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 75per 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).

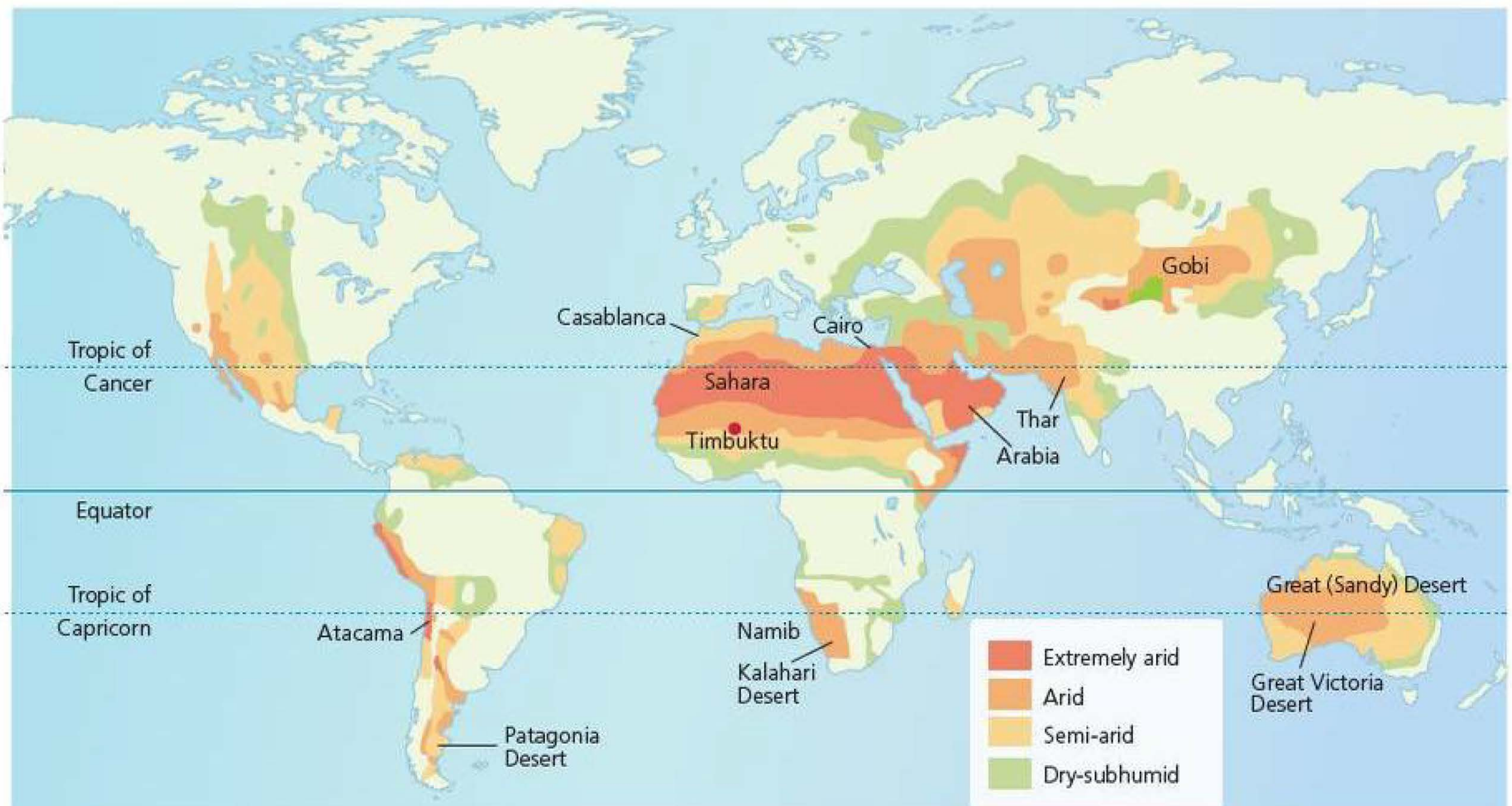

Figure 10.1 The global distribution of arid areas

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.

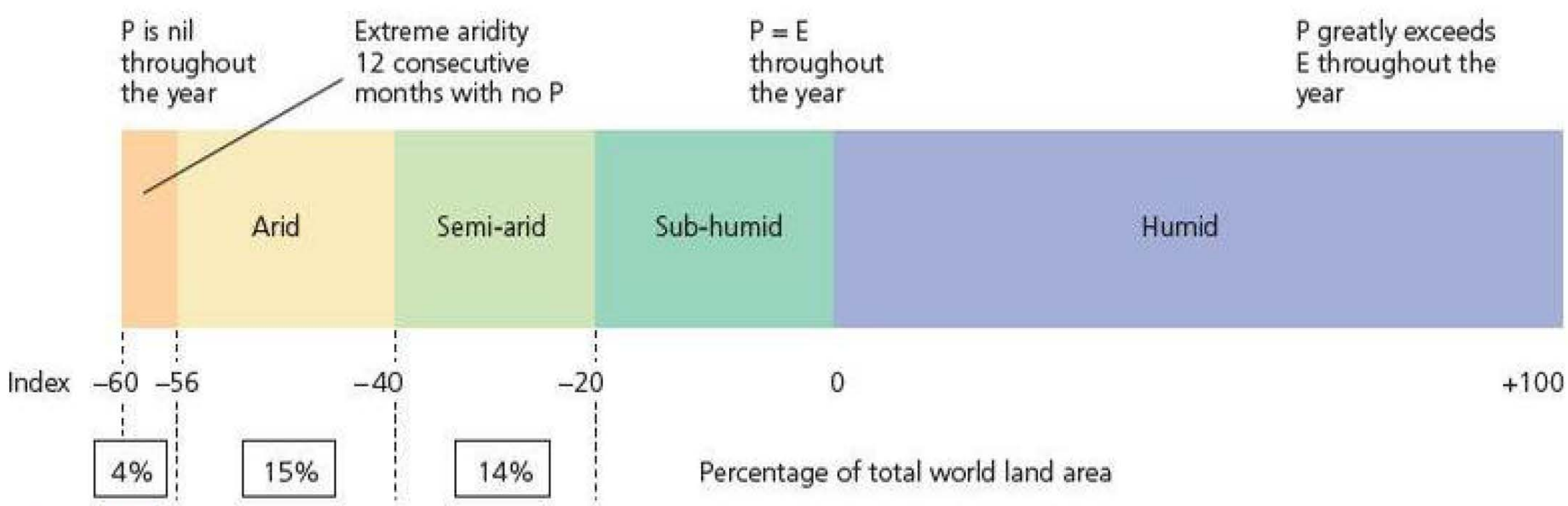

Figure 10.2 The index of aridity

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.

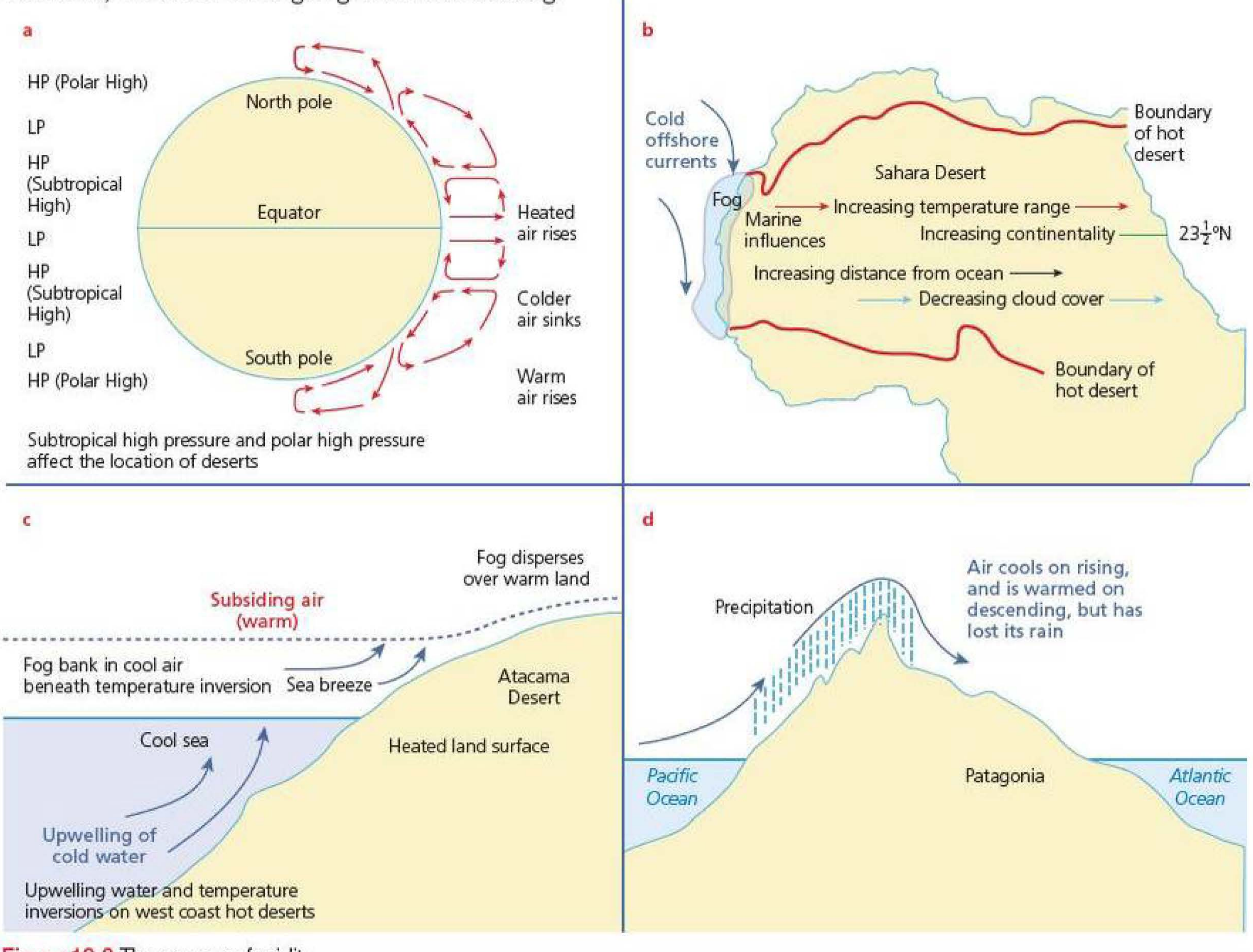

Figure 10.3 The causes of aridity

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**