10 Hot arid and semi-arid environments

10.1 Hot arid and semi-arid climates

Global distribution and climatic characteristics

Figure 10.1 and Tables 10.1 and 10.2 show the distribution of arid environments. While Africa has the greatest proportion of these, Australia is the most arid continent with about 75 per cent of the land being classified as arid or semi-arid. Most arid areas are located in the tropics, associated with the subtropical high-pressure belt. However, some are located alongside cold ocean currents (such as the Namib and Atacama deserts), some are located in the lee of mountain ranges (such as the Gobi and Patagonian deserts), while others are located in continental interiors (such as the Sahara and the Australian deserts).

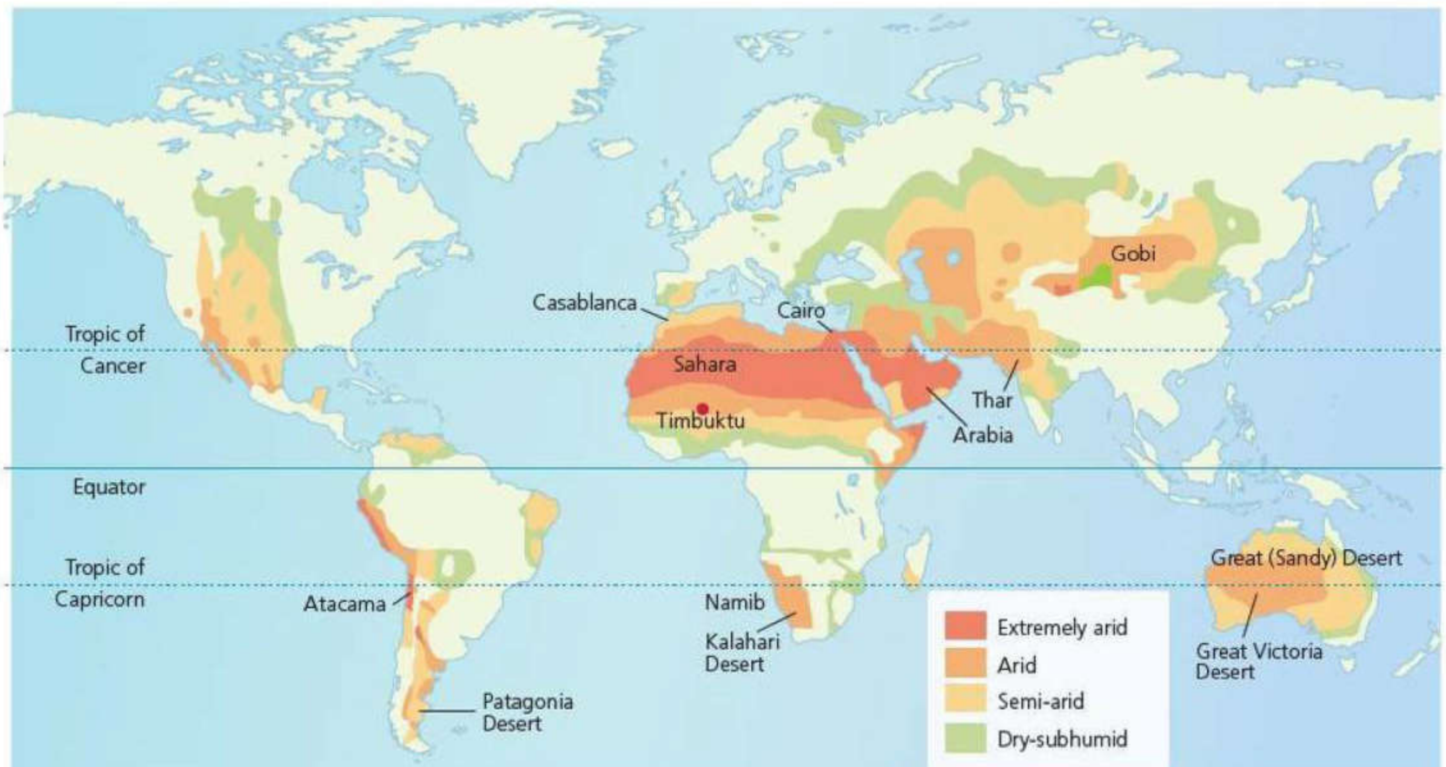


Figure 10.1 The global distribution of arid areas

Table 10.1 The extent of global arid areas (as a percentage of the global land area)

Classification	Semi-arid	Arid	Extremely arid	Total
Köppen (1931)	14.3	12.0	–	26.3
Thornthwaite (1948)	15.3	15.3	–	30.6
Meigs (1953)	15.8	16.2	4.3	36.3
Shantz (1956)	5.2	24.8	4.7	34.7
UN (1977)	13.3	13.7	5.8	32.8

Table 10.2 Distribution of arid lands by continent (as a percentage of the global total)

Continent	Percentage arid
Africa	37
Asia	34
Australasia	13
North America	8
South America	6
Europe	2

Definitions of aridity

There are many definitions of the term 'arid'. Literary definitions use such terms as 'inhospitable', 'barren', 'useless', 'unvegetated' and 'devoid of water'. Scientific definitions have been based on a number of criteria including climate, vegetation, drainage patterns and erosion processes. What they share is a consideration of moisture availability, through the relationship between precipitation and evapotranspiration.

Most modern systems for defining **aridity** are based on the concept of water balance; that is, the relationship that exists between inputs in the form of precipitation (P) and the losses arising from evaporation and transpiration (E). The actual amount of evapotranspiration that will occur depends on the amount of water available, hence geographers use the concept of potential evapotranspiration (PE), which is a measure of how much evapotranspiration would take place if there was an unlimited supply of water.

Meigs' (1953) classification is probably the most widely used today. It was produced for UNESCO and was concerned with food production. Arid areas that are too cold for food production (such as polar and mountainous regions) were omitted. Meigs based his classification scheme on Thornthwaite's (1948) indices of moisture availability (Im):

$Im = (100\,S - 60D)/PE$

where PE is potential evapotranspiration, S is moisture surplus and D is moisture deficit, aggregated on an annual basis and taking soil moisture storage into account.

When P = PE throughout the year the index is 0.

When P = 0 throughout the year, the index is –60.

When P greatly exceeds PE throughout the year, the index is 100 (see Figure 10.2).

Meigs identified three types of arid area:

- semi-arid: $-40 < Im < 20$
- arid: $-56 < Im < -40$
- hyper-arid (extremely arid): < -56 Im.

Grove (1977) attached mean annual precipitation to the first two categories: 200–500 millimetres for arid and 25–200 millimetres for semi-arid, but these are only approximate. Hyper-arid areas have no seasonal precipitation and occur where twelve consecutive months without precipitation have been recorded. According to these definitions, arid areas cover about 36 per cent of the global land area.

Aridity is a permanent water deficit, whereas drought is an unexpected short-term shortage of available moisture.

Rainfall effectiveness (P–E) is influenced by a number of factors:

- **Rate of evaporation** – this is affected by temperature and wind speed, and in hot, dry areas evaporation losses are high
- **Seasonality** – winter rainfall is more effective than summer rainfall since evaporation losses are lower
- **Rainfall intensity** – heavy intense rain produces rapid runoff with little infiltration
- **Soil type** – impermeable clay soils have little capacity to absorb water, whereas porous sandy soils may be susceptible to drought.

Another classification is based on rainfall totals. This states that semi-arid areas are commonly defined as having a rainfall of less than 500 millimetres per annum, while arid areas have less than 250 millimetres and **extremely arid areas** less than 125 millimetres per annum. In addition to low rainfall, dry areas have variable rainfall. For example, annual rainfall variability in a rainforest area might be 10 per cent. If the annual rainfall is about 2000 millimetres, this means that in any one year the rainfall would be somewhere between 1800 millimetres and 2200 millimetres. As rainfall total decreases, variability increases. For example, areas with a rainfall of 500 millimetres have an annual variability of about 33 per cent. This means that in such areas, rainfall could range between 330 millimetres and 670 millimetres. This variability has important consequences for vegetation cover, farming and the risk of flooding.

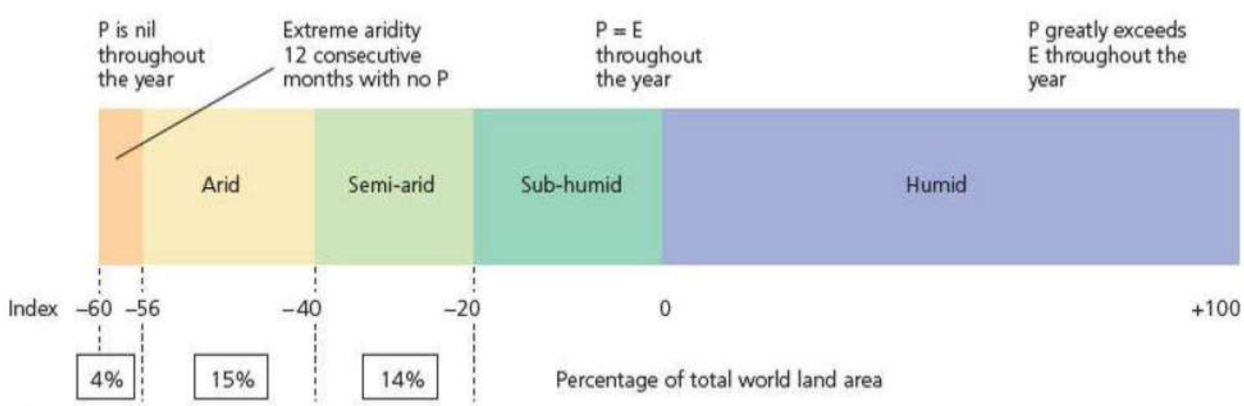


Figure 10.2 The index of aridity

All three areas are considered as part of the arid zone. This is because:

- the division between the three is arbitrary and varies depending on the classification used
- annual precipitation is highly variable and in any one year could be extremely low
- these areas share the same processes and landforms
- in the twentieth century, climate change and human activities have caused the expansion of some arid areas into semi-arid areas
- semi-arid areas are often termed 'deserts' by their inhabitants.

It is important to remember that there are other factors that influence arid areas. There are hot deserts (tropical and subtropical) and cold deserts (high latitude and high altitude). Coastal deserts, such as the Atacama and the Namib, have very different temperature and humidity characteristics from deserts of continental interiors, such as central areas of the Sahara. There are also shield deserts, as in India and Australia, which are tectonically inactive, and mountain and basin deserts, such as south-west USA, which are undergoing mountain building.

Causes of aridity

Arid conditions are caused by a number of factors. The main cause is the global atmospheric circulation. Dry, descending air associated with the **subtropical high-pressure belt** is the main cause of aridity around 20°–30°N (Figure 10.3a). Here, the stable, adiabatically warmed, subsiding body of air prevents rising air from reaching any great height. Convection currents are rarely able to reach sufficient height for condensation and precipitation. After the air has subsided, it spreads out from the centre of high pressure (Figure 10.3a). It thereby prevents the incursion of warm maritime air into the region, reinforcing its aridity. The distribution of land and sea prevents the formation of a single zone of high pressure – rather it is divided into discrete cells such as those over South America and Africa. Tropical and subtropical deserts cover about 20 per cent of the global land area. These are large arid zones composed of central arid areas surrounded by relatively small, marginal semi-arid belts. Rainfall is very unreliable and largely associated with seasonal movements of the inter-tropical convergence zone.

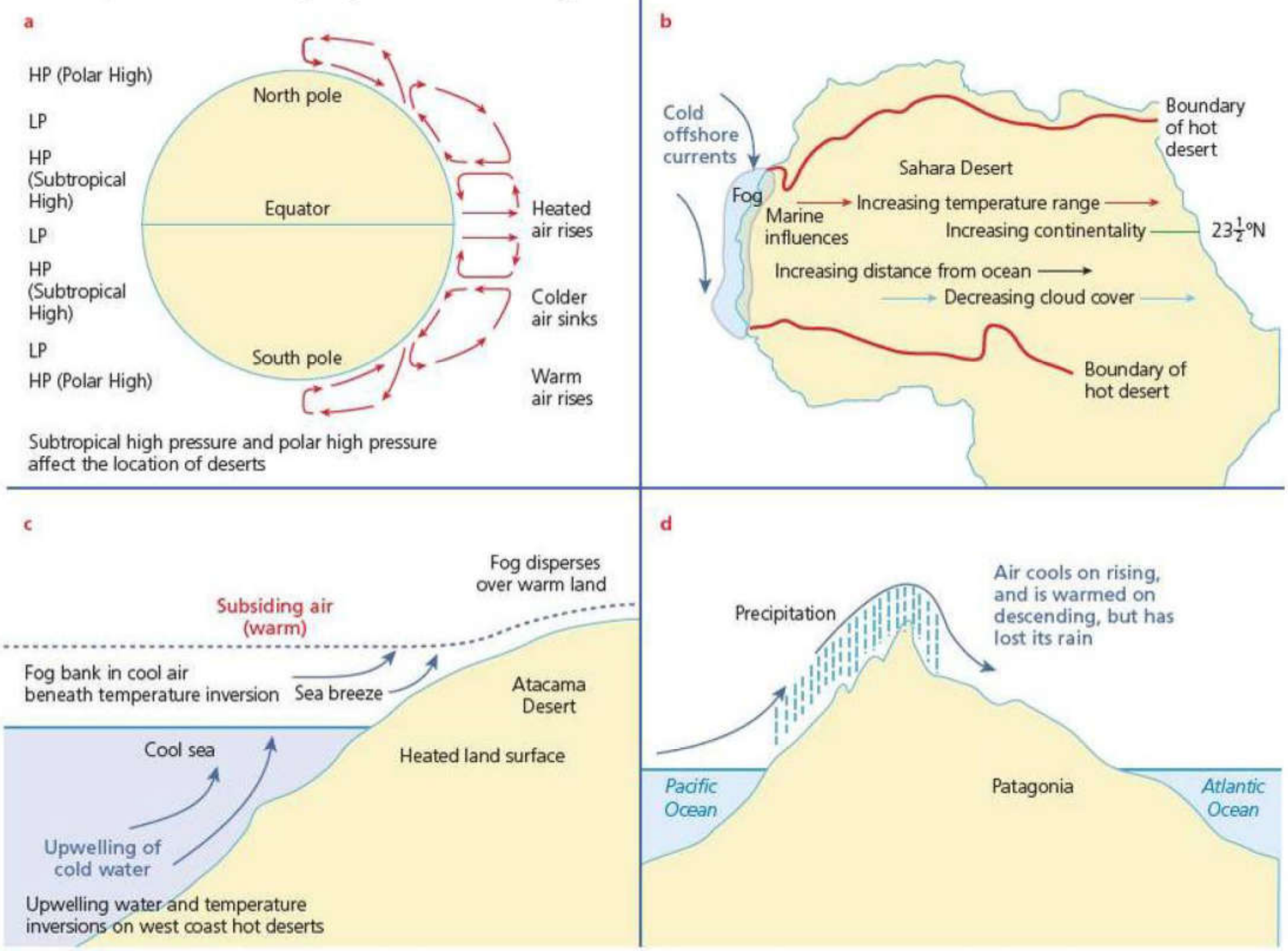


Figure 10.3 The causes of aridity

In addition, distance from sea, continentality, limits the amount of water carried by winds (Figure 10.3b). Precipitation and evapotranspiration are usually lower than in arid areas, resulting from subtropical high-pressure belts. Cold winters are common. These areas are characterised by a relatively small area of aridity surrounded by an extensive area of semi-aridity. The three major northern hemisphere deserts (Gobi and Turkestan in Asia and the Great Basins in North America) are mid-continental and receive little rain. The major central deserts of Australia and Africa also receive little rain as the precipitation is lost when air masses pass over the land. Rainshadow effects further increase the aridity of continental interiors.

In other areas, such as the Atacama and Namib deserts, cold offshore currents limit the amount of condensation into the overlying air (Figure 10.3c). Cold currents reinforce climatic conditions, causing low sea-surface evaporation, high atmospheric humidity, low precipitation (very low rainfall, with precipitation mainly in the form of fog and dew) and a small temperature range.

Others are caused by intense rainshadow effects, as air passes over mountains. This is certainly true of the Patagonian desert (Figure 10.3d). This can reinforce aridity that has been caused primarily by atmospheric stability or continentality. The prevailing winds in the subtropics are trade winds, which blow from the north-east in the northern hemisphere and the south-east in the southern hemisphere. Where the trade winds meet mountain barriers, such as the Andes or the Rockies, the air is forced to rise. Orographic or relief rainfall is formed on the windward side; but on the lee side dehydrated air descends, creating a rainshadow effect. If the mountain ranges are on the east side of the continent then the rainshadow effect creates a much larger extent of arid land. For example, in Australia the Great Dividing Range intercepts rain on the east coast, creating a rainshadow effect to the west.

A final cause, or range of causes, is human activities. Many of these have given rise to the spread of desert conditions into areas previously fit for agriculture. This is known as desertification, and is an increasing problem.

Section 10.1 Activities

1. Explain the term *rainfall effectiveness*.
2. Describe the location of the world's dry areas as shown on Figure 10.1.
3. Briefly explain why there are deserts on the west coast of southern Africa and the west coast of South America.
4. Explain the main causes of aridity.

Key features of hot arid and semi-arid environments

Desert rainfall

The main characteristic of deserts is their very low rainfall totals. Some coastal areas have extremely low rainfall: Lima in Peru receives just 45 millimetres of rain and Swakopmund in Namibia just 15 millimetres. Very often, they may receive no rain in a year. Desert rain is also highly variable. The inter-annual variability (V) is expressed:

$$V\% = \frac{\text{mean deviation from the average}}{\text{the average rainfall}} \times 100\%$$

Variability in the Sahara is commonly 50–80 per cent, compared with just 20 per cent in temperate humid areas. Moreover, individual storms can be substantial. In Chicama, Peru, 394 millimetres fell in a single storm in 1925, compared with the annual average of just 4 millimetres! Similarly, at El Djem in Tunisia 319 millimetres of rain fell in three days in September 1969, compared with the annual average of 275 millimetres.

However, many desert areas receive low-intensity rainfall. Analysis of figures for the Jordan desert and for Death Valley in south-west USA show that most rainfall events produce 3–4 millimetres, similar to temperate areas. In coastal areas with cold offshore currents, the formation of fog can provide significant amounts of moisture. In the coastal regions of Namibia, fog can occur up to 200 times a year, and extend 100 kilometres inland. Fog provides between 35 and 45 millimetres of precipitation per annum. Similarly, in Peru fog and low cloud provide sufficient moisture to support vegetation growth.

Temperature

Deserts exhibit a wide variation in temperature. Continental interiors show extremes of temperature, both seasonally and diurnally. In contrast, coastal areas have low seasonal and diurnal ranges. The temperature in coastal areas is moderated by the presence of cold, upwelling currents. Temperature ranges are low – in Callao in Peru the average diurnal range is just 5 °C, but it has a seasonal range of 8 °C. In contrast, in the Sahara the annual range can be up to 20 °C. Mean annual temperatures are also lower in coastal areas: 17 °C in the Namib and 19 °C in the Atacama.

Continental interiors have extremes of temperature, often exceeding 50 °C. Daily (diurnal) ranges may exceed 20 °C. In winter, frost may occur in a high-altitude interior desert.

Wind in deserts

Hot arid and semi-arid climates are characterised by high wind-energy environments. This is partly due to the lack of vegetation, and so therefore there is a lesser degree of friction with air movement.

Classification of desert climates

Semi-arid outer tropical climate (BShw)

Bordering the deserts, these areas have long dry winters dominated by subsiding air. Brief, erratic rains occur, associated with the ITCZ at its poleward limit. However, owing to the hot temperatures and rapid evaporation, this climate zone is less effective for plant growth. Years of average rainfall may be followed by many years of drought, as in the case of the Sahel region south of the Sahara.

Semi-arid: poleward of hot deserts (BShs)

Summer months are dry and very hot. During winter, occasional rain is associated with mid-latitude depressions. These areas are very variable in terms of rainfall – years of drought may be followed by storms, bringing hundreds of millimetres of rain. Winter rain generally supports coarse grass and drought-tolerant plants.

Hot desert climates (BWh)

In the subtropics, descending air affects the very dry western parts of land masses between 20° and 25° and strongly influences adjacent areas. Even if the air contains a considerable amount of water vapour, relative humidity is low. Stable, subsiding air prevents convective updraughts, which rarely reach sufficient height for cumulonimbus clouds to develop. Occasionally they may develop and result in sheetwash and flash flooding.

During the day, temperatures may reach 50–55 °C, and at night, due to the clear skies, they may fall to 20–25 °C. During winter, daytime temperatures may reach 15–20 °C whereas at night it may be cold enough to allow dew to form.

Table 10.3 Climate data for some arid and semi-arid cities

Cairo													
	J	F	M	A	M	J	J	A	S	O	N	D	Yr
Temperature													
Daily max. (°C)	19	21	24	28	32	35	35	35	33	30	26	21	**28**
Daily min. (°C)	9	9	12	14	18	20	22	22	20	18	14	10	**16**
Average monthly (°C)	14	15	18	21	25	28	29	28	26	24	20	16	**22**
Rainfall													
Monthly total (mm)	4	4	3	1	2	1	0	0	1	1	3	7	**27**
Sunshine													
Daily average	6.9	8.4	8.7	9.7	10.5	11.9	11.7	11.3	10.4	9.4	8.3	6.4	**9.5**
Casablanca													
	J	F	M	A	M	J	J	A	S	O	N	D	Yr
Temperature													
Daily max (°C)	17	18	20	21	22	24	26	26	26	24	20	18	**22**
Daily min (°C)	8	9	11	12	15	18	19	20	18	15	12	10	**14**
Average monthly (°C)	13	13	15	16	18	21	23	23	22	20	17	14	**18**
Rainfall													
Monthly total (mm)	78	61	54	37	20	3	0	1	6	28	58	94	**440**
Sunshine													
Daily average	5.2	6.3	7.3	9.0	9.4	9.7	10.2	9.7	9.1	7.4	5.9	5.3	**7.9**
Timbuktu, Mali													
	J	F	M	A	M	J	J	A	S	O	N	D	Yr
Temperature													
Daily max (°C)	31	35	38	41	43	42	38	35	38	40	37	31	**37**
Daily min (°C)	13	16	18	22	26	27	25	24	24	23	18	14	**21**
Average monthly (°C)	22	25	28	31	34	34	32	30	31	31	28	23	**29**
Rainfall													
Monthly total (mm)	0	0	0	1	4	20	54	93	31	3	0	0	**206**
Sunshine													
Daily average	9.1	9.5	9.6	9.7	9.8	9.4	9.6	9	9.3	9.5	9.5	8.9	**9.4**

Section 10.1 Activities

1 Explain the term *rainfall variability*.
2 Compare and contrast the seasonal and monthly temperature ranges for Casablanca and Timbuktu.
3 Using the geographical locations of Casablanca and Timbuktu, suggest reasons for the differences you have noted in their seasonal and monthly temperature ranges.
4 Compare and contrast the precipitation totals for Cairo, Casablanca and Timbuktu. Suggest reasons for the differences you have identified.

10.2 Landforms of hot arid and semi-arid environments

Weathering processes

Weathering in deserts is superficial and highly selective. The traditional view was that all weathering in deserts was mechanical due to the relative absence of water. However, it is increasingly realised that chemical weathering is important, and that water is important for mechanical weathering, especially exfoliation. Weathering is greatest in shady sites and in areas within reach of soil moisture. Chemical weathering is enhanced in areas that experience dew or coastal fog. As rainfall increases, weathering increases; and soils tend to have more clay, less salt and more distinct horizons. Salt weathering is frequent in arid areas because desert rocks often have soluble salts, and these salts can disintegrate rocks through salt crystal growth and hydration.

Salt crystallisation causes the decomposition of rock by solutions of salt (Figure 10.4). There are two main types of salt crystal growth. First, in areas where temperatures fluctuate around 26–28 °C, sodium sulphate (Na_2SO_4) and sodium carbonate (Na_2CO_3) expand by about 300 per cent. This creates pressure on joints, forcing them to crack. Second, when water evaporates, salt crystals may be left behind. As the temperature rises, the salts expand and exert pressure on rock. Both mechanisms are frequent in hot desert regions where low rainfall and high temperatures cause salts to accumulate just below the surface.

Experiments investigating the effectiveness of saturated salt solutions have shown a number of results:

- The most effective salts are sodium sulphate, magnesium sulphate and calcium chloride.
- The rate of disintegration of rocks is closely related to porosity and permeability.

Figure 10.4 Salt crystallisation

- Surface texture and grain size control the rate of rock breakdown. This diminishes with time for fine materials and increases over time for coarse materials.
- Salt crystallisation is more effective than insolation weathering, hydration or freeze–thaw. However, a combination of freeze–thaw and salt crystallisation produces the highest rates of breakdown.

The most effective salts are, in descending order, sodium sulphate (Na_2SO_4), magnesium sulphate ($MgSO_4$) and calcium chloride ($CaCl_3$). Sodium sulphate caused a 100 gramme block of stone to break down to about 30 grammes – a loss of 70 per cent (Figure 10.5). Similarly, magnesium sulphate reduced a 95 gramme block to just over 40 grammes, a loss of over 50 per cent. The least effective salts were common salt (NaCl) and sodium carbonate (Na_2CO_3).

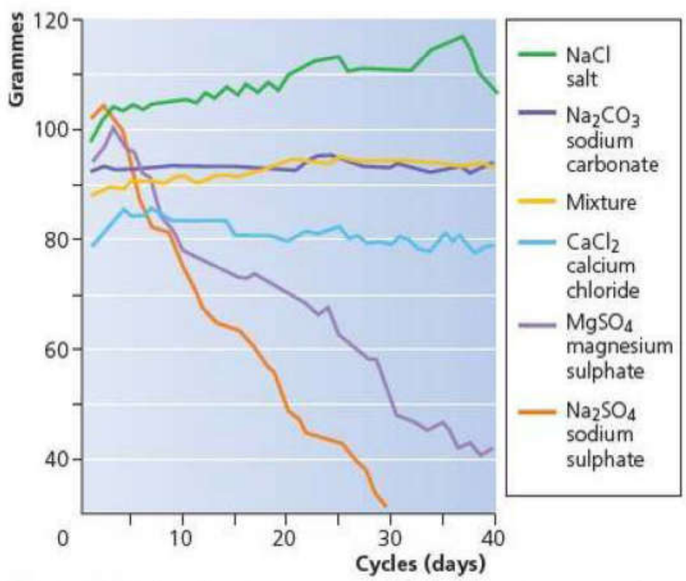


Figure 10.5 The effects of common salts on sandstone under laboratory conditions

Thermal fracturing refers to the break-up of rock as a result of repeated changes in temperature over a prolonged period of time. Disintegration or insolation weathering is found in hot desert areas where there is a large diurnal temperature range. In many desert areas, daytime temperatures exceed 40 °C, whereas night-time temperatures are little above freezing. Rocks heat up by day and contract by night. As rock is a poor conductor of heat, stresses occur only in the outer layers. This causes peeling or exfoliation to occur. Griggs (1936) showed that moisture is essential for this to happen. In the absence of moisture, temperature change alone did not cause the rocks to break down. The role of salt in insolation weathering has also been studied. The expansion of many salts such as sodium, calcium, potassium and magnesium has been linked with exfoliation. However, some geographers find little evidence to support this view.

In some instances, rocks may be split in two. Block disintegration is most likely to result from repeated heating and cooling. Such rocks are known as *kernsprung*. A more localised effect is granular disintegration. This occurs due to certain grains being more prone to expansion and contraction than others – this exerts great pressure on the grains surrounding them and forces them to break off.

Hydration is the process whereby certain minerals absorb water, expand and change. For example, gypsum is changed to anhydrate. Although it is often classified as a type of chemical weathering, mechanical stresses occur as well. When anhydrite ($CaSO_4$) absorbs water to become gypsum ($CaSO_4.2H_2O$), it expands by about 0.5 per cent. More extreme is the increase in volume of up to 1600 per cent by shales and mudstones when clay minerals absorb water.

Freeze–thaw occurs when water in joints and cracks freezes at 0 °C. It expands by about 10 per cent and exerts pressure up to a maximum of 2100 kg/cm^2 at −22 °C. This greatly exceeds most rocks' resistance. However, the average pressure reached in freeze–thaw is only 14 kg/cm^2.

Freeze–thaw is most effective in environments where moisture is plentiful and there are frequent fluctuations above and below freezing point. It can occur in deserts at high altitude and in continental interiors in winter.

☐ Processes of erosion, transport and deposition by wind

The importance of wind in deserts has been hotly debated by geographers. At the end of the nineteenth century, it was considered to be a very effective agent in the formation of desert landforms. By contrast, in the twentieth century the role of wind was played down, in part because much of the research into deserts took place in high-relief, tectonically active areas such as the south-west USA. It was argued that:

- wind-eroded landscapes were only superficially eroded
- some features, such as playas, were formed by other processes, especially tectonic ones
- desert surfaces were protected from the wind by crusts, salts and gravel
- wind erosion depends on the availability of abrasive sands and only operates over a limited height range
- water is still very active.

However, in the middle of the twentieth century the use of aerial photography and satellites showed major features aligned with prevailing wind systems, such as yardangs in the Sahara, Iran, Peru and Arabia. In addition, examination of desert playas, which are large and frequent, showed that some are tectonic but others are aeolian. Dunes on the lee side of playas suggest that the dunes were deposited by excavating winds. In the Qattara Depression in the Sahara, 3335 km^3 of material has been removed by the wind. Moreover, meteorological observations of dust storms have illustrated the importance of winds. The Great American Dust Storm of 12 November 1933, which marked the beginning of the Dust Bowl, stretched from Canada to western Ohio and the Missouri Valley, an area larger than France, Italy and Hungary! The increased frequency of dust storms in the USA was due to severe drought and poor agricultural techniques. Although the land was not desert, it took on desert characteristics. In the 1970s, there was an increase in the number of dust storms in the Sahel region of Africa. Some of these storms travelled across the Atlantic to reach the Caribbean and were also associated with an increase in asthma there, partly as a result of increased dust, and partly as a result of the transfer of bacteria by winds across the Atlantic Ocean. Finally, as already noted, during the last glaciations some areas in the tropics were wetter and some were drier. It is estimated that the rate of dust removal and deposition was 100 times greater than it is at present.

Erosion

By itself, wind can only blow away loose, unconsolidated material so gradually lowering the surface by deflation. At wind speeds of 40 kilometres per hour, sand grains will move by surface creep and saltation. Much transport of sand will therefore be limited to a metre or so above the surface (Figure 10.6). Most abrasion (corrasion) occurs in this zone, by sand particles hitting against rocks. Higher wind speeds will cause dust storms. Extremely rare gusts of over 150 kilometres per hour are needed to roll pebbles along the ground. Fine dust is moved easily by light winds.

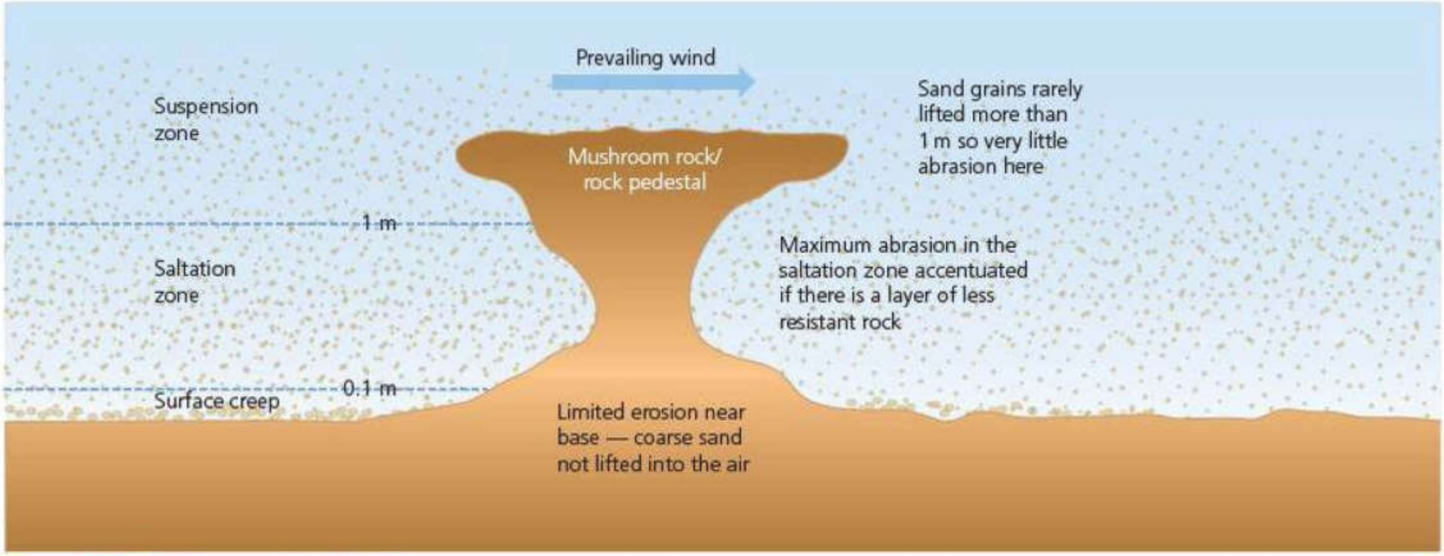


Figure 10.6 Wind transport and erosion

Transport

Sand-sized particles are well suited to transport by the wind. Sand movement occurs when wind speeds exceed 20 kilometres per hour. Grains initially begin to roll (traction), and then follow a bouncing action, known as saltation. The saltating grains are typically 0.15–0.25 millimetres in diameter. In contrast, larger grains (0.26–2 millimetres) move by surface creep and smaller grains (0.05–0.14 millimetres) move through suspension.

Deposition

Deposition occurs when the wind speed is reduced. The form taken by the deposited material is influenced by:

- the nature of any surface irregularity
- the amount and type of material carried by the wind, itself controlled by velocity
- the flow pattern of the dominant wind (shaping the material being deposited)
- the presence or absence of vegetation and groundwater.

Deserts occupy about 20 per cent of the world and their area is expanding. For example, the arid belt of the southern Sahara, known as the Sahel, has extended considerably into the savanna lands of Ethiopia, causing widespread famine there.

Sand drifts (temporary pockets of sand found in 'wind shadow' areas) and sand sheets (wide areas of flat or undulating sandscape) are common in desert areas. However, the formation of different types of sand dune seems to typify desert deposition.

☐ Characteristic landforms of wind action

As well as blowing away layers of unconsolidated material over wide areas, deflation can be localised to produce deflation basins. It is not fully understood why localised deflation occurs – faulting may produce the initial depression that is enlarged by the eddying nature of the wind; differential erosion could also cause the initial trigger, as could solution weathering in a past pluvial period. Many such basins are found in the Sahara west of Cairo. Some basins have become so deflated that their bases reach the water table and so form an oasis, for example the Baharia and Farafra oases and the massive Qattara Depression, which lies 128 metres below sea level.

Selective deflation causes various different types of desert landscape:

- **hammada desert** – all loose material is blown away, leaving large areas of bare rock, often strewn with large, immovable weathered rocks
- **desert pavement** – pebbles are concentrated, for example by a flash flood, and packed together into a mosaic; the tops are then worn flat by wind erosion and perhaps become shiny as a coat of desert varnish develops
- **reg desert** – here, the finest material has been deflated, leaving a gravelly or stony desert
- **erg desert** – this is the classic sandy desert.

Wind erosion only takes place when the wind is loaded with loose materials, especially sand grains. Dust particles are ineffective. The wind throws the particles of sand against rock faces, creating abrasion or corrasion (a sand-blast effect). Large rock fragments, too heavy to be transported by the wind, are worn down on the windward side – these worn fragments are called ventifacts.

In areas of homogeneous rock, the wind will smooth and polish the surface. However, if the rocks are heterogeneous, for example weakened by joints or faults, some dramatic landforms will result from wind erosion, with rock faces etched, grooved, fluted and honeycombed, forming towers, pinnacles and natural arches. Undercutting (abrasion occurring at about 1 metre above the ground) is common, and produces distinctive landforms, including:

- gours – mushroom pinnacles where the base has been undercut, and bands of hard and soft rock have been differentially sand-blasted
- zeugens – develop where differing rock strata lie horizontally; after being eroded by the wind, the rocks form small plateau-like blocks that are isolated residuals of the original plateau, called 'mesas' (if quite large) and 'buttes' (if relatively small) in parts of Colorado, USA
- yardangs – occur where hard and soft rocks lie side by side; the softer rocks are worn down to form troughs, while the harder rocks stand up as wind-worn ridges or yardangs.

Wind-borne material is in constant motion and consequently attrition of this material occurs, the particles becoming rounder and smaller. Wind rounds material more effectively than running water because:

- wind speeds are greater
- distances over which the attrition takes place are often much greater
- the grains are not protected by a film of water.

Section 10.2 Activities

Outline the ways in which wind can erode desert surfaces.

Sand dunes

Only about 25–33 per cent of the world's deserts are covered by dunes, and in North America only 1–2 per cent of the deserts are ergs (sandy deserts) (Table 10.4). Large ergs are found in the Sahara and Arabia. The sand that forms the deserts comes from a variety of sources: alluvial plains, lake shores, sea shores and from weathered sandstone and granite.

The geometry of dunes is varied and depends on the supply of sand, the wind regime, vegetation cover and the shape of the ground surface.

Some dunes are formed in the lee of an obstacle. A nebkha is a small dune formed behind a tree or shrub, whereas a lunette dune is formed in the lee of a depression (Figure 10.7). Lunettes may reach a height of about 10 metres. They are asymmetric in cross-section, with the steeper side facing the wind. However, most dunes do not require an obstacle for their formation.

Barchan dunes are crescent-shaped and are found in areas where sand is limited but there is a constant wind supply. They have a gentle windward slope and a steep leeward slope up to 33°. Variations include barchan ridges and tranverse ridges, the latter forming where sand is abundant, and where the wind flow is checked by a topographic barrier, or increased vegetation cover. Barchans can be as wide as 30 metres.

Parabolic dunes have the opposite shape from barchans – they are also crescent-shaped but point downwind. They occur in areas of limited vegetation or soil moisture.

Linear dunes or seifs are commonly 5–30 metres high and occur as ridges 200–500 metres apart. They may extend for tens, if not hundreds, of kilometres. They are found in areas where there is a seasonal change in wind direction. It is believed that some regularity of turbulence is responsible for their formation (Figure 10.8).

Where the winds come from many directions, star dunes may be formed. Limbs may extend from a central peak. Star dunes can be up to 150 metres high and 2 kilometres wide.

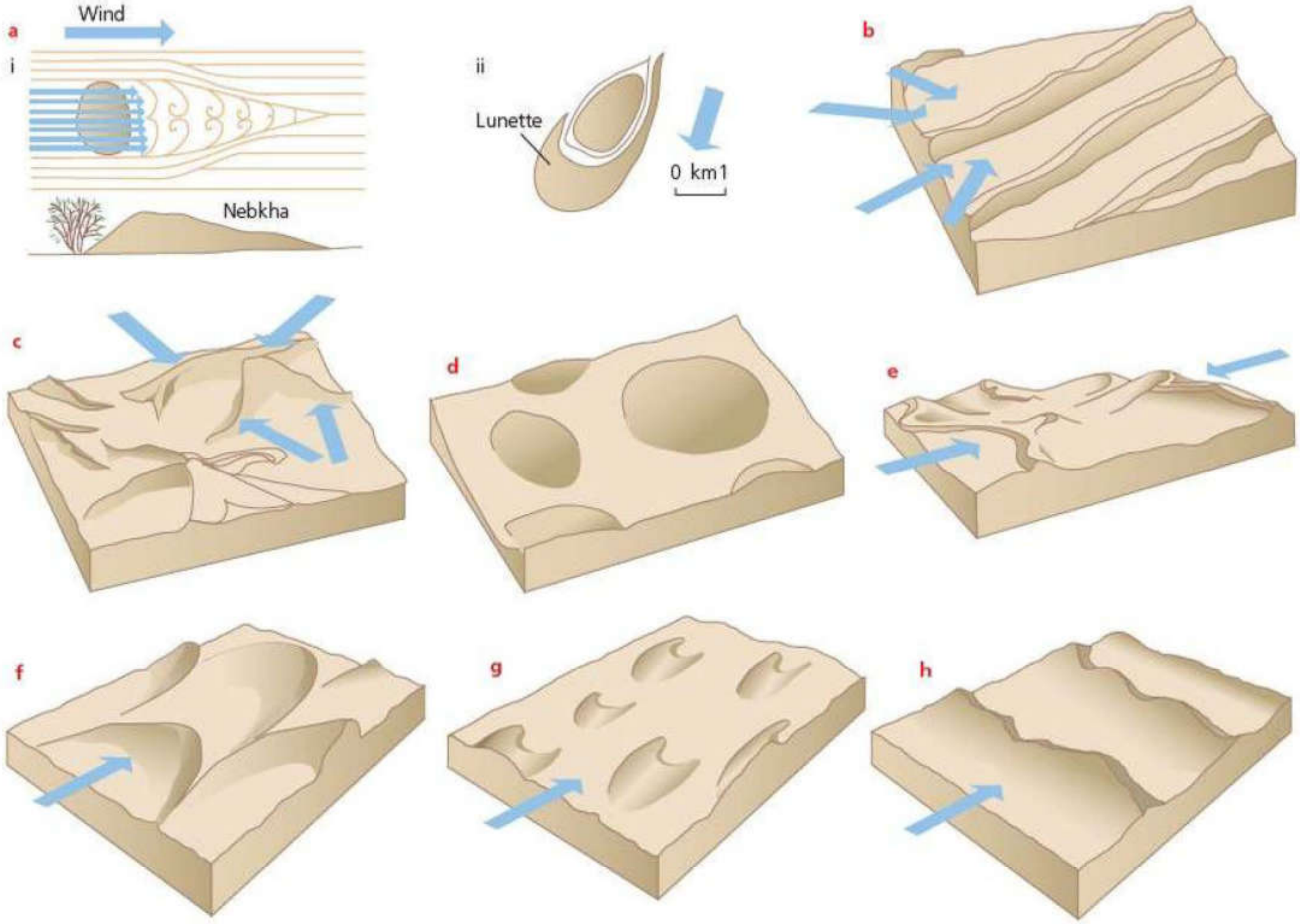
Dune types can merge. Crescent barchans can be transformed into longitudinal seif dunes, depending on the wind regime. The overemphasis on barchans and seif dunes is somewhat misleading. Less than 1 per cent of sand dunes are of these types. Dunes are not necessarily longitudinal or transverse – many are oblique. Grain size is also important – coarse sand is associated with rounded dunes, of subdued size and long wavelength. Fine sand produces stronger relief with smaller wavelengths.

Section 10.2 Activities

Comment on the regional distribution, and relative importance, of linear dunes, as shown in Table 10.4.

Table 10.4 The relative importance (percentage figures) of major dune types in the world's deserts

Desert	Thar	Takla Makan	Namib	Kalahari	Saudi Arabia	Ala Shan	South Sahara	North Sahara	North-east Sahara	West Sahara	Average
Linear dunes	13.96	22.12	32.84	85.85	49.81	1.44	24.08	22.84	17.01	35.49	**30.54**
Crescent dunes	54.29	36.91	11.80	0.59	14.91	27.01	28.37	33.34	14.53	19.17	**24.09**
Star dunes	–	–	9.92	–	5.34	2.87	–	7.92	23.92	–	**5.00**
Dome dunes	–	7.40	–	–	–	0.86	–	–	0.8	–	**0.90**
Sheets and streaks	31.75	33.56	45.44	13.56	23.24	67.82	47.54	35.92	39.25	45.34	**38.34**
Undifferentiated	–	–	–	–	6.71	–	–	–	4.50	–	**1.12**



a Dune formation
b Linear dunes or seifs
c Star dunes
d Dome dunes
e Reversing dunes
f Parabolic dunes
g Barchan dunes
h Barchanoid ridge

Figure 10.7 Some sand dune types

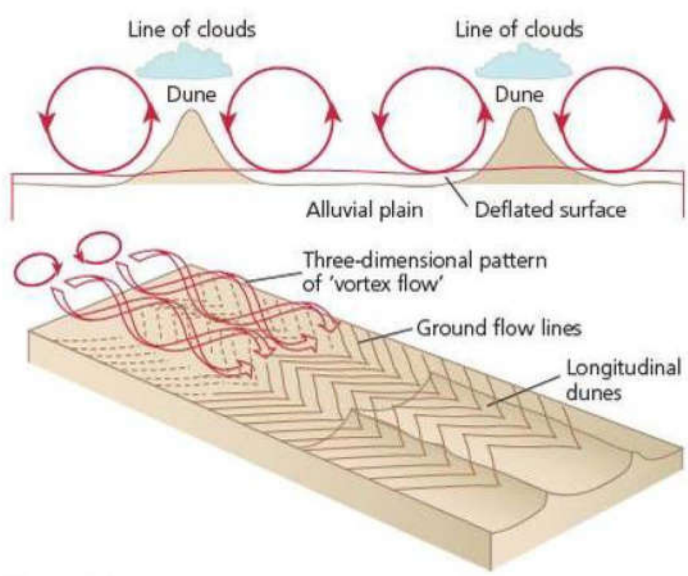


Figure 10.8 Turbulence and the formation of seif dunes

Water action and its characteristic landforms

Despite the low rainfall in arid regions, rivers play an important part in the development of many arid landforms. The **hydrological regime** (annual and seasonal pattern) is very irregular and can be unpredictable. Rainfall may be irregular and **episodic** (sporadic) but some desert areas experience occasional heavy downpours. These downpours may generate sudden **flash floods** and **sheet floods** (where the water is not confined in an identifiable channel).

Rivers in arid lands can be divided into three types:

- **Exogenous** rivers have their origin in humid areas – they are exotic rivers. The Nile flows through the Sahara but rises in the monsoonal Ethiopian Highlands and in equatorial Lake Victoria.
- **Endoreic** rivers flow into inland lakes. The Jordan River flows into the Dead Sea and the Bear River flows into the Great Salt Lake.

- Ephemeral rivers flow only after rainstorms. They can generate high amounts of discharge because torrential downpours exceed the infiltration capacity of the soils. Most ephemeral streams consist of many braided channels separated by islands of sediment.

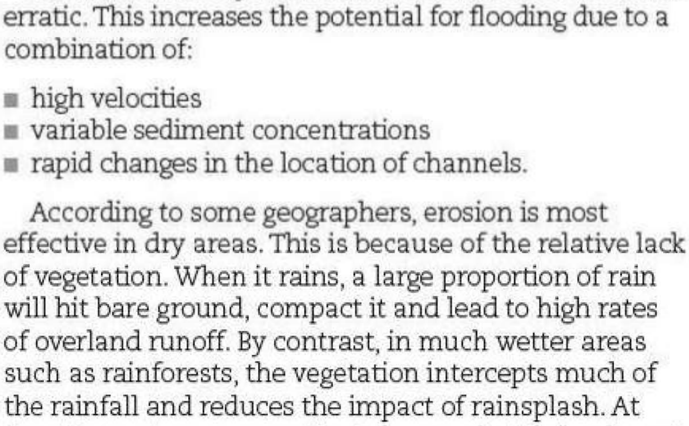
Even areas of low-intensity rain can generate much overland flow. This is because of the lack of vegetation and the limited soil development. The presence of duricrusts also reduces the ability of water to infiltrate the soil.

Surface runoff is typically in the form of sheet flow, where water flows evenly over the land. The runoff may become concentrated into deep, steep-sided valleys known as wadis or arroyos.

Stream flow in dry areas is seasonal, and in some cases erratic. This increases the potential for flooding due to a combination of:

- high velocities
- variable sediment concentrations
- rapid changes in the location of channels.

According to some geographers, erosion is most effective in dry areas. This is because of the relative lack of vegetation. When it rains, a large proportion of rain will hit bare ground, compact it and lead to high rates of overland runoff. By contrast, in much wetter areas such as rainforests, the vegetation intercepts much of the rainfall and reduces the impact of rainsplash. At the other extreme, areas that are completely dry do not receive enough rain to produce much runoff. Hence it is the areas that have variable rainfall (and a variable vegetation cover) that experience the highest rates of erosion and runoff (Figure 10.9). Moreover, as the type of agriculture changes, the rate of erosion and overland runoff change (Figure 10.10). Under intense conditions this creates gullies.



Rates of transport (and therefore denudation) tend to be highest in semi-arid areas and especially in more humid areas where vegetation is removed

Figure 10.9 Rainfall, vegetation cover and soil erosion

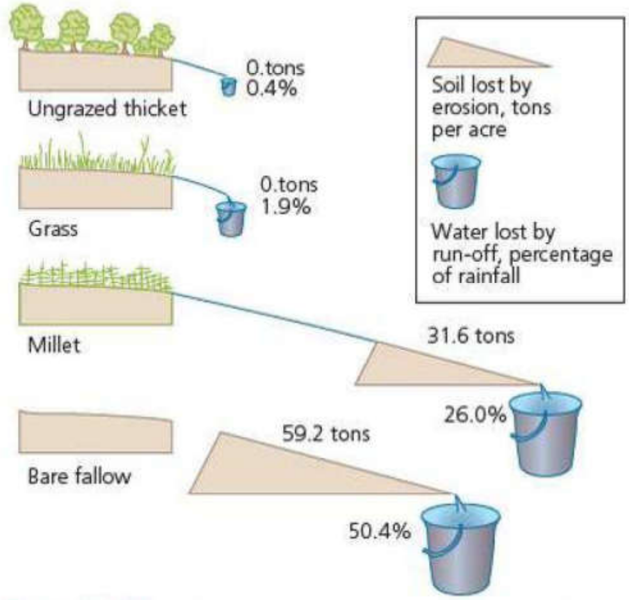


Figure 10.10 The impact of vegetation type on runoff and soil erosion

There is a paradox that in deserts most runoff occurs on low-angle slopes. This is due to particle size. Coarse debris makes up the steeper slopes, while fine material makes up the low-angle slopes. Coarse debris allows more infiltration, so there is less overland flow on steeper slopes.

High concentrations of sediment in runoff from desert uplands illustrate (a) the erodibility of unvegetated areas and (b) the contemporary nature of the work of water in deserts. Desert streams are cloudy and muddy – up to 75 per cent of the flow may be solid matter. This solid matter is important for the formation of alluvial fans (and for silt building up behind dams). An alluvial fan is a cone of sediment occurring between a mountain and a lowland plain; that is, the piedmont zone (literally the foot of the mountain) (Figure 10.11). They can be up to 20 kilometres wide and up to 300 metres at the apex. They generally form when a heavily sediment-laden river emerges from a canyon. The river, no longer confined to the narrow canyon, spreads out laterally, losing height, energy and velocity, so that deposition occurs; larger particles are deposited first and finer materials are carried further away from the mountain. If a number of alluvial fans merge, the feature is known as a bajada (bahada).

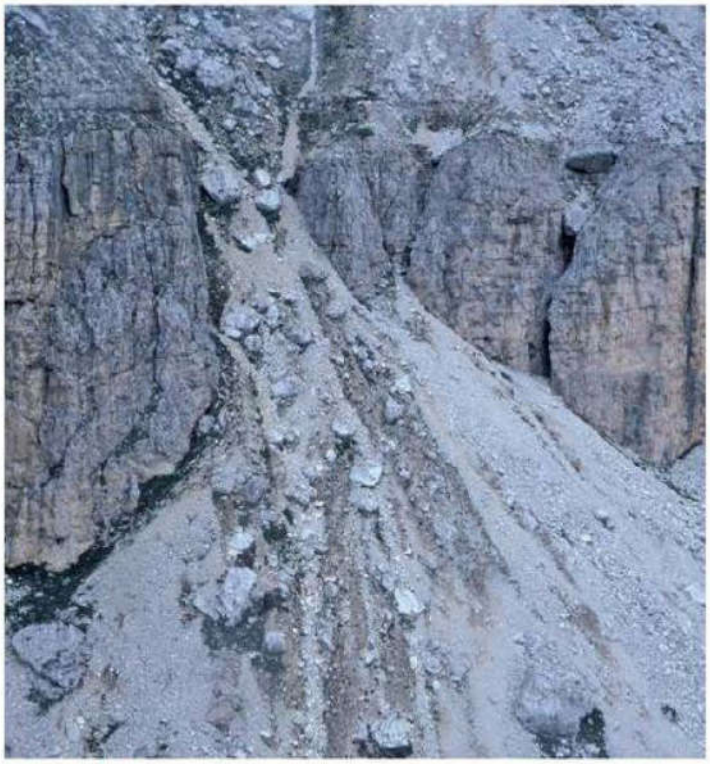


Figure 10.11 An alluvial fan

On a larger scale, pediments are gently sloping areas (< 7°) of bare rock where there is a distinct break with the mountain region (Figure 10.12). One idea is that they are the result of lateral planation. Another hypothesis involves sub-surface weathering. This is likely to be accentuated at the junction of the mountain and the plain because of the concentration of water there through percolation. The weathering will produce fine-grained material that can be removed, in the absence of vegetation cover, by sheetfloods, wind and other processes.

Salt lakes (chottes/playas) are found in the lowest part of the desert surface, where ephemeral streams flow into inland depressions, for example the Chott el Djerid of Tunisia. After flowing into the depression, water evaporates, leaving behind a thick crust. Sodium chloride is the most common salt found in such locations, but there could also be gypsum (calcium sulphate), sodium sulphate, magnesium sulphate and potassium and magnesium chlorides.

In some semi-arid areas, water action creates a landscape known as badlands. These are areas where soft and relatively impermeable rocks are moulded by rapid runoff that results from heavy but irregular rainfall. There is insufficient vegetation to hold the regolith and bedrock together, and rainfall and runoff are powerful enough to create dramatic landforms. Badlands generally have the following features:

- wadis of various sizes with debris-covered bottoms
- gullies that erode headwards, leading to their collapse
- slope failure and slumping
- alluvial fans at the base of slopes
- natural arches formed by the erosion of a cave over time.

An excellent example of badland topography is in southern Tunisia around Matmata.

Wadis are river channels that vary in size from a few metres in length to over 100 kilometres. They are generally steep-sided and flat-bottomed. They may be formed by intermittent flash floods or they may have been formed during wetter pluvial periods in the Pleistocene. The relative infrequency of flash floods in some areas where wadis are found could suggest that they were formed at a time when storms were more frequent and more intense. In contrast, **arroyos** are channels that have enlarged by repeated flooding. They are common in semi-arid areas on alluvium and solid rock.

Mesas are plateau-like features with steep sides at their edges. Buttes are similar but much smaller. Water has eroded most of the rock, leaving a thin pillar. Inselbergs (see Topic 7, Section 7.2) may be the result of deep chemical weathering during wetter pluvial periods. Overlying sediments were subsequently removed by river activity. They are isolated steep-sided hills. A good example is Uluru (Ayers Rock) in Australia.

High runoff and sediment yields cause much dissection and high drainage densities (total length of water channel per km^2). In the Badlands of the USA, drainage densities can be as high as 350 km/km^2, whereas in a typical temperate region it is 2–8 km/km^2. In contrast, in sandy deserts (high infiltration), drainage densities can be as low as 0–1 km/km^2.

Section 10.2 Activities

1 Study Figure 10.9, which shows the relationship between rainfall, vegetation cover and erosion.
   a Why is there limited erosion in areas where rainfall is very low?
   b Why is there limited erosion in areas where rainfall is very high?
   c Why are there high rates of erosion in areas with about 600 millimetres of rain?
2 Figure 10.10 shows the effects of crop type on runoff and erosion. Describe what happens when scrubland (ungrazed thicket) is used for either pastoral agriculture (grass) or arable agriculture (millet). Describe and explain the effects of the removal of vegetation on runoff rates and erosion rates.

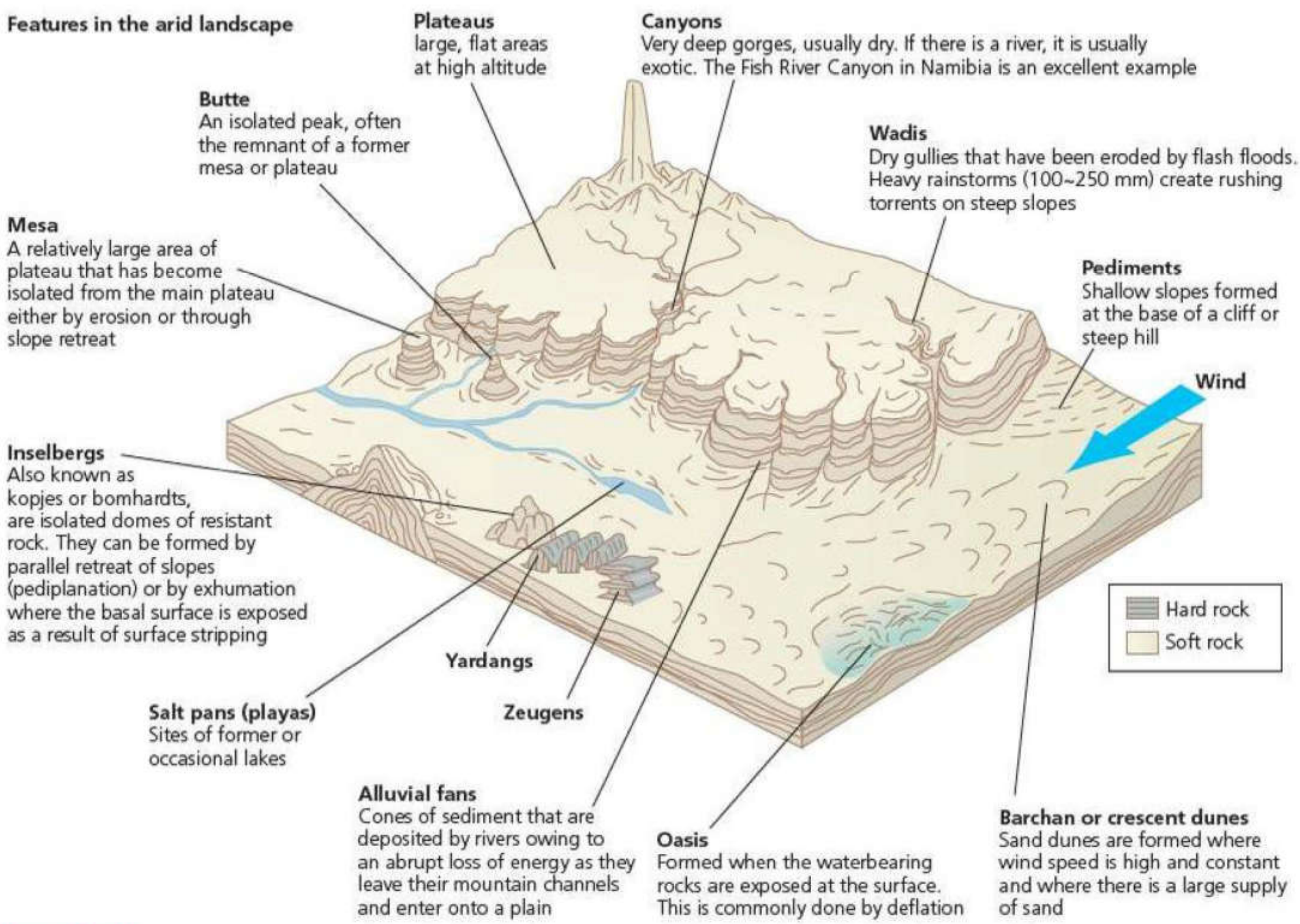


Figure 10.12 Desert landforms

□ Relative roles of aeolian and river processes

Evidence of past climate change in deserts

During the Pleistocene Ice Age, high latitudes contained more ice (30 per cent of the world surface) than today (10 per cent of the world surface), while low-latitude areas experienced increased rainfall – episodes known as 'pluvials'. Some deserts, however, received less rainfall – these dry phases are known as 'interpluvials'.

There is widespread evidence for pluvial periods in deserts (Figure 10.13):

- shorelines marking higher lake levels around dry, salty basins
- fossil soils of more humid types, including horizons containing laterite
- spring deposits of lime, called 'tufa', indicating higher groundwater levels
- river systems now blocked by sand dunes
- animal and plant remains in areas that are now too arid to support such species
- evidence of human habitation, including cave paintings.

Wetter conditions existed in the tropics, causing lakes to reach much higher levels and rivers to flow into areas that are now dry. On the margins of the Sahara, Lake Chad may have been 120 metres deeper than it currently is, and may have extended hundreds of kilometres north of its present position.

The evidence for drier conditions includes sand dune systems in areas that are now too wet for sand movement to occur. Dunes cannot develop to any great degree in continental interiors unless the vegetation cover is sparse enough to allow sand movement. If the rainfall is much over 150 millimetres, this is generally not possible. Satellite imagery and aerial photographs have shown that some areas of forest and savanna, with 750–1500 millimetres of rain, contain areas of ancient degraded dunes. Today, about 10 per cent of the land area between 30 °N and 30 °S is covered by active sand deserts, but about 18 000 years ago this area was about 30 per cent sand desert.

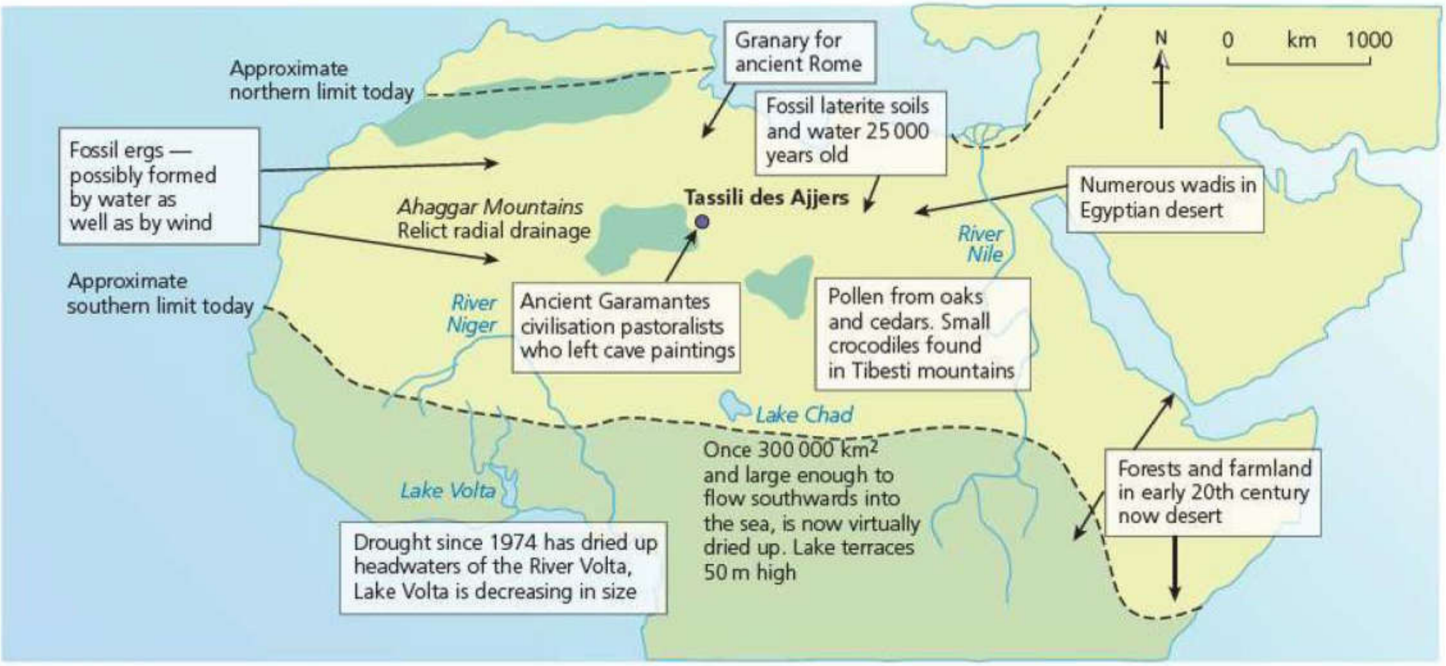


Figure 10.13 The evidence for climate change in the Sahara

Case Study: Climate change in Australia

Glacial periods triggered decreased rainfall and increased windiness. At least eight episodes of dune building have occurred over the last 370 000 years. The largest sand dune system in the world is the Simpson desert, which was formed only 18 000 years ago. The Simpson desert covers 159 000 km^2 and consists of linear dunes 10–35 metres high and up to 200 kilometres long (Figure 10.14). They run parallel to each other, with an average spacing over 510 metres. The dunes are fixed (vegetated) except for their crests, which are mobile. The Simpson desert dunes form part of a continental anticlockwise swirl that relates to the dominant winds of the subtropical anticyclone system.

Figure 10.14 Dunes in Australia

Section 10.2 Activities

Examine the evidence to suggest that some deserts in the past were **a** wetter and **b** drier.

Equifinality: different processes, same end product

A question frequently asked is whether desert landforms are the result of wind action or water action. This is a simplification because there are other processes than wind and water acting in desert regions. For example, stone pavements are surfaces of coarse debris lying above finer material. They could be caused by:

- deflation of fine material, leaving coarse material behind
- removal of fine material by rainsplash or sheetwash
- vertical sorting by frost action or hydration.

It may even be a combination of processes.

Similarly, depressions can be caused by a variety of processes:

- deflation removing finer material, as in the Qattara Depression, Sahara
- tectonic, for example block faulting in the basin and range region of the USA
- solution of limestone during a pluvial period as, for example, in Morocco
- animal activity as, for example, in Zimbabwe where herds are concentrated near water holes and accentuate the initial depression.

Gully development is normally associated with river activity. However, there are different reasons for their development:

- Some are related to increased discharge due to climate change.
- Others are caused by the removal of vegetation by people exposing the surface to accelerated rates of erosion.
- Some develop where concrete structures have been built to improve runoff.
- Tectonic disturbances can initiate gully development, especially uplift.
- Catastrophic flooding may be responsible for some gully development.

10.3 Soils and vegetation

An ecosystem is the interrelationship between plants and animals and their living and non-living environments. A biome is a global ecosystem, such as the tropical rainforest, savanna or hot desert ecosystem.

Deserts have low rates of biomass productivity – on average, net primary productivity of 90 g/m²/year. This is due to the limited amount of organic matter caused by extremes of heat and lack of moisture. Productivity can generally be positively correlated with water availability. Despite the diversity of life forms found in deserts, desert flora and fauna are relatively species poor. At the continental scale, species diversity of lizards and rodents has been correlated with increasing precipitation. Desert vegetation is simple in that its structure is poorly developed and its cover becomes increasingly open and discontinuous with increasing aridity. Given the extreme conditions, it is not surprising that the biodiversity is limited.

Energy flow in deserts is controlled by water, which can be very irregular. The impact of herbivores in deserts is similar to that in other ecosystems, with about 2–10 per cent of the primary production being directly consumed. Some studies have indicated that 90 per cent or more of seed production may be eaten by seed-eaters such as ants and rodents. Energy flow in hot deserts is less than in semi-arid areas due to the lack of rainfall, and less biomass.

Owing to the low and irregular rainfall, inputs to the nutrient cycle (dissolved in rain and as a result of chemical weathering) are low (Figure 10.15). Most of the nutrients are stored in the soil, and there are very limited stores in the biomass and litter. This is due to the limited amount of biomass and litter in the desert environment. In some deserts, nutrient deficiency (especially of nitrogen and/or phosphorus) may become critical. The rapid growth of annuals following a rain event rapidly depletes the store of available nutrients, while their return in decomposition is relatively slow. Desert ecosystems are characterised by smaller stores of nutrients in the soil (due to low rates of chemical weathering), and low amounts of nutrients in the biomass, due to the dry conditions. In semi-arid areas the amount of nutrients available increases with rainfall and chemical weathering.

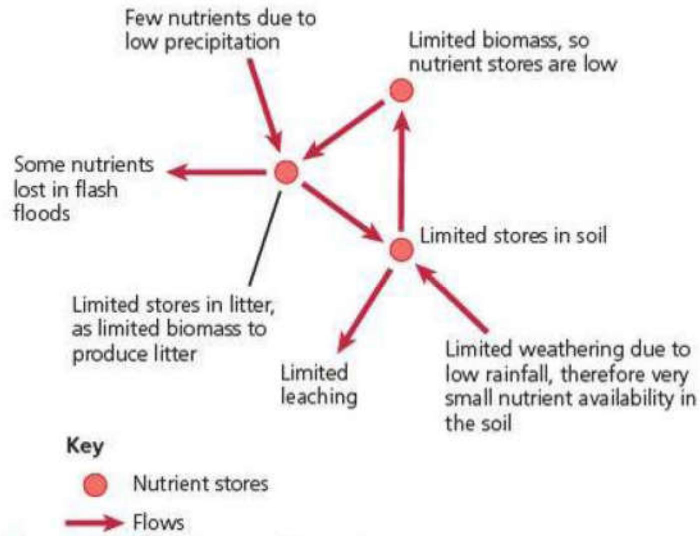


Figure 10.15 Nutrient cycle in a desert

Decomposition, like growth, is slow. Microbial decomposers are limited. Two important processes are involved in nutrient cycling:

- the fragmentation, erosion and transport of dead organic matter (DOM) by wind and runoff
- consumption of DOM by detritivores such as termites, ants and mites, which are relatively abundant in deserts.

In the absence of leaching, nutrients may accumulate in the upper layers of the soil. A large proportion of the nutrients is held either in young tissue or in the fertile islands surrounding large plants where, as a result of slightly lower temperatures and higher humidity, decomposition is lower and DOM accumulates.

Desert ecosystems are sometimes considered to be fragile, due to the extreme climatic conditions and the relative lack of biodiversity. Nevertheless, despite the extreme short-term variability of the desert environment, the desert ecosystem is considered, in the long term, to be both stable and resilient. This is due to the adaptations of desert organisms to survive water stress – in some cases for years. The hogweed (*Boerhavia repens*) plant in the Sahara takes just 8–10 days from seed germination to seed production. It therefore produces seeds before the water runs out, and flowers at a time when insect pollinators are abundant. Desert ecosystems may appear fragile, but in fact they are very resilient.

Plant and animal adaptations

Desert vegetation is generally ephemeral (it appears or flowers after rain). Some desert vegetation has a very short life cycle, some less than eight weeks. Vegetation is generally shallow-rooted, small in size and with small leaves. In contrast, vegetation in semi-arid areas is succulent (able to store water), and more vegetation is located near to water sources.

Desert plants and animals have acquired similar morphological, physiological and behavioural strategies that, although not unique to desert organisms, are often more highly developed and effectively utilised than their moist counterparts.

The two main strategies are avoidance and tolerance of heat and water stress (Table 10.5). The *evaders* comprise the majority of the flora of most deserts. They can survive periods of stress in an inactive state or by living permanently or temporarily in cooler and/or moister environments, such as below shrubs or stone, in rock fissures or below ground. Of desert animals, about 75 per cent are subterranean, nocturnal or active when the surface is wet. In such ways, plants and animals can control their temperature and water loss.

Section 10.3 Activities

1 Describe the typical nutrient cycle of a desert as shown in Figure 10.15.
2 Explain why deserts have low values for NPP (net primary productivity).

Table 10.5 Adaptations of plants and animals to hot desert environments

Strategy	Plants	Animals
Stress-evading strategies		
	Inactivity of whole plants Cryptobiosis* of whole plant Dormancy of seeds	Dormancy in time (diurnal and seasonal) and space (take refuge in burrows) Cryptobiosis of mature animals (aestivation of snails, hibernation) Cryptobiosis of eggs, shelled embryos, larvae: permanent habitation or temporary use of stress-protected microhabitats
Structural and physiological stress-controlling strategies		
Strategies reducing water expenditure	Small surface : volume ratio Regulation of water loss by stomatal movements Xeromorphic features Postural adjustments	Small surface : volume ratio Regulation and restriction of water loss by concentrated urine, dry faeces, reduction of urine flow rate Structures reducing water Postural adjustment
Strategies to prevent death by overheating	Transpiration cooling High heat tolerance Mechanisms decreasing and/or dissipating heat load	Evaporative cooling High heat tolerance Mechanisms decreasing and/or dissipating heat load
Strategies optimising water uptake	Direct uptake of dew, condensed fog and water vapour Fast formation of water roots after first rain Halophytes: uptake of saline water, high salt tolerance, salt-excreting glands	Direct and indirect uptake of dew, condensed fog and water vapour (e.g. arthropods, water enrichment of stored food) Fast drinking of large quantities of water (large mammals), uptake of water from wet soil (e.g. snails) Uptake of highly saline water, high salt tolerance, salt-excreting glands
Strategies to control reproduction in relation to environmental conditions	'Water clocks' of seed dispersal and germination Suppression of flowering and sprouting in extreme years	Sexual maturity, mating and birth synchronised with favourable conditions Sterility in extreme drought years

* Cryptobiosis: an ametabolic state of life in response to adverse environmental stress; when the environment becomes hospitable again, the organism returns to its metabolic state.

Temperature adaptations

Desert plants and animals are able to function at higher temperatures than their mesis (moist environment) counterparts. Some cacti such as the prickly pear can survive up to 65 °C, while crustose lichens can survive up to 70 °C. The upper lethal levels for animals are lower, although arthropods, particularly beetles and scorpions, can tolerate 50 °C. Plants and animals are able to modify the heat of the desert environment in a number of ways:

- Changing the orientation of the whole body enables the organism to minimise the areas and/or time they are exposed to maximum heat – many gazelle, for example, are long and thin.
- Light colours maximise reflection of solar radiation.
- Surface growth (spines and hairs) can absorb or reflect heat, which **a** keeps the undersurface cooler and **b** creates an effective boundary layer of air, which insulates the underlying surface.
- Body size is especially important in controlling the amount of heat loss – evaporation and metabolism

are proportional to the surface area of the plant or animal. The smaller the organism, the larger the surface area to volume ratio and the greater the heat loss.

- Large desert animals such as the camel and the oryx can control heating by means of evaporative cooling. Cooling by transpiration is also thought to be most effective in cacti and small-leaved desert shrubs because of their surface-area-to-volume ratio.

Water loss

Physical droughts refer to water shortages over an extended period of time. **Physiological drought** occurs when drought conditions are experienced by plants despite there being sufficient soil moisture. In hot arid areas, this is associated with high rates of evapotranspiration. To reduce water loss, desert plants and animals have many adaptations. Again, a small surface-area-to-volume ratio is an advantage (Figure 10.16b). Water regulation by plants can be controlled by diurnal closure of stomata, and xerophytic plants have a mix of thick, waxy cuticles, sunken stomata and leaf hairs (Figure 10.16e). The most drought-resistant plants are the **succulents**, including cacti, which possess well-developed storage tissues (Figure 10.16a); small surface-to-volume ratios and rapid stomatal closure especially during the daytime; deep tap roots (Figure 10.16b and 10.16c); and very small leaves (Figure 10.16d).

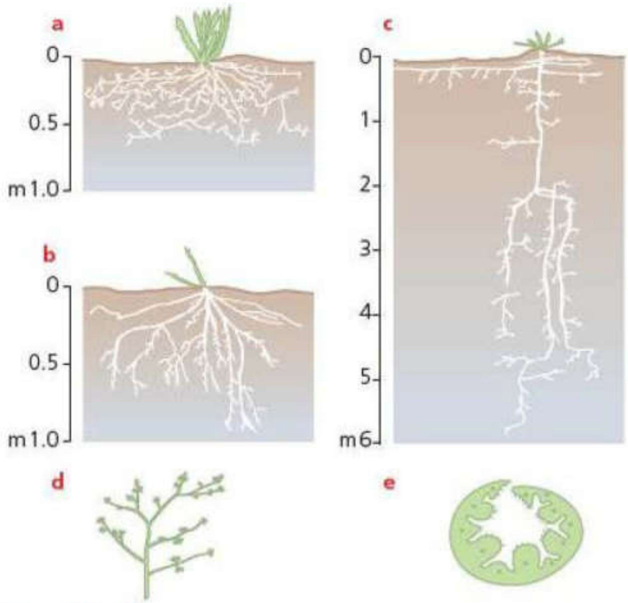


Figure 10.16 Plant adaptations to drought

Some plants and many arthropods are drought-resistant. The creosote bush can survive up to a year without rain. Rapid uptake of water is also a characteristic of many desert organisms, including lichen, algae and camels. Animals can rapidly imbibe, and salt-tolerant plants have a high cell osmotic pressure that allows the efficient uptake of alkaline water. The roots of many desert plants can exert a greater suction pressure so they can extract water from fine water-retentive soils.

Reproduction

Desert survival is also dependent on an organism's ability to reproduce itself. Desert fauna and flora have developed several different strategies. High seed production and efficient dispersal are more essential than in humid environments. Some seeds have built-in 'water clocks' and will not germinate until a certain amount of water becomes available. Some arid-zone shrubs, such as the ironwood and the smokewood, have seeds with coats so tough that germination can only take place after severe mechanical abrasion during torrential flash floods. In both plants and animals, reproduction is suppressed during periods of drought.

Desert soils

Desert soils, called **aridisols**, have a low organic content and are only affected by limited amounts of leaching. Soluble salts tend to accumulate in the soil either near the water table or around the depth of moisture percolation. As precipitation declines, this horizon occurs nearer to the surface. Desert soils also have a limited clay content. In semi-arid areas, there is a deeper soil, more chemical weathering and more biomass in the soil, due to the higher rainfall.

The accumulation of salt in desert soils is important. Salt concentrations may be toxic to plants. This is more likely in areas where there is a high water table or in the vicinity of salt lakes. Soils with a saline horizon of NaCl (sodium chloride) are called **solonchaks** and those with a horizon of Na_2CO_3 (sodium carbonate) are termed **solonetz**. Solonchaks are white alkali soils, whereas solonetz are black alkali soils. A high concentration of salt can cause the breakdown of soil structure, increase water stress and affect the health of plants.

Sometimes the concentration of salts becomes so great that crusts are formed on the surface or sub-surface. There are different types of hard crust (duricrusts). Calcrete or caliche is formed of calcium carbonate and is the most common crust in warm desert environments. It can be up to 40 metres, comprising boulders, gravels, silt and calcareous materials. It predominates in areas of between 200 and 500 millimetres.

Silcrete is a crust cemented by silica. It may produce an impermeable hard pan in a soil. Silcretes are found in areas that have more than 50 millimetres but less than 200 millimetres of rain, such as southern Africa and Australia.

Section 10.3 Activities

1 Describe the ways in which plants have adapted to drought, as shown in Figure 10.16.
2 Describe and explain the main characteristics of desert soils.

Case Study: Salinisation in Pakistan

Irrigation has been practised in Pakistan since at least the eighth century CE. Much of the irrigation takes place along the Indus and Punjab rivers. The irrigation system here is among one of the most complex in the world, and provides Pakistan with most of its food and commercial crops, such as wheat, cotton, rice, oil seed, sugar cane and tobacco. Hence the health of the irrigated area is essential to the health of the national economy.

Many of the drainage canals are in a poor state. Many are unlined and seepage is a major problem. Consequently, there has been a steady rise in the water table, which has caused widespread waterlogging and **salinisation**. Up to 40 000 hectares of irrigated land are lost annually.

There have been attempts to rectify the problem. Two main methods are used: pumping water from aquifers (to reduce the water table) and vertical and horizontal drainage of saline water. These have met with some success. In parts of the lower Indus plain, water tables have been reduced by as much as 7 metres, and up to 45 per cent of saline soils have been reclaimed. However, the use of reclaimed land for agriculture only results in salinisation again.

Desertification

Desertification is defined as land degradation in humid and semi-arid areas; that is, not including non-desert (arid) areas. It involves the loss of biological and economic productivity and it occurs where climatic variability (especially rainfall) coincides with unsustainable human activities (Figure 10.17). For example, if the surface cover is removed and the surface colour becomes lighter, its reflectivity (albedo) changes. It reflects more heat, absorbs less, and so there will be less convectional heating, less rain and possibly more drought. Desertification occurs in discontinuous and isolated patches – it is not the general extension of deserts as a consequence of natural events like prolonged droughts, as in China in the 2000s.

Desertification leads to a reduction in vegetation cover and accelerated soil erosion by wind and water, lowering the carrying capacity of the area affected. Desertification is one of the major environmental issues in the world today. At present, 25 per cent of the global land territory and nearly 16 per cent of the world's population are threatened by desertification.

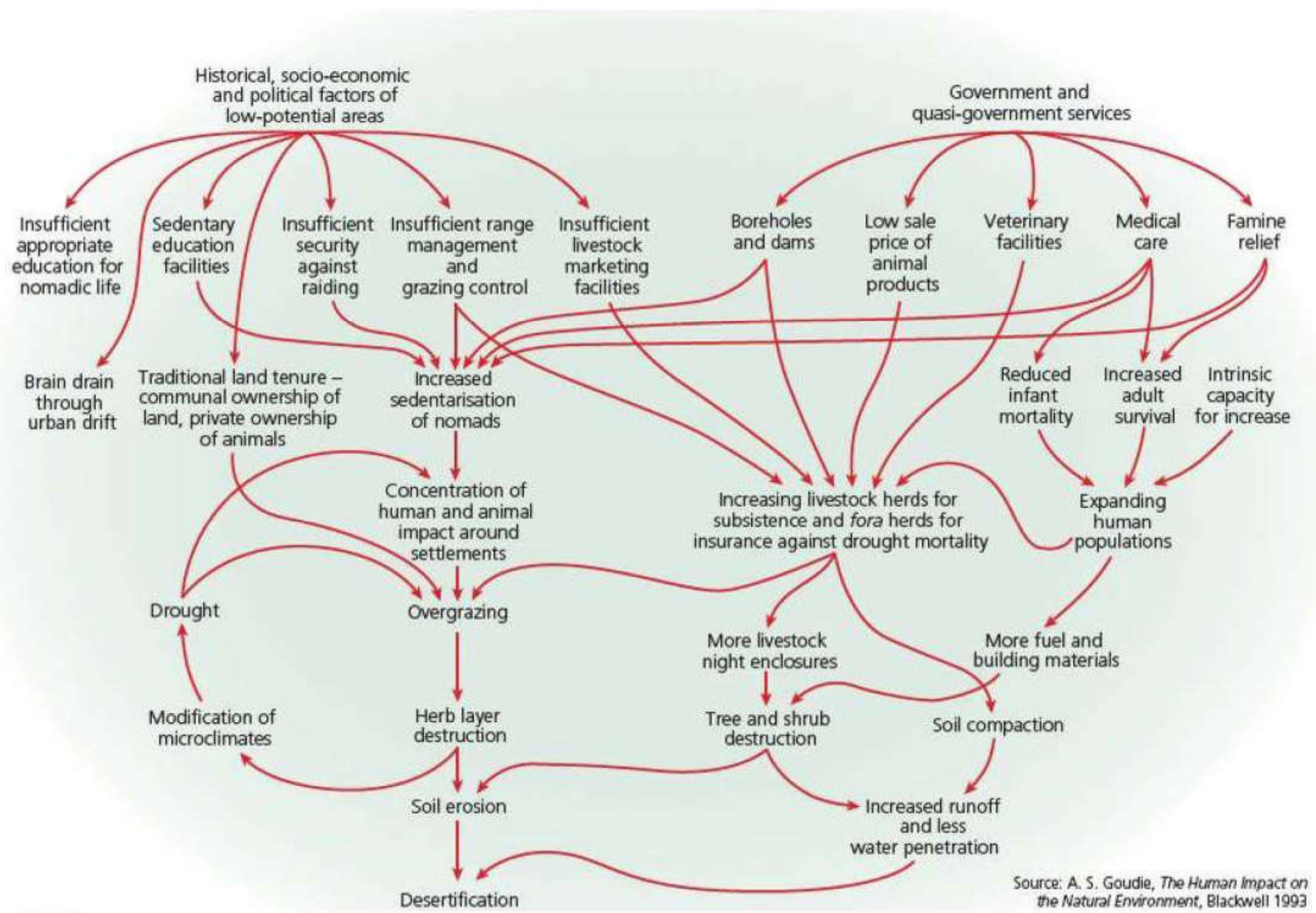


Figure 10.17 A model of desertification

Causes of desertification

Desertification can be a natural process intensified by human activities. All the areas affected by desertification are marginal and characterised by highly variable rainfall. An exception to this are the parts of the rainforest desertified following inappropriate farming techniques.

Natural causes of desertification include temporary drought periods of high magnitude and long-term climate change towards aridity. Many people believe that it is a combination of increasing animal and human population numbers, which causes the effects of drought to become more severe. Desertification occurs when already fragile land in arid and semi-arid areas is over-exploited. This overuse can be caused by overgrazing, when pastoralists allow too many animals to graze on a fixed area of land; overcultivation, where the growing of crops exhausts soil nutrients; and deforestation, when too few trees are left standing after use as firewood, to act as windbreaks or to prevent soil erosion.

- **Overgrazing** is the major cause of desertification worldwide. Vegetation is lost both in the grazing itself and in being trampled by large numbers of livestock. Overgrazed lands then become more vulnerable to erosion as compaction of the soils reduces infiltration, leading to greater runoff, while trampling increases wind erosion. Fencing, which confines animals to specific locations, and the provision of water points and wells, have led to severe localised overgrazing. Boreholes and wells also lower the water table, causing soil salinisation.
- **Overcultivation** leads to diminishing returns, where the yield decreases season by season, requiring an expansion of the areas to be cultivated simply to maintain the same return on the agricultural investment. Reducing fallow periods and introducing irrigation are also used to maintain output, but all these contribute to further **soil degradation** and erosion by lowering soil fertility and promoting salinisation.
- **Deforestation** is most obvious where land has been cleared to extend the area under cultivation and in the surrounds of urban areas where trees are stripped for firewood. The loss of vegetation cover increases rainsplash erosion, and the absence of root systems allows easy removal of the soil by wind and water.

Other factors are involved, including the following:

- The mobility of some people has been limited by governments, especially where their migratory routes crossed international boundaries. Attempts to provide permanent settlements have led to the concentration of population and animals, with undesirable consequences.
- Weak or non-existent laws have failed to provide environmental protection for marginal land by preventing or controlling its use.
- Irrational use of water resources has caused water shortages or salinisation of soil.
- International trade has promoted short-term exploitation of land by encouraging cash crops for export. This has disrupted local markets and created a shortage of staple foods.
- Civil strife and war diverts resources away from environmental issues.
- Ignorance of the consequences of some human actions, and the use of inappropriate techniques and equipment, have contributed to the problem.

Consequences of desertification

There are some serious consequences of desertification (Table 10.6).

Table 10.6 Consequences of desertification

Environmental	Economic	Social and cultural
• Loss of soil nutrients through wind and water erosion • Changes in composition of vegetation and loss of biodiversity as vegetation is removed • Reduction in land available for cropping and pasture • Increased sedimentation of streams because of soil erosion and sediment accumulations in reservoirs • Expansion of area under sand dunes	• Reduced income from traditional economy (pastoralism and cultivation of food crops) • Decreased availability of fuelwood, necessitating purchase of oil/kerosene • Increased dependence on food aid • Increased rural poverty	• Loss of traditional knowledge and skills • Forced migration due to food scarcity • Social tensions in reception areas for migrants

Combating desertification

There are many ways of combating desertification, which depend on the perceived causes (Table 10.7).

Table 10.7 The strategies for preventing desertification, and their disadvantages

Cause of desertification	Strategies for prevention	Problems and drawbacks
Overgrazing	• Improved stock quality: through vaccination programmes and the introduction of better breeds, yields of meat, wool and milk can be increased without increasing the herd size. • Better management: reducing herd sizes and grazing over wider areas would both reduce soil damage.	• Vaccination programmes improve survival rates, leading to bigger herds. • Population pressure often prevents these measures.
Overcultivation	• Use of fertilisers: these can double yields of grain crops, reducing the need to open up new land for farming. • New or improved crops: many new crops or new varieties of traditional crops with high-yielding and drought-resistant qualities could be introduced. • Improved farming methods: use of crop rotation, irrigation and grain storage can all increase and reduce pressure on land.	• Cost to farmers. • Artificial fertilisers may damage the soil. • Some crops need expensive fertiliser. • Risk of crop failure. • Some methods require expensive technology and special skills.
Deforestation	• Agroforestry: combines agriculture with forestry, allowing the farmer to continue cropping while using trees for fodder, fuel and building timber. Trees protect, shade and fertilise the soil. • Social forestry: village-based tree-planting schemes involve all members of a community. • Alternative fuels: oil, gas and kerosene can be substituted for wood as sources of fuel.	• Long growth time before benefits of trees are realised. • Expensive irrigation and maintenance may be needed. • Expensive. Special equipment may be needed.

Section 10.3 Activities

1 Suggest a definition for the term *desertification*.
2 Outline the main natural causes of desertification.
3 Briefly explain two examples of desertification caused by people.
4 Comment on the effects of desertification.
5 To what extent is it possible to manage desertification?

Case Study: Desertification in China

Parts of China are among the most seriously desertified areas in the world. More than 27 per cent, or 2.5 million km², of the country comprises desert (whereas just 7 per cent of Chinese land feeds about a quarter of the world's population). China's phenomenal economic growth over the last ten years has been at a serious environmental cost. According to the China State Forestry Administration, the desert areas are still expanding by between 2460 and 10400 km² per year. Up to 400 million people are at risk of desertification in China – the affected area could cover as much as 3.317 million km² or 34.6 per cent of the total land area. Much of it is happening on the edge of the settled area – which suggests that human activities are largely to blame.

Causes of desertification

Desertification is widely distributed in the arid, semi-arid and dry sub-humid areas of north-west and northern China and western parts of the north-east of the country (Figure 10.18). Much of the country is affected by a semi-permanent high-pressure belt, which causes aridity. In addition, continental areas experience intensive thunderstorms, which can cause accelerated soil erosion. Drought plagues large parts of northern China. In addition to dry weather, human activities such as livestock overgrazing, cultivation of steep slopes, rampant logging and excessive cutting of branches for firewood are at the root of the crisis.

Figure 10.18 Desertification in China

- In the Inner Mongolia Autonomous Region, over 133 000 hectares of rangeland has been seriously degraded by overgrazing. The density of animals now exceeds the carrying capacity of the land.
- On the loess plateau, cultivation of steep slopes is the main cause of desertification. On slopes of less than 5°, the loss of topsoil per annum is about 15 tonnes/hectare. In contrast, on slopes of over 25° it rises to 120–150 tonnes/hectare. However, there is very little loss of soil on terraced slopes.
- Illegal collection of fuelwood and herbal medicines has removed more than one-third of vegetation in the Qaibam basin since the 1980s.

Rates and types of desertification

In China, the main types of desertification include sandy desertification caused by wind erosion; land degradation by water erosion; soil salinisation; and other land degradation caused by engineering construction of residential areas and communications, and industrial activities such as coal mining and oil extraction (Tables 10.8 and 10.9).

Table 10.8 Land in China desertified by different processes

Types of desertification	Area (km^2)	% of total
Wind erosion	379 600	44.1
Water erosion	394 000	45.7
Salinisation	69 000	8.3
Engineering construction	19 000	1.9
Total	**861 600**	**100.0**

Table 10.9 Soil degradation in China (million hectares)

		Negligible	Light	Moderate	Strong	Extreme
Water erosion	**Loss of topsoil**	15.8	105.9	44.9	3.8	0.2
	Terrain deformation	0.5	7.9	5.9	24.0	–
	Off-site effects	0.2	0.2	0.2	–	–
Wind erosion	**Loss of topsoil**	1.7	65.9	2.5	+	+
	Terrain deformation	+	7.2	5.5	57.9	–
	Off-site effects	+	2.0	6.5	0.2	–
Chemical deterioration	**Fertility decline**	32.4	31.7	4.8	–	–
	Salinisation	0.5	6.8	2.6	–	–
	Desertification	–	+	–	–	–
Physical deterioration	**Aridification**	–	23.7	–	–	–
	Compaction and crusting	–	0.5	–	–	–
	Waterlogging	3.8	–	–	–	–
Total degradation	**All types**	**55.0**	**251.9**	**72.9**	**86.0**	**0.25**

Note: (–) no significant occurrence; (+) less than 0.1 but more than 0.01 million hectares; for calculation of the totals (+) is equivalent to 0.05 million hectares.

Sandy desertification through wind erosion

In northern China, the main land degradation is sandy desertification caused by wind erosion, an area that covers about 379 600 km^2 and is mainly distributed in the arid and semi-arid zones where the annual rainfall is below 500 millimetres.

Sandy desertification in northern China has been caused mainly by irrational human economic activities, and the growth rate of desertified land increased from 1560 km^2/year during the 1950s to 2100 km^2/year between the mid-1970s and the late 1980s, and since the late 1980s has increased to 2460 km^2/year.

Desertification through water erosion

Soil loss through water erosion is the most serious land degradation in China. By a rough estimate, annual soil loss caused by water erosion has reached about 5 billion tonnes, of which about two-fifths pours into the seas.

Salinisation

About 69 000 km^2 of China's farmland has been salinised, mainly in the arid and semi-arid regions of north-west China and the sub-humid regions of the North China Plain.

Desertification caused by engineering construction

A new type of desertification has spread very quickly, with some large-scale projects such as the development of oilfields and mining; construction of residential areas; and communications. These developments have led to increased wind and water erosion.

Some consequences of desertification

Desertification brings many adverse impacts. It causes a decrease in farmland availability, declining crop productivity, falling incomes, disruptions to communications and may eventually cause out-migration. Desertification also causes an increase in sandstorms, silting of rivers and reservoirs and increased soil erosion.

- Desertification causes annual direct economic losses valued at US$6.5 billion.
- In the north-west, where the problems are the biggest, desertification has escalated rapidly (see above).
- Each year, another 180 000 hectares of farmland in China is salinised, causing productivity to fall by 25–75 per cent, and about 200 000 hectares turns into desert; about 2 million hectares of pasturage are degraded each year.
- Erosion claims about 5 billion tonnes of China's topsoil each year, washing away nutrients equivalent to 54 million tonnes of chemical fertiliser – twice the amount China produces in a year.
- In the 1950s, dust storms affected Beijing once every seven or eight years, and only every two or three years in the 1970s. By the early 1990s, dust storms were an annual problem.

- Desertification has led to a heavy loss of land in pastoral, dry farming areas in northern China and in hilly areas in southern China.
- The government fears that encroaching sands will reach Beijing by the year 2035 as any serious drought turns farmlands into dunes in northern parts of the country, just 100 kilometres away. These dunes are advancing at a rate of 3.5 kilometres a year.

Possible solutions

The China National Research and Development Centre on Combating Desertification (RDCCD) was established to assist the government in implementing the UN Convention to Combat Desertification, which was established to enable China and other countries to combat desertification by developing profitable techniques and environmentally improved practices, and to meet the needs of poverty alleviation.

There are a number of effective measures that can be taken to combat desertification (Table 10.10).

Table 10.10 Methods of combating desertification

Method	Description
Fixing sand by planting	Effective; economic – source of additional fuel and forage
Fixing sand by engineering	Cover sand with straw, clay, pebbles, branches – used successfully along railways, motorways and near cities
Fixing sand using chemical methods	Create a protective layer over the sand – used in areas of high economic value such as airports and railways
Water-saving techniques	Spray irrigation, drip irrigation, prevention of seepage in channels, water transport in pipes
Integrated water management	Terraces, check dams, silt arresters

In 1978, China implemented a forest shelterbelt development programme in its northern, north-western and north-eastern regions, where 16 million hectares of plantations were established, which increased the forest cover from 5 per cent to 9 per cent. It also brought 10 per cent of the desertified land under control and protected 11 million hectares of farmland. In 1991, this was extended as a nationwide campaign.

To protect Beijing, the government issued a ban on the foraging and distribution of three wild plants – facai, liquorice and ephydra – grown in the country's dry western regions. It also plans to build a second green belt of forest around Beijing to achieve a forest coverage of 49.5 per cent by 2020.

Major problems in combating desertification

China is a developing country, and as economic growth exerts great pressure on its funds, the state input to combat desertification is limited. In addition:

- Public awareness needs to be raised, and education regarding desertification improved.
- Legislation is incomplete and the legal enforcement system is imperfect.
- The speed at which desertification is being tackled lags behind the rate of development.
- There is a shortage of funds to combat desertification.

Conclusions

China suffers as a result of desertification. This is the result of a combination of natural reasons and human ones. Economic growth and population pressure are placing a great strain on China's environment. Nevertheless, there have been a number of strategies to tackle desertification, and some of these have had impressive results. However, despite these successes, the rate of desertification appears to be exceeding the rate of environmental restoration. Unless China can tackle its desertification problem, there will be an increase in problems related to its overall development and standards of living.

Section 10.3 Activities

1 Outline **a** the causes and **b** the impacts of desertification in China.
2 To what extent is it possible to manage desertification in China?

Soil degradation

Soil degradation is the decline in quantity and quality of soil. It includes:

- erosion by wind and water
- biological degradation – for example, the loss of humus and plant/animal life
- physical degradation – loss of structure, changes in permeability
- chemical degradation – acidification, declining fertility, changes in pH
- salinisation
- chemical toxicity.

Causes of degradation

The universal soil loss equation (USLE) A = RKLSCP is an attempt to predict the amount of erosion that will take place in an area on the basis of certain factors that increase susceptibility to erosion (Table 10.11).

The complexity of soil degradation means that it is hard to make a single statement about its underlying causes. Soil degradation encompasses several issues at various spatial and time scales (Figure 10.19):

- **Water erosion** – water erosion accounts for about 60 per cent of soil degradation; there are many types of erosion, including surface, gully, rill and tunnel erosion.

Table 10.11 Factors relating to the universal soil loss equation

Factor	Description
Ecological conditions	
Erosivity of soil R	Rainfall totals, intensity and seasonal distribution. Maximum erosivity occurs when the rain falls as high-intensity storms. If such rain is received when the land has just been ploughed or full crop cover is not yet established, erosion will be greater than when falling on a full canopy. Minimal erosion occurs when rains are gentle, and fall onto frozen soil or land with natural vegetation or a full crop cover.
Erodibility K	The susceptibility of a soil to erosion. Depends on infiltration capacity and the structural stability of soil. Soils with a high infiltration capacity and high structural stability that allow the soil to resist the impact of rainsplash have the lowest erodibility values.
Length–slope factor LS	Slope length and steepness influence the movement and speed of water down the slope, and thus its ability to transport particles. The greater the slope, the greater the erosivity; the longer the slope, the more water is received on the surface.
Land-use type	
Crop management C	Most control can be exerted over the cover and management of the soil, and this factor relates to the type of crop and cultivation practices. Established grass and forest provide the best protection against erosion and, of agricultural crops, those with the greatest foliage and thus greatest ground cover are optimal. Fallow land or crops that expose the soil for long periods after planting or harvesting offer little protection.
Soil conservation P	Soil conservation measures can reduce erosion or slow the runoff of water, such as contour ploughing and use of bunds, strips and terraces.

Source: adapted from Hugget et al, Physical Geography – a Human Perspective, *Arnold 2004*

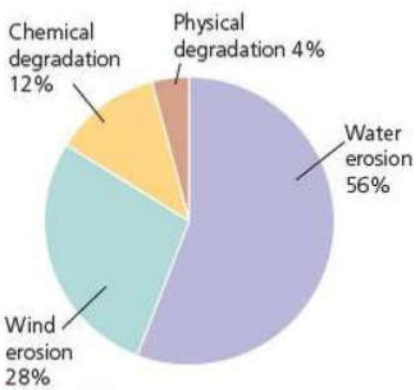


Figure 10.19 Types of soil degradation

- **Wind erosion** involves removal of material, especially of fine-grained loess and silt-sized materials or smaller.
- **Acidification** is the change in the chemical composition of the soil, which may trigger the circulation of toxic metals.
- **Eutrophication** (nutrient enrichment) may degrade the quality of groundwater; over-abstraction of groundwater may lead to dry soils.
- **Salt-affected soils** are typically found in marine-derived sediments, coastal locations and hot arid areas where capillary action brings salts to the upper part of the soil; soil salinity has been a major problem in Australia following the removal of vegetation for dryland farming.
- **Atmospheric deposition** of heavy metals and persistent organic pollutants may change soils so that they become less suitable to sustain the original land cover and land use.
- **Climate change** will probably intensify the problem; it is likely to affect hydrology and hence land use.

Climate change, higher average temperature and changing precipitation patterns may have three direct impacts on soil conditions. The higher temperatures cause higher decomposition rates of organic matter. Organic matter in soil is important as a source of nutrients and it improves moisture storage. More floods will cause more water erosion, while more droughts will cause more wind erosion.

Besides these direct effects, climate change may:

- create a need for more agricultural land to compensate for the loss of degraded land
- lead to higher yields for the major European grain crops due to the carbon dioxide fertilisation – the increase in carbon dioxide in the atmosphere leads to increased plant growth by allowing increased levels of photosynthesis.

These two indirect effects appear to balance out.

Human activities

Human activities have often led to degradation of the world's land resources (Figure 10.20 and Table 10.12). A global assessment of human-induced soil degradation has shown that damage has occurred on 15 per cent of the world's total land area (13 per cent light and moderate; 2 per cent severe and very severe). These impacts frequently lead to a reduction in yields. Land conservation and rehabilitation are essential parts of sustainable agricultural development. While severely degraded soil is found in most regions of the world, the negative economic impact of degraded soil may be most severe in countries that are most dependent on agriculture for their income.

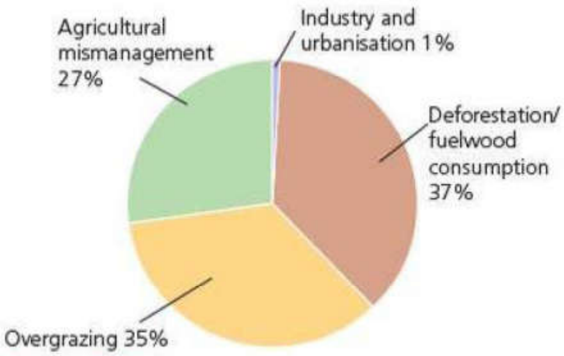


Figure 10.20 Causes of soil degradation

Table 10.12 Human activities and their impact on soil erosion

Action	Effect
Removal of woodland or ploughing established pasture	The vegetation cover is removed, roots binding the soil die and the soil is exposed to wind and water. Particularly susceptible to erosion if on slopes.
Cultivation	Exposure of bare soil surface before planting and after harvesting. Cultivation on slopes can generate large amounts of runoff and create rills and gullies.
Grazing	Overgrazing can severely reduce the vegetation cover and leave the surface vulnerable to erosion. Grouping of animals can lead to overtrampling and creation of bare patches. Dry regions are particularly susceptible to wind erosion.
Roads or tracks	They collect water due to reduced infiltration that can cause rills and gullies to form.
Mining	Exposure of the bare soil.

Managing soil degradation

Abatement strategies, such as afforestation, for combating accelerated soil erosion are lacking in many areas. To reduce the risk of soil erosion, farmers are encouraged towards more extensive management practices such as organic farming, afforestation, pasture extension and benign crop production. Nevertheless, there is a need for policy-makers and the public to intensify efforts to combat the pressures on and risks to the soil resource.

Methods to reduce or prevent erosion can be mechanical, for example physical barriers such as embankments and windbreaks, or they may focus on vegetation cover and soil husbandry. Overland flow of water can be reduced by increasing infiltration.

Mechanical methods include building bunds, terracing, contour ploughing and planting shelterbelts (trees or hedgerows). The key is to prevent or slow the movement of rainwater downslope. Contour ploughing takes advantage of the ridges formed at right-angles to the slope, which act to prevent or slow the downward accretion of soil and water. On steep slopes and those with heavy rainfall, such as areas in South East Asia that experience the monsoon, contour ploughing is insufficient and so terracing is practised. The slope is broken up into a series of level steps, with bunds (raised levees) at the edge. The use of terracing allows areas to be cultivated that would not otherwise be suitable. In areas where wind erosion is a problem, shelterbelts of trees or hedgerows are used. The trees act as a barrier to the wind and disturb its flow. Wind speed is reduced, which therefore reduces its ability to disturb the topsoil and erode particles.

Preventing erosion by different cropping techniques largely focuses on:

- maintaining a crop cover for as long as possible
- keeping in place the stubble and root structure of the crop after harvesting
- planting a grass crop.

A grass crop maintains the action of the roots in binding the soil, minimising the action of wind and rain on a bare soil surface. Increased organic content allows the soil to hold more water, thus preventing aerial erosion and stabilising the soil structure. In addition, care is taken over the use of heavy machinery on wet soils and ploughing on soils sensitive to erosion, to prevent damage to the soil structure.

There are three main approaches in the management of salt- and chemical-affected soils:

- flush the soil and leach the salt away
- apply chemicals, for example gypsum (calcium sulphate), to replace the sodium ions on the clay and colloids with calcium ones
- reduce evaporation losses in order to limit the upward movement of water in the soil.

Soil degradation is a complex issue. It is caused by the interaction of physical forces and human activities. Its impact is increasing and it is having a negative effect on food production. Some areas are more badly affected than others, but in a globalised world the impacts are felt worldwide. The methods of dealing with soil degradation depend on the cause of the problem, but also on the resources available to the host country. Degradation is a problem that is not going to go away and is likely to increase over the next decades as population continues to grow, and people use increasingly marginal areas.

Section 10.3 Activities

1. Explain the meaning of the term *soil degradation*.
2. Outline the natural causes of soil degradation.
3. a Comment on the human causes of soil degradation.
   b To what extent is it possible to manage soil degradation?
4. Study Table 10.13, which shows annual soil losses from a small catchment in the Lake Victoria basin.
   a Describe how the range of soil loss varies with the type of land cover.
   b Suggest reasons for the patterns you have identified in a.

Table 10.13 Annual soil losses from a small catchment in the Lake Victoria basin

Land use	Land cover (%)	Range of soil loss (tonnes/ha/year)
Annual cropland	6	65–93
Rangeland	15	42–68
Bananas/Coffee	63	36–47
Bananas	6	22–32
Forest	1	0
Papyrus marsh	9	0

10.4 Sustainable management of hot arid and semi-arid environments

Sustainable management is management that meets the needs of the present generation without compromising the ability of future generations to meet their own needs. It is a process by which human potential (quality of life) is improved and the environment (resource base) is used and managed to supply humanity on a long-term basis.

Nearly three-quarters of the world's drylands are degraded and it has been estimated that desertification costs an estimated $42 million each year. Are there sustainable options for the world's drylands?

☐ Changing land-use trends

Case Study: Game farming in the Eastern Cape province of South Africa

A shift from pastoralism to **game farming** has been identified in the Eastern Cape province of South Africa since the 1980s (Figure 10.21). Examples include Bushbuck Ridge Game Farm, AddoAfrique Estate and Kichaka Lodge. In some cases, this change has been made by private landowners to diversify their operations. In other cases, private landowners have removed all stock and replaced it with game. In a survey of the Eastern Cape region of South Africa, it was found that 2.5 per cent of the study area had converted entirely from stock to game farming. A total of 41 game species was recorded on the 63 game farms surveyed. Most farmers expressed a positive attitude towards game farming and are trying to implement conservation measures. The main activity for which game is utilised is hunting – both recreational and trophy hunting. The foreign ecotourist and the hunting market have been strong driving forces behind the introduction of **extra-limital** (non-native) species to the region.

Figure 10.21 Location of the Eastern Cape province of South Africa

This change in land use has drawn the attention of scientists worldwide, and specifically with reference to desertification of rangelands. Desertification currently affects about one-sixth of the world's population and 70 per cent of all drylands, which amounts to 3.6 billion hectares. Widespread poverty is one of the key impacts of desertification.

In South Africa, the thicket vegetation of the Eastern Cape has been recognised as being particularly vulnerable to degradation, due mainly to years of overgrazing. Over 95 per cent of this vegetation is under threat from overgrazing by domestic stock; bush clearing for agriculture and urban development; coastal resort development; and invasion by alien vegetation.

The average game farm size is 4496 hectares. Most of the game farms are concentrated in the south and central regions of the Eastern Cape. Land-use changes first started to occur in the 1970s, and were characterised by two basic trends that included either the landowners themselves changing from being stock farmers to game farmers, or investors purchasing stock farms and financing their conversion to game farms.

Utilising game has provided an important secondary income to most mixed farmers. The impetus behind the growing game industry can be attributed to a number of socio-political, economic and ecological motivations. For example:

- Recently changed labour legislation stipulates increased wages for workers on farms. This has made landowners regard game farming as an alternative to stock farming, as it is considered to be potentially less labour-intensive than traditional stock farming.
- Increased stock theft, especially of small domestic stock, has rendered stock farming economically less viable.
- Vermin such as the jackal and caracal sometimes come from adjacent game farms' statutory reserves and this has resulted in increased stock losses.
- Decades of overgrazing has led to rangeland degradation, thereby reducing livestock production. By (re)introducing (indigenous) game species that are better adapted to their

natural environment, periodic droughts can be survived both economically and demographically.

- Game is considered to contribute, in the long term, to **veld** restoration (rather than its degradation).
- There is good potential for foreign exchange earnings from trophy hunting and tourism.

A total of 41 game species were recorded on the 63 farms surveyed. The high diversity that was recorded was not, however, found on any single farm. Rather, 11–15 species occurred on a third of the game farms, with only five game farmers maintaining more than 20 species.

Game farming has been described as a potential ecologically sustainable form of land use, but the introduction of extra-limital species may threaten this state. In order to guarantee tourist satisfaction, farmers have found it necessary to erect game-proof fences around their farms with the purpose of introducing 'hunting' or 'tourist' species, whether indigenous or extra-limital. Kudu and bushbuck, both indigenous to thicket vegetation, are among the most desired hunting species in the Eastern Cape. Promotion of these animals as hunting species may promote ecologically sound farming practices, without the introduction of extra-limital species.

There is also the ecological risk of allowing certain species to hybridise by keeping such species in the same fenced area. Some farmers in the survey had both blue and black wildebeest species on their property, and some had both Blesbok and Bontebok antelope; both pairs of species have the ability to hybridise.

Section 10.4 Activities

1 Define *sustainable development*.
2 To what extent is game farming a form of sustainable development? Justify your views.

Case Study: The establishment of drought-resistant fodder in the Eastern Cape

Pastureland in the Eastern Cape is especially fragile due to drought and overgrazing (Figures 10.22 and 10.23). In the former homelands Ciskei and Transkei, there are additional problems of population pressure and, sometimes, the absence of secure land-ownership policies. During periods of prolonged drought, levels of cattle, sheep and goats decrease significantly. However, trying to decrease herd size has proved unpopular and unsuccessful. An alternative is to produce drought-resistant **fodder crops** such as the American aloe and prickly pear, saltbrush and the indigenous gwanish.

Figure 10.22 Gully erosion due to overgrazing

Figure 10.23 Concentration of sheep at a waterhole – note the irrigation scheme in the background

The American aloe (Figure 10.24) has traditionally been used for fencing, for kraals (animal compounds) and for soil conservation, but has also been used as a fodder in times of drought. It has a number of advantages:

- It requires little moisture (annual rainfall in this region is around 450 mm).
- It is not attacked by any insects.
- Although low in protein, it raises milk production in cows.
- It can be used for soil conservation.
- After 10 years, it produces a pole that can be used for fencing or building.
- It can act as a windbreak.
- The juice of the aloe is used in the production of tequila.

Figure 10.24 American aloe

Saltbrush provides protein-rich fodder that is eaten by sheep and goats. Goats, in particular, thrive on saltbrush. It requires less than half the water need by other crops such as lucerne, and once established it requires no irrigation. It remains green throughout the year and therefore can provide all-year fodder. However, it is difficult to propagate and needs high-quality management.

The spineless cactus or prickly pear (Figure 10.25) features prominently in the agriculture of many countries, such as Mexico, Peru and Tunisia, where it is used as fodder and as a fruit crop for 2–3 months each year. This plant is becoming more widespread in the Eastern Cape. Two varieties are common: one, insect-resistant, is used as fodder in times of drought, while the other, which needs to be sprayed to reduce insect damage, yields high-quality fruit. The fruit is sold at prices comparable with apples and oranges. Pruning is needed annually. This provides up to 100 tonnes of fodder per hectare per year.

Figure 10.25 Prickly pear

In the former Ciskei region of the Eastern Cape, drought in the 1980s prompted the government to embark on a series of trials with prickly pear, saltbrush and American aloe in order to create more fodder. One of the main advantages of the prickly pear is its low water requirements. This makes it very suitable to the region where rainfall is low and unreliable. Although there are intensive irrigation schemes in the region, such as at Keiskammahoek, these are expensive and are inappropriate to the area and to the local people.

Although prickly pear is mainly used as a fodder and fruit crop, it is also used for the production of carminic acid for the cochineal dye industry and as a means of soil conservation. Nevertheless, prickly pear has been described by some development planners as a 'weed, the plant of the poor, a flag of misery ... inconsistent with progress'.

Section 10.4 Activities

1 Outline the advantages of the American aloe plant.
2 Comment on the advantages and disadvantages of using the prickly pear.

Case Study: Essential oils in the Eastern Cape

About 65 per cent of the world's production of essential oils is from LICs such as India, China, Brazil, Indonesia, Mexico, Egypt and Morocco. However, the USA is also a major producer of essential oils such as peppermint and other mints. The South African essential oils industry has only recently emerged in this area. Currently, the South African essential oils industry exports mainly to HICs in Europe (49 per cent), the USA (24 per cent) and Japan (4.5 per cent). The most significant essential oils produced by South Africa are eucalyptus, citrus, geranium and buchu.

Globally, the essential oils industry – valued at around $10 billion – is enjoying huge expansion. Opportunities include increasing production of existing products and extending the range of crops grown. Developing the essential oils industry in South Africa would achieve much-needed agricultural and agri-processing diversification in the province.

Currently, the South African essential oils industry comprises about 100 small commercial producers, of which less than 20 per cent are regular producers.

Several factors make South Africa an attractive essential oils market:

- Much of the demand is in the northern hemisphere and seasonal effects make southern hemisphere suppliers globally attractive.
- South Africa traditionally has strong trade links with Europe, as a major importer of fragrance materials.
- South Africa is being established as a world-class agricultural producer in a wide range of products.

The Eastern Cape is set to become one of the main contributors to South Africa's burgeoning essential oils industry, with 10 government-sponsored trial sites currently in development throughout the province. Six of these form part of the Essential Oil Project of Hogsback, where approximately 8 hectares of communal land are being used. A project at Keiskammahoek has been operational since 2006. These trials form part of a strategy to develop a number of essential oil clusters in the Eastern Cape.

The production of essential oils holds considerable potential as a form of sustainable agricultural development in the former Ciskei region of the Eastern Cape. Not only are the raw materials already here, but it is a labour-intensive industry and would employ a large number of currently unemployed and underemployed people.

The essential oils industry has a number of advantages:

- It is a new or additional source of income for many people.
- It is labour-intensive and local in nature.
- Many plants are already known and used by local people as medicines, and they are therefore culturally acceptable (Figure 10.26).
- In their natural state, the plants are not very palatable nor of great value and will not therefore be stolen.
- Many species are looked upon as weeds. Removing these regularly improves grazing potential as well as supplying raw materials for the essential oils industry.

Some species such as geranium, peppermint and sage require too much land, labour and water to be very successful. Wild als (*Artemesia afra*) is an indigenous mountain shrub, used for the treatment of colds. Its oil has a strong medicinal fragrance and is used in deodorants and soaps. Double

Figure 10.26 A herbalist's preparation table

cropping in summer when the plant is still growing and in autumn at the end of the growing season yields the best results. Demand for *Artemisia* has not outstripped the supply of naturally growing material but it is increasingly being cultivated as a second crop. It requires minimal input in terms of planting, tillage and pest control, and it is relatively easy to establish and manage. Moreover, it can stabilise many of the maize fields and slopes where soil erosion is a problem. The local people are very enthusiastic about growing it, especially when they are given appropriate economic incentives.

Khakibush or *Tagetes* is an aromatic. In the former Ciskei area, it is a common weed in most maize fields. Oil of tagetes is an established essential oil, although its market is limited. Local people are again quite enthusiastic about collecting khakibush if the incentives are there. Harvesting takes place over a period of up to three months and provides a great deal of extra employment, as well as eradicating a weed. At present, the supply of khakibush and those in the maize fields is sufficient to meet demand. An increase in demand might lead to the establishment of *Tagetes* as secondary crop in maize fields – not just as a 'weed'.

Section 10.4 Activities

1 Suggest why the essential oils industry has developed in the Eastern Cape province.
2 To what extent could the essential oils industry be considered a form of sustainable development?

Case Study: Developing sustainable farming in Egypt

The Nile provides Egypt with almost all of its water, 85 per cent of which goes to agriculture – but population growth and increased demands for water is putting a strain on water resources. Up to 95 per cent of Egypt's population lives in the Nile Valley and Delta, increasing the pressure on land resources. The same area accounts for the bulk of Egyptian food production. Although one-third of Egypt's annual share of the Nile is used for irrigation, it contains pollutants and pesticides from upstream countries and from Egypt itself. Since chemical pesticides were first introduced to Egypt in the early 1950s, a million tonnes have been released into the environment. To compound the matter, Ethiopia is building the Grand Ethiopian Renaissance Dam on the Blue Nile, which is likely to cut supplies of fresh water to Egypt.

However, Egypt is developing forms of sustainable agriculture. One of the leading individuals is Faris Farrag, who has developed aquaponics at his farm outside Cairo called 'Bustan' (Arabic for orchard). Aquaponics is an integrated form of farming that originated in Central America. It enables farmers to increase yields by growing plants and farming fish in the same closed freshwater system.

Bustan is the first commercial aquaponics farm in Egypt. Water circulates from tanks containing fish through hydroponic trays that grow vegetables including cucumber, basil, lettuce, kale, peppers and tomatoes. Each tank contains about a thousand tilapia fish, which are native to Egypt and are known for resisting slight water pH and temperature variations. Water from the pond is then used to water the olive trees that produce a high-quality olive oil. This organic and closed system mimics natural processes and enables waste to be efficiently reused. The fish tanks provide 90 per cent of the nutrients plants need to grow. The ammonia that results from the fish breathing is naturally transformed into nitrogen and absorbed by the plants before being sent back to the fish tanks, ammonia-free and healthy.

Just outside the fish tanks lies a large pond covered with a slimy layer of duckweed, a highly nutritious floating plant that is regularly scraped, dried and fed to the fish as vegetable protein.

Bustan uses 90 per cent less water than traditional farming methods in Egypt. It produces 6–8 tonnes of fish per year and can potentially yield 45 000 heads of lettuce if it were to grow just a single type of vegetable. Hydroponics can make lettuce grow 20 per cent faster than average.

Bustan is a labour-intensive farm and uses sustainable biological pest-control methods, such as ladybirds to kill aphids, in order to avoid chemical inputs. Farrag intends to establish a permaculture system by introducing chickens that would feed on compost and produce natural fertilisers for the soil.

This method of farming could serve as a means of income generation for unemployed women, as well as a means of education for sustainable farming. However, it is quite costly, especially for those on a low income. Inside Bustan, the pumps used to filter water require a source of energy, mainly oil. Farrag has invested more than $43 500 to develop this scheme.

Small hydroponic units could be established for rooftops, balconies and kitchens. Vertical and rooftop farming, in light of the country's serious water and food crisis, is also an effective way to grow organic food while cutting transportation costs, emissions and waste.

Section 10.4 Activities

Research Bustan online and watch a video clip. Find out about fish farms in the desert and rooftop farms in Cairo.