK	1258
USA	2842
Yemen	140
World average	1385

▲ **Table 3.1** National selected water footprints

Source: http://waterfootprint.org/en/water-footprint/national-water-footprint and IRIN

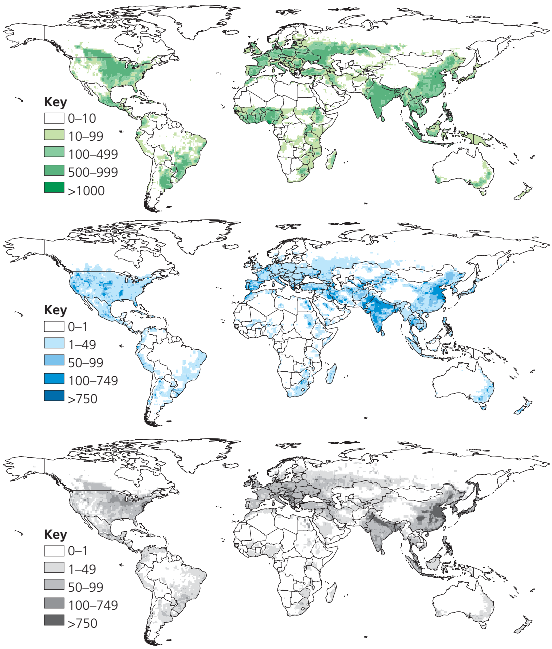
KEY TERMS

Green water The rainfall that is stored in the soil and evaporates from it; the main source of water for natural ecosystems, and for rain-fed agriculture, which produces 60 per cent of the world's food.

Blue water Renewable surface water runoff and groundwater recharge; the main source for human withdrawals and the traditional focus of water resource management.

Grey water Wastewater that has been produced in homes and offices. It may come from sinks, showers, baths, dishwashers, washing machines, etc., but does not contain faecal material.

Blackwater Wastewater that contains faecal material/sewage.



▲ **Figure 3.10** Green-water, blue-water and grey-water footprints

- Although river flow used to be generally low from September onwards, violent autumn storms over the Colorado Plateau contributed to another high, although shorter-lived, peak discharge in the autumn months.
- But the construction of large dams across the Colorado River has smoothed out the naturally occurring flood peaks and periods of low flows; the Hoover Dam now stores the equivalent of two years' river flow in Lake Mead. The mean annual flood at the gauging station at Lee's Ferry has been reduced from 2264 cubic metres per second to 764 cubic metres per second (according to data collected in the 1980s).

CONTEMPORARY CASE STUDY: WATER SUPPLY ISSUES IN YEMEN AND THE UAE

▲ **Figure 3.21** The physical geography of Yemen and the United Arab Emirates. ©Philip's.

	Yemen	United Arab Emirates
Population	28 million	6 million
PPP ($)	2400	68,100
Crude birth rate (‰)	6.0	15.1
Crude death rate (‰)	6.0	1.9
Growth rate (%)	2.28	2.37
Life expectancy (years)	65.9	77.7
Infant mortality rate (‰)	46	10
Access to water (%) – urban	72	99.6
Access to water (%) – rural	46	199
Literacy (%)	70	93.8
Total fertility rate	3.63	2.32
Contribution to GDP (%) – agriculture	21.8	0.8
Contribution to GDP (%) – industry	9.8	39.5
Contribution to GDP (%) – services	68.4	40.1
Population below the poverty line (%)	54	19.5

▲ **Table 3.10** Factfile for the Yemen and the UAE

Source: *CIA World Factbook*, 2017

(NB The figures for UAE's contribution do not add up to 100%.)

Yemen's water challenge

One of Yemen's main challenges is severe water scarcity, especially in the highlands. Indeed, Yemen could become the first nation to run out of water, in particular its capital city, Sana'a. Another challenge is the high level of poverty, making it difficult to provide reliable safe water. Access to water supply is as low or even lower than in many sub-Saharan African countries. In addition, the ability of institutions to plan, build, operate and maintain infrastructure remains limited. Finally, the ongoing civil war since 2015 and military attacks by Saudi Arabia make it even more difficult to improve or even maintain existing levels of service.

	J	F	M	A	M	J	J	A	S	O	N	D
Temp. (°C)	24	25	27	28	30	32	32	31	31	28	27	26
Ppt. (mm)	5	2	5	2	2	2	5	3	2	2	2	5

▲ **Table 3.11** Climate data for Aden, Yemen

Enhanced water supplies in the UAE

▲ **Figure 3.22** A desalination plant in the UAE

	J	F	M	A	M	J	J	A	S	O	N	D
Temp. (°C)	21	21	25	30	33	36	38	38	35	32	25	23
Ppt. (mm)	19	25	22	7	0	0	0	0	0	1	3	16

▲ **Table 3.12** Climate data for Dubai, UAE

In contrast, on the opposite northern side of the Arabian Peninsula, the UAE is actively promoting the adoption of innovative technologies to reduce water wastage, protect the interests of water consumers and protect the environment. These pivotal actions enable the UAE to ensure a water-secure and sustainable future.

●	The UAE is one of the top ten water-scarce countries in the world due to its hyper-arid climate – less than 100 mm/year rainfall.
●	This country consumes more water than double the global national average.
●	The UAE ranks as the world's second largest desalination producer (accounting for 14 per cent of the world's desalinated water). The Fujairah power and desalination plant, producing 455,000 cubic metres of freshwater per day, is the largest desalination hybrid plant in the world.
●	Masdar City in Abu Dhabi (part of the UAE) recently launched a pilot programme for advanced energy-efficient seawater desalination technologies suitable to be powered solely by renewable energy sources.

▲ **Table 3.13** Key facts about water in the UAE

5 Evaluating the issue

▶ *To what extent can water security ever be guaranteed in water-scarce places?*

Possible contexts for exploring water security and scarcity

Water security is defined in the United Nations Sustainable Development Goals as having access to sufficient amounts of safe drinking water. It is influenced by many factors, including precipitation amount and type, evaporation rates, climate change, pollution, competing demands for water, political stability and water infrastructure (such as the size, age and quality of pipes). Water is a vital resource but its availability varies spatially and temporally, and is not guaranteed in all places at all times, nor for all people.

Water-scarce places exist at many different scales:

- *Large continental areas of desert spanning multiple countries.* The Sahara and Sahel are notable examples where political control over **exotic rivers** such as the Nile or Colorado has become a vital factor affecting the water security of individual states.
- *Entire countries that are for the most part arid.* The examples of Yemen and the United Arab Emirates (UAE) in the Middle East illustrate the complex situation regarding water security. Both areas are deserts. They share similar physical conditions – high temperatures, low rainfall and a lengthy coastline. However, there is considerable variation in the water security of both countries. Indeed, in some parts of the Middle East, water is considered to be more valuable than gold – it has been termed 'blue gold'.
- *Particular arid regions and local places found within some countries.* This is true of the USA, China and India for instance. There is also a great surplus of water in other, less populated, parts of these countries, thereby creating the possibility of water transfers to water-scarce areas.

Evaluating the view that water security *cannot* be guaranteed in water-scarce places

A lack of water security leads to increased morbidity and mortality. Around 1.8 billion people globally use a source of drinking water that is faecally contaminated. Water scarcity affects more than 40 per cent of the global population and is projected to rise. More than 80 per cent of wastewater resulting from human activities is discharged into rivers or sea without any treatment, leading to pollution.

Turning to examples of arid countries where water scarcity is widespread, Yemen, as we have seen (page 92), is the poorest country, and most water-stressed, in the Middle East. It is predicted that it may be the first country to run out of water – or that its capital city, Sana'a, could be the first capital city to run dry. The average Yemeni person receives just 140 m^3 of water per year – compared with 1000 m^3 for the average person in the Middle East. This is partly due to population growth (the rate of natural increase is slightly above 2 per cent) and its naturally arid desert location. Global climate change is influencing Yemen's water security too. Average rainfall in Sana'a dropped from 240 mm between 1932 and 1968, to 180 mm between 1983 and 2000. The water table at Sana'a was 30 m below the surface in 1970 – by 2015 it was 1200 m below the surface. Global climate change is adding to Yemen's problems. A combination of lower rainfall and higher temperatures reduces water availability, while continued population growth creates more demand for water for food production and drinking water, among others.

However, water insecurity is also a product of political factors in Yemen. Since the start of the 2015 Yemeni civil war, conditions have deteriorated. Up to 80 per cent of the country's population struggles to access drinking water. Water infrastructure has been targeted by planes. In 2016, a major desalination plant in the western city of Mokha was destroyed by a Saudi Arabian bomb. A blockade of imports resulted in a lack of oil required to pump groundwater. This forced many Yemeni to search for meagre sources of polluted surface water. The use of contaminated water has resulted in an increase in disease occurrence. In 2017, Yemen experienced over 1900 fatalities due to an outbreak of cholera. Moreover, some 14,000 under-five year olds die each year due to malnutrition.

Options are limited. The cost of pumping desalinated water from the Red Sea, some 250 km over the mountains that rise nearly 300 m, would push the price of water to US$10/m^3. The cost of water has already risen 50 per cent since the start of the civil war, and some families spend up to a third of their income on water. This has an impact on how much they can spend on food. Typically the poorest households spend up to 80 per cent of their income on food, hence an obvious conflict of resource allocation occurs.

Human factors such as persisting poverty and conflict, along with longer-term climatic changes (see Chapter 5, pages 129–59), make it hard to see how water security improvements in Yemen and certain other countries including South Sudan and Somalia can be achieved.

Interactions between water-scarce neighbouring countries

Another important geographical scenario to consider is the way different water-scarce countries and regions may be dependent on a shared water source such as an exotic river or **transboundary aquifer**. Geopolitical factors – and a failure of global governance – can result in some countries suffering water scarcity due to the excessive demands placed on shared water resources by others. For example:

- The Nubian Sandstone Aquifer System under the eastern Sahara Desert is the largest aquifer in the world. It is believed to hold some 150,000 km^3 of water. It is a fossil aquifer and is not currently being replenished. In recent years, Libya has developed its Great Man-made River Project in which it has been extracting 2.4 million km^3 of water annually for irrigation purposes. This is the world's largest irrigation project.
- India, Nepal, Bhutan and Pakistan are involved in a huge 'water grab' in the Himalayas, as they seek new sources of electricity to power their economies. Altogether, the countries have plans for more than 400 hydro-electric dams which could provide more than 160,000 MW of

electricity. In addition, China has plans for around 100 dams to generate a similar amount of power from major rivers rising in Tibet. A further 60 or more dams are being planned for the Mekong River which also rises in Tibet. Hence, other downstream users may have access to less water in the future.

- The Grand Ethiopian Renaissance Dam, currently being built, will have a capacity of 66 km^3. When the reservoir is flooded, a process that could take between five and fifteen years, downstream countries (Egypt and Sudan) will have reduced flows, which will have serious impacts on their economic growth (agriculture and tourism, for example). International rivers are extremely difficult to manage, as increased use by upstream countries will affect countries downstream, both in terms of quantity of supplies and, possibly, water quality.

Evaluating the view that water security *can* be guaranteed in water-scarce places

As we have seen, some arid states *have* made great steps towards tackling the risk of water scarcity. The UAE (see pages 93–4), a country in the same region as Yemen and having a very similar climate, has delivered water security for its citizens. This is largely due to economic and political stability, however, which not all states enjoy. The demand for water in the UAE has increased with population growth, increased standard of living, industrialisation and the growth of the tourism sector. Much of the wealth of the UAE has been generated by the sale of oil and its reinvestment into other sectors, such as tourism, global trade and finance.

The UAE is an applied example of the Ester Boserup thesis of population and resources, i.e. that people will develop solutions to solve problems, once they arise. In Boserup's view, although rising population pressure could lead to resource depletion, human ingenuity and flexibility will ultimately find new methods of technology and/or organisation in order to increase society's resource base.

- For example, the UAE has used desalinisation technology to increase water resources. Moreover, much of this is now done using renewable solar energy sources. The long-term goal is to extend renewable energy desalination throughout the UAE and MENA (Middle East–North Africa) region.
- The UAE's flagship sustainable city, Masdar City, has developed SMART-consumption, resulting in water consumption being over 50 per cent less than in other UAE cities. This includes smart-water meters, movement sensors instead of traditional taps, and hyper-efficient water appliances (washing machines and showers). Masdar's planners aim to reduce water consumption from 250 l/day at present to 105 l/day.
- Elsewhere in the world, modified irrigation techniques, such as drip irrigation, have been successfully introduced as a 'technological fix' for water scarcity.

Delivering water security through political co-operation

Turning to the issue of shared water sources, it is not inevitable that countries need suffer water insecurity due to a lack of political co-operation and agreements. At a national scale, Singapore illustrates how imports of water can help to make up the country's water supply. Singapore provides affordable high-quality water through supplies such as rainwater harvesting, reservoirs, desalination and water imports from Malaysia. It has been importing water from Malaysia since 1927 and has a deal that extends until 2061. Although it wishes to be self-sufficient in water by 2062, it currently imports around 66 per cent of the water it needs. Similarly, Hong Kong imports around 80 per cent of its water from Guangdong, China.

Water transfers can be achieved internally, i.e. *within* countries. The South-to-North Water

Diversion Project in China is the largest transfer of water between river basins in history. Since 2014 much of the drinking water consumed in Beijing has travelled over 1430 km from the Danjiangkou reservoir in central China. It takes fifteen days to reach Beijing. Two-thirds of the city's tap water and a third of its total supply now comes from Danjiangkou. In India, inter-basin transfers move excess water from the Brahmaputra and Ganga regions to dry areas such as Rajasthan, Gujarat and Tamil Nadu.

However, not all water management schemes are successful in all that they do – the River Colorado has failed to reach the sea most years since the 1960s, with harmful impacts for river and estuarine ecosystems. Only during El Niño weather events (which bring unusually large amounts of snow and rain to the Colorado Rockies and drainage basin) does the Colorado now ever reach the sea. Nevertheless, relatively effective water-sharing agreements between different US states and (to a lesser extent) Mexico continue to deliver water security to different user groups who depend on the continued benefits of irrigation, power generation, domestic and industrial water supplies and recreation.

Arriving at an evidenced conclusion

There are quantitative (measured) and qualitative (experienced) aspects to water security across a variety of spatial and temporal scales. Some places lack sufficient amounts of water; and not all available water is safe. Poor water quality jeopardises human health over a large part of the Earth's land surface.

Even in the same world region, such as the Middle East, there are widely different experiences of water security. In the case of Yemen, a poor country, much of its water is needed for food supply. This country lacks the funds to develop desalination plants and pump water from underground aquifers, while civil war has destroyed parts of its water infrastructure, reducing the country's ability to utilise groundwater. In contrast, the UAE – where natural freshwater resources are severely limited in size, and there are increasing demands due to population growth and rising affluence – is a place where solutions for water scarcity have been found, albeit at great expense. The UAE shows that water security *can* be guaranteed provided there is sufficient economic and political stability.

In some areas, political co-operation can help deliver water security to multiple countries, states and/or different user groups. Internal transfers of water – for example, from southern China to northern China – can guarantee water security for places where water is naturally relatively scarce. However, the extent to which current strategies and 'fixes' are future-proof is debateable, especially in emerging economies where populations and average incomes are still rising. Ultimately, lifestyle changes may be necessary: for example, typical per capita water footprints would be reduced if people ate less meat and repaired (rather than replaced) manufactured goods. In addition, further reductions in population growth might ease pressures on water resources: whether world population growth eventually peaks at around 9 billion or 11 billion is probably the most important factor affecting future water scarcity both globally and locally.

KEY TERMS

Exotic river This starts out from a humid region and flows into a dry region. A river flowing through a desert can be considered exotic due to its existence in an otherwise arid region.

Transboundary aquifer A store of groundwater that extends over a number of countries, e.g. the Nubian Sandstone Aquifer System which stretches across the eastern Sahara, under Egypt, north-west Sudan, north-east Chad and eastern Libya.

Chapter summary

- ✔ The water budgets of different places vary greatly because of vastly differing temperature and rainfall patterns.
- ✔ Some places, such as those with a monsoonal climate, enjoy a water surplus at some times of the year and a deficit at other times, creating challenges for water management.
- ✔ Billions of people live in regions that experience some degree of water scarcity attributable to aridity or recurring drought; many hundreds of millions lack access to adequate safe water for much of the year.
- ✔ Water availability is also affected by human factors, including the virtual water transfers associated with trade, water transfer schemes, dam building and land grabs.
- ✔ There are many technologies that can help improve water supplies and the efficiency with which it is used, including desalination and efficient forms of irrigation such as drip irrigation. However, these can be costly to introduce and not all developing countries have the means to afford them.
- ✔ In large river basins, effective water management may require a high level of international co-operation and agreements.

Refresher questions

1. What is meant by the following geographical terms: water budget; soil moisture deficit; soil moisture recharge; steady state equilibrium?
2. Using examples, outline the difference between (i) physical water scarcity and economic water scarcity, (ii) improved and unimproved water sources, (iii) drought and aridity.
3. Using examples, explain the water footprint concept.
4. Briefly outline the main features of the changing global pattern of water use.
5. Using examples, explain why water availability in a country may vary (i) seasonally, (ii) between urban and rural areas.
6. Using examples, explain what is meant by the following geographical terms: land grab; virtual water?
7. Explain why some irrigation methods are better than others in terms of their efficiency of use of hydrological resources.
8. Explain the challenges and opportunities associated with large-scale desalinisation as a potential 'technological fix' for water insecurity in contrasting places you have studied.
9. Explain how dam construction can (i) modify water cycle flow and storage patterns in a drainage basin, (ii) become a source of geopolitical tension.

Discussion activities

1. In small groups, discuss the relative importance of physical and human factors as a cause of global water insecurity. In your view, are human or physical factors ultimately most important?
2. In pairs, devise a long-term research programme lasting several years to create a water budget model (such as Figure 3.1) for a place that has never been studied before. How would you collect the data that is needed? How many years would the study need to run for before researchers were satisfied that their data was representative of a typical year?
3. As a whole class activity, discuss the size of your own water footprint(s), taking into account drinking, bathing, cleaning.
4. In small groups, discuss your consumption of virtual or embedded water, focusing on fruit and vegetables imported from other countries and the place of origin for clothing and other manufactured goods you own. Are you aware of any products you consume that have originated in countries where water is scarce?
5. As a whole class activity, discuss the view that water scarcity will eventually become a thing of the past on account of technological progress.

FIELDWORK FOCUS

The topic of access to (safe) water can be used as the basis for a number of different A-level individual investigation themes.

A *Investigate the players who have power over water supplies in your local area.* Secondary data can be collected by monitoring your local newspaper (and their website) to investigate water issues in your area, along with the Environment Agency website. For primary data, (i) identify the different organisations involved in managing water, and (ii) arrange to carry out an in-depth interview with one or more managers. You could conduct a questionnaire in the area to find out more about people's perception of local water supply issues and how they are being managed.

B *Investigate the global flows of virtual water which link your school (or another local institution) with other places (and water cycles) around the world.* You could arrange for an interview with a school chef or administrator in order to find out where the food the school uses is sourced from, which will most likely include local and global production networks. Secondary research will help you find out how much water is embedded in certain items such as bananas, rice or potatoes. By collecting data about the volumes of food purchased by your school, you can begin to estimate the total virtual water demand (and use world maps to show where the flows come from). You might also carry out a questionnaire among students and staff to investigate their awareness of the water footprint concept.

C *Investigate soil moisture status (as a proxy for water availability) in your local area.* Primary data can include soil moisture content – you will need to borrow or buy specialist equipment for this task, however, such as a soil moisture gauge (these can be purchased easily online). Monitoring will ideally need to be done over an extended period of time, and should be carried out in conjunction with readings for precipitation and temperature. Ideally, the data will be collected over several months in order to include a good balance of wet days and dry days, and possibly changes in temperature. It may be possible to get figures for actual and potential evapotranspiration by logging into the Meteorological Office Rainfall and Evaporation Calculation System (MORECS).

Further reading

Ward, C. (2015) *The Water Crisis in Yemen: Managing Extreme Water Scarcity in the Middle East*, I.B. Taurus

United Nations Sustainable Development Goals – water and sanitation, www.un.org/sustainabledevelopment/water-and-sanitation

www.unwater.org/publication_categories/sdg-6-synthesis-report-2018-on-water-and-sanitation

The World's Water, http://worldwater.org

World Bank, www.worldbank.org/en/topic/water

World Health Organisation, www.who.int/topics/water/en