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VCE GEOGRAPHY SERIES

3rd Edition

UNIT
1

Hazards and Disasters

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Hazards and Disasters

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Contents

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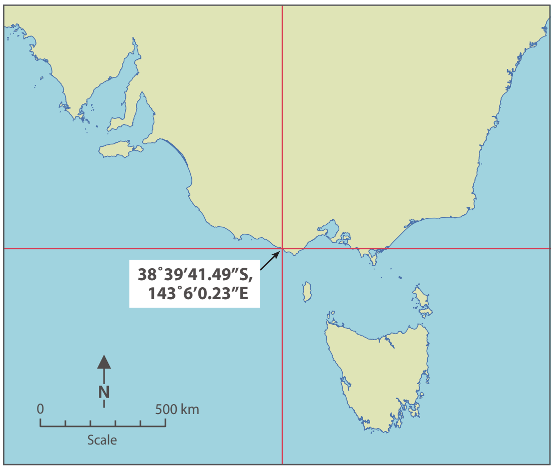
Geographical concepts and questions

Geographers investigate and interpret the *places* that make up our world by exploring, analysing and understanding their characteristics and the *processes* that shape them. Geographers use a number of concepts in this *process*. Concepts are the big, organising ideas which, together, uniquely belong to Geography as a field of study.

VCE Geography is underpinned by twelve interrelated key geographical concepts. These should form part of your vocabulary and guide you in your thinking, description, analysis, synthesis and communication in Geography. The concepts are used in conjunction with skills, and are applied to topics of study to create a uniquely geographical way of investigating and understanding the world.

In VCE Geography the twelve key geographical concepts are: *place*, *scale*, *distance*, *distribution*, *environment*, *interconnection*, *movement*, *region*, *change*, *process*, *spatial association* and *sustainability*. It will become clear through your work with the concepts in this chapter that they *interconnect* with, and support one another extensively.

The purpose of this chapter is to provide an understanding of, and some experience with, using key concepts that are important to the study of Geography, particularly as they relate to hazards and disasters. Your aim should be to understand and apply each concept as a means of thinking and working geographically.



▲ **Figure 1.1** A map showing the absolute location of a *place* – the Twelve Apostles

▲ **Figure 1.2** A *place* – the Twelve Apostles

Key geographical concepts in context

Place

'Where's your *place*?' It is a common enough question to ask someone where they live, but there is more behind this question than you might think. A reply might be as generic as a reference to a suburb, as specific as a street address, or (with the aid of a smartphone) even a latitude and longitude. The latter two are regarded as absolute locations, there being no other *place* on Earth that meets that locational definition. In addition, a six-figure grid reference from a topographic map will allow you to give an absolute location. Location is the 'where of *place*' and is an important component of *place* in its own right. Figure 1.1 shows the location 38°39'41.49" S latitude, 143°6'0.23" E longitude mapped – which, by itself, is rather meaningless. When it is linked with further information, such as the *place* shown in Figure 1.2, the absolute location takes on meaning and significance as one of Victoria's iconic landscapes. Even if you have never visited this *place*, it is likely to have meaning for you.

Relative location refers to the *distance* and direction from one *place* to another. The use of *place* names, landmarks and *regions* helps to specify the relative location of one *place* by comparing it to the location of another *place*.

Understanding a *place* relates to how people perceive and attach meaning to a location and its immediate surroundings; this creates their 'sense of *place*'. Though people may recognise the significance of the *place* as a home, the sense of *place* is naturally much greater for the person living there because of their direct attachment to, experiences in, and valuing of that *place*.

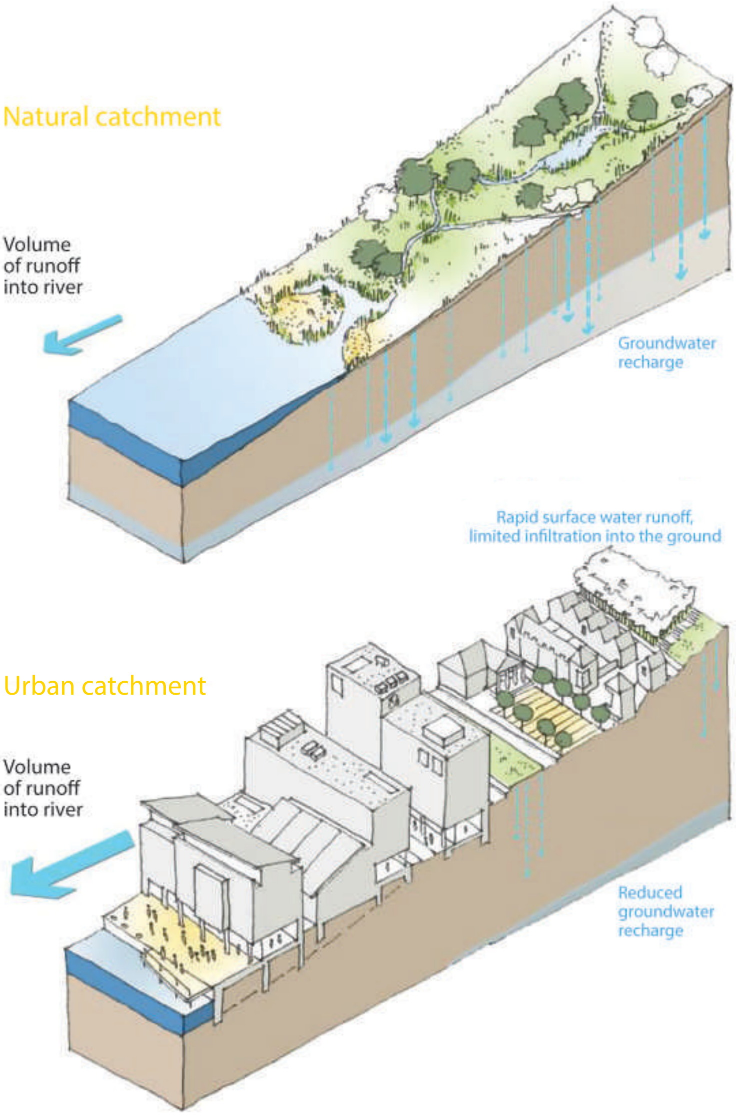
With the meaning of *places* comes value. A value could be the monetary value for a property, or a *place* could be valued for its aesthetic beauty, untouched remoteness or, for some people, a spiritual significance and attachment to *place* going back many generations.

Place is important when investigating hazards and disasters. Consider that a hazard event occurring where no-one lives may never actually become a disaster because no-one is affected. An unpopulated *place* that has value for other reasons, perhaps a national park containing sites of Indigenous or ecological significance, could be said to suffer a disaster if its value is reduced or lost because of some human or natural event.

The potential for hazard events to occur shapes people's perceptions of *places*, particularly in terms of liveability, especially where safety is concerned. People often adapt *places* to potential hazards and do their best to reduce their effects, as in bushfire-prone *regions*. People can also reduce the effects of flooding in cities and towns, but urbanisation often actually increases the size and frequency of flooding; seen in Figure 1.3.

Sometimes people are unaware of the hazards that *places* face, particularly if that hazard has not occurred itself as a disaster for a long period of time, or is linked to a one-off event. When a hazard occurs in a *place*, a disaster causing significant damage to property or loss of life can also occur, as shown in Figure 1.4.

▼ **Figure 1.3** Run-off to a river for a natural and urban catchment



The population of Beirut in Lebanon were unaware of the hazard the *place* faced due to the large amount of ammonium nitrate stored at the city's port. Due to the high population density of this *place*, the 4 August 2020 explosion caused a disaster with considerable deaths and injuries as well as damage to property. *Place*, together with its population and other contributing factors, is therefore a key consideration in what turns hazard events into disasters. Specifically, a hazard refers to the conditions that might in future contribute to a hazard event (in cases of significant harm this event is called a disaster). The risk refers to the likelihood of a disaster occurring (often referred to as a mathematical probability of occurring during a particular period such as a year or century). The disaster is when the hazard actually harms a significant number of people or their *environment*. In the Beirut case above, the hazard was storing explosive material in an unprotected building in a city, the risk was high because of many potential causes of ignition and high surrounding population density, and the hazard event was classified as a disaster because the explosion caused a large loss of life and injury as well as enormous damage to infrastructure.

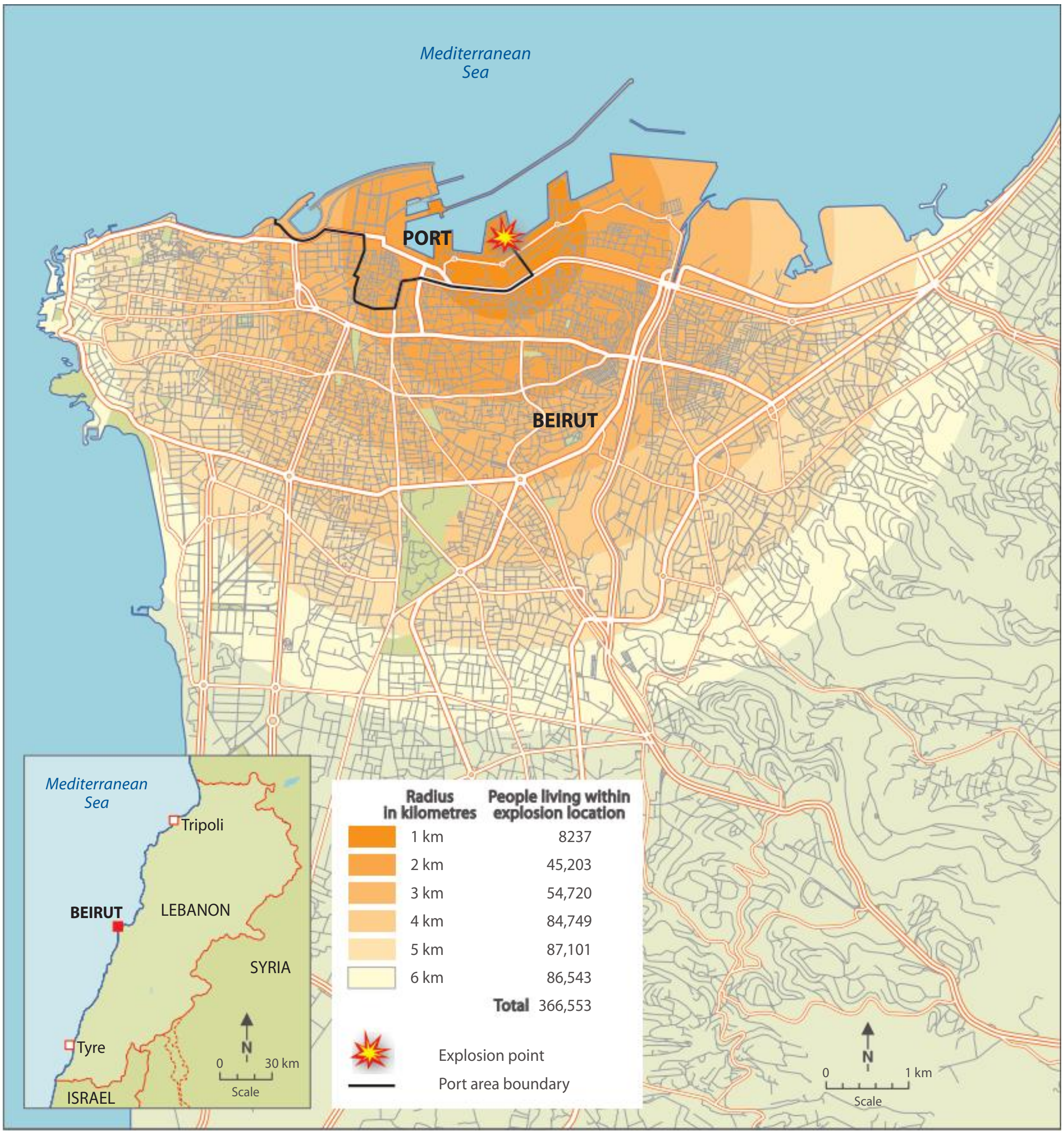


Figure 1.4 Location of the August 2020 Beirut explosion, Lebanon

Scale

Scale refers to the size of something compared with something else and is used in one of two practical ways in Geography.

In one sense, we use *scale* on maps to determine the size relationship between the reality of something on the Earth's surface and the size at which that thing can be represented on a much smaller map. The location of the fires that occurred in Australia 2019–2020 are shown by using three maps at different *scales* in Figure 1.5. The *scale* of a map influences how it can be used. Smaller-*scale* maps depict a larger area in less detail, often being useful to show an overview or context for what is being studied, such as the inset maps of Australia in Figure 1.5. Large-*scale* maps show smaller areas in greater detail. The main map in Figure 1.5 provides detail of the location and the extent of the area of these fires in relation to other features such as towns/settlements, state borders, national parks and mountain ranges and can be used to estimate *distances* and the extent and area of the fires with greater accuracy than the smaller-*scale* map.

Scale on a map can be expressed in various ways, as shown in Figure 1.6. Note that a ratio *scale* of 1:100,000 means that 1 centimetre on the map represents 100,000 centimetres on the Earth.

The second use of *scale* is observational. These are the logical and descriptive size-based units into which geographers divide the world in order to structure the study and understanding of *places*, *regions* and phenomena such as natural or human events. The *scales* geographers use are summarised in Figure 1.7.

Risks involved in different types of hazards vary in their *scale* of *distribution*, and disasters have impacts at a variety of *scales*. News reporting following disasters commonly includes statements such as 'the *scale* of the devastation was immense', 'it is a national disaster', or 'a catastrophe of global significance'. Though the statements are emotive, they are also descriptive of *scale*. Different *scales* can be involved when seeking explanations for, or impacts and outcomes about, hazard and disaster events. Although the location of the 2019–2020 fires shown in Figure 1.5 occurred across many local areas, their impact was certainly national – but it was also international, if not global, in terms of media interest in the disaster as well as *environmental* impacts on climate and biodiversity.

Geographers require the ability to freely zoom in and zoom out in their *scale* view, when seeking explanations, relationships, influences and outcomes of and between phenomena.

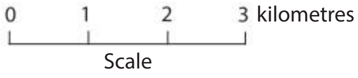
Figure 1.5 Location of the 2019–2020 Australian fires

▼ **Figure 1.6** Map *scale* can be expressed as a statement, a ratio or in linear format

Statement:

One centimetre (on the map) represents one kilometre (on the Earth)

Linear:



Ratio:

1 : 100,000

▼ **Figure 1.7** Applying observational *scale* in Geography

Observational *scale*	Examples
Local	Involving a limited area such as a farm, shopping centre, a suburb or rural town; the immediate area around a location
National	Involving an entire county, or being of national significance and impact
International	Involving two or more countries, crossing national borders
Global	Involving the entire Earth, or impacting on the planet as a whole
Regional	Flexibly defined, varies in size and nature; may be inter-national i.e. covering more than one nation, or intra-national i.e. within a nation (see *Region* page 8)

Distance

Distance is measured in a number of ways. In its simplest form, it is the space between two different locations and can be determined using an absolute measure such as kilometres. *Distance* is used to assist with defining where things are located often also using *direction*. As an example, in Figure 1.5 Mallacoota is located approximately 460 kilometres south south-west of Newcastle.

Distance is clearly used as an indication of proximity, which often suggests the existence of relationships between things. Greatly distant phenomena are less likely to directly influence one another.

Relative *distance* is a second broad category that can be measured in other ways. The amount of time it takes to travel a given *distance* (for example, 'I live 20 minutes away from here.') is an example of relative *distance*. It is also possible to use less tangible measures such as psychological *distance*, where familiar *places* seem closer than less familiar ones (for example, 'Until I travelled there, I didn't realise that Mildura was located so far from Melbourne.').

▼ **Figure 1.8** Disaster type affecting highest number of people by country, Africa 2000–2019

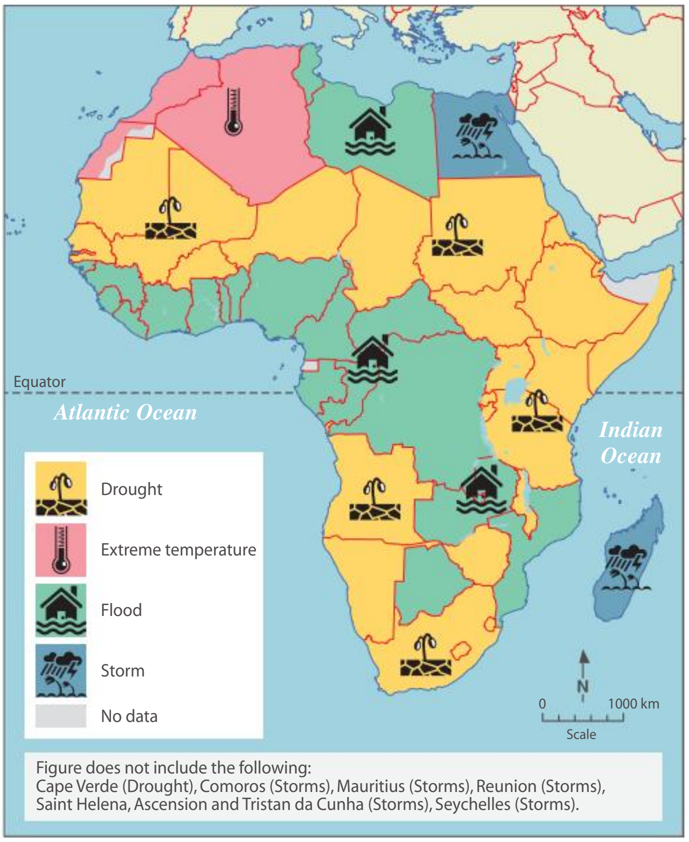
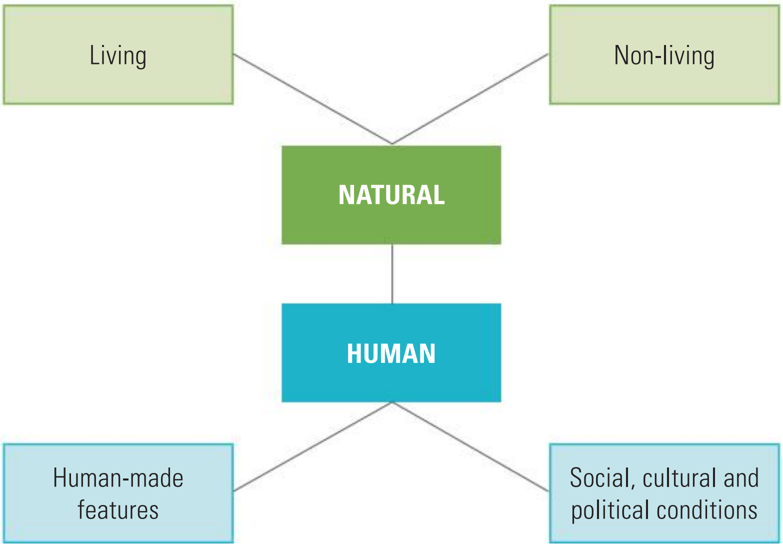


Figure does not include the following:
Cape Verde (Drought), Comoros (Storms), Mauritius (Storms), Reunion (Storms), Saint Helena, Ascension and Tristan da Cunha (Storms), Seychelles (Storms).

▼ **Figure 1.9** Components of the *environment*



Distance can be applied in various ways to understand hazards and disasters. With increasing *distance* from the explosion in the port of Beirut there was less impact from the blast (see Figure 1.4). Figure 1.5 shows the large *distance* the 2019–2020 fires spread across Victoria and New South Wales.

Distribution

Distribution involves the arrangement of features or objects on the Earth's surface. *Distributions* can occur at all *scales*, and often patterns can be observed and described as the arrangement or density of phenomena. Figure 1.8 maps the *distribution* of the disaster type affecting the highest number of people by country within Africa between 2000 and 2019. The *distribution* of hazards is not uniform across the Earth or within a given country or *region*. Figure 1.8 shows that different *regions* of Africa were subject to different types of disasters. *Distributions* can also be seen over time, as well as space, or both space and time together. If we were to view a map of disasters occurring in Africa for this year, the *distribution* and type of disasters would be different to that shown in Figure 1.8.

Environment

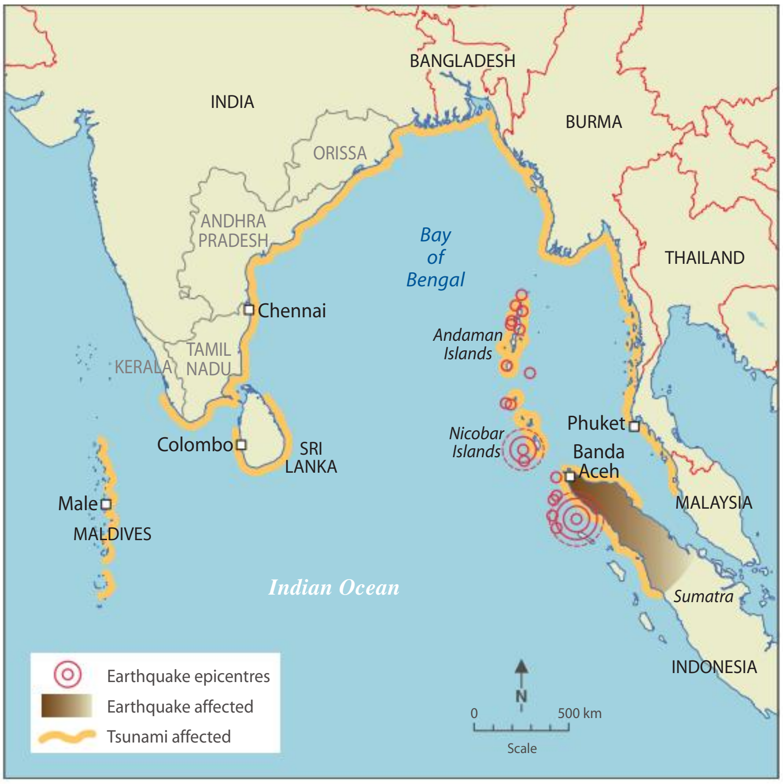
Environment refers to the world around us. It comprises the *interconnected* living and non-living physical elements of the Earth's surface and atmosphere as well as human-made features and the human conditions of *places* (see summary in Figure 1.9). The natural *environment* includes weather and climate, landforms, water features, natural vegetation and soils, and these features can be classified as living or non-living. The human *environment* includes surroundings made by people such as settlements, transport routes and nodes, and farmlands as well as the social, cultural and political conditions affecting a *place*. These conditions may be located in or beyond a particular *place* and may include economic influences.

Hazards are often associated with disasters that occur in the natural *environment* as a result of natural *processes* such as volcanic activity, earthquakes, floods, storms and bushfires (as shown in Figure 1.5). However, hazards can occur in the human *environment* as the result of human activity such as air pollution or nuclear accidents. The explosion that occurred in Beirut shown in Figure 1.4 is an example of such an event. Hazards can occur in both the natural and human *environments* and can be the result of natural *processes* and human activity.

Interconnection

The concept of *interconnection* emphasises that all *places* and *environments* are *interconnected* in some way and that they do not exist in isolation, whether at a local or global level. Geographical phenomena are connected to each other through *environmental processes* or human activities.

Hazards have many *interconnections*. For example, tornadoes develop from thunderstorms, drought can create conditions suitable for bushfires and earthquakes can trigger volcanic eruptions. Outbreaks of disease can often occur following a disaster created by a hazard. An example of *interconnection* can be seen with the 2004 Indian Ocean earthquake and tsunami as illustrated in Figure 1.10. The earthquake that occurred in the sea near Banda Aceh in Sumatra in west Indonesia generated a series of massive tsunami waves. The coastlines around the Indian Ocean were impacted by the tsunami. There was an *interconnection* between the site of the earthquake and the sites impacted by the tsunami waves because of the *distribution* of geographical factors in that *region* including the shape, elevation and location of coastlines, the depth of the ocean, and the *distance* the waves travelled. Use of the concept of *interconnection* enables us to have a better understanding of the complex links between *environments* in our world.

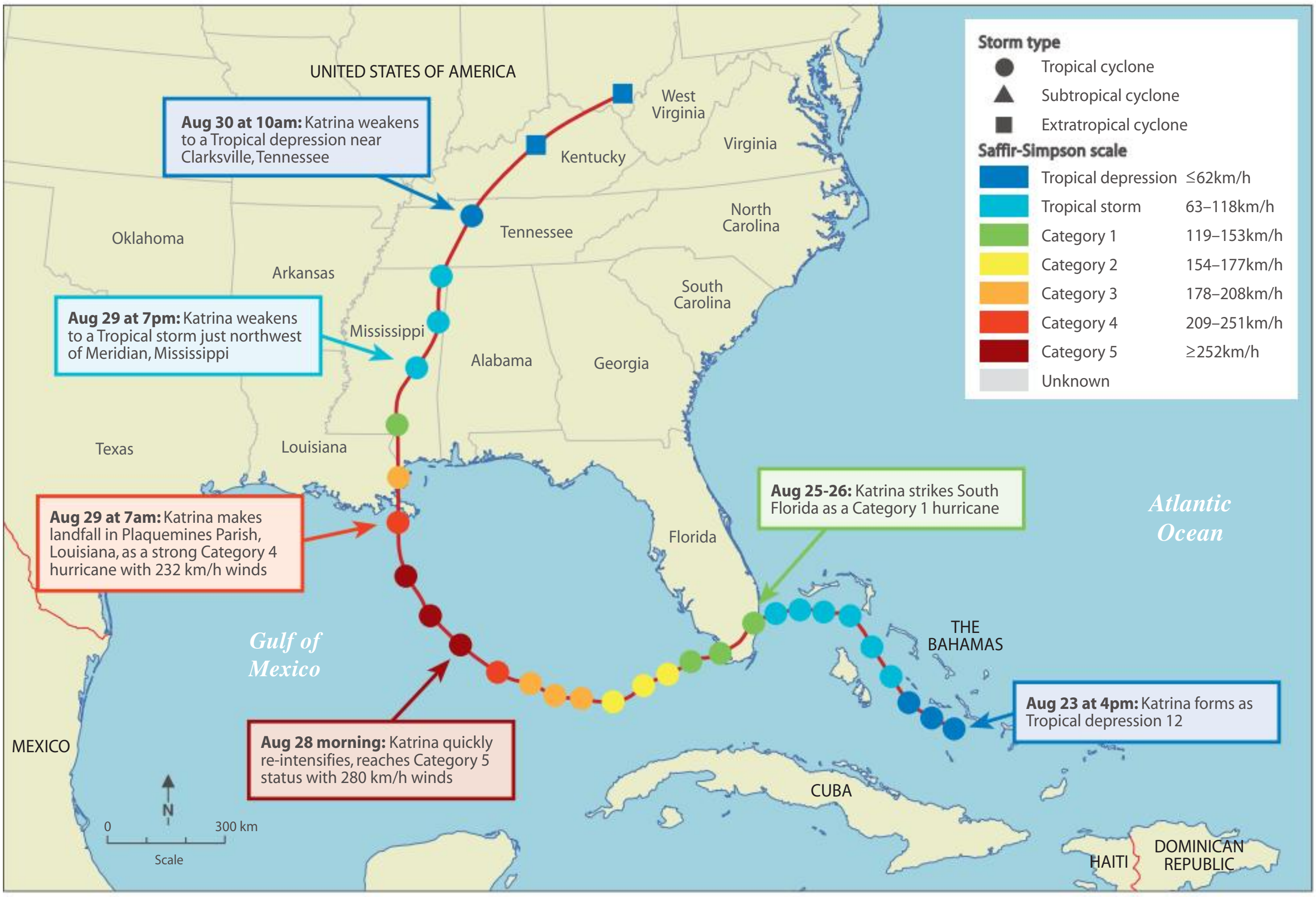


▲ **Figure 1.10** 2004 Indian Ocean earthquake and tsunami

Movement

Movement involves a *change* in the location of phenomena such as people, goods and ideas through travel or flow. In the context of hazards and disasters, *movement* can be seen in many ways such as the flow of flood waters, the development of tsunami waves across the ocean or earthquake waves through the Earth's crust, the spread of an oil slick or debris fields in the ocean, a radiation cloud, or the transmission of disease among a population. *Movement* can be involved in the cause of a hazard, for example, Hurricane Katrina created a disaster as strong winds *moved* with the path of the hurricane, shown in Figure 1.11. Displaced people leaving disaster-affected *regions* as refugees exhibit another form of *movement*.

Where *movement* is concerned, *distance*, direction, the mechanism bringing about *movement*, in addition to the frequency, volume or *scale* of *movement*, may all be considered. *Movement* is represented in different



▲ **Figure 1.11** The path of Hurricane Katrina, 23–30 August, 2005 ways graphically – colour and lines can show the date and size of spread while arrows can show the *distance* and direction of *movement*.

Region

A *region* is a definable area containing one or more characteristics that distinguish it from surrounding areas. *Regions* can be defined at a range of *scales* by physical characteristics such as mountain ranges and drainage basins, politically by official decisions about boundaries and names, and by common usage or for a given purpose by selecting a particular characteristic such as the western suburbs of Melbourne. Smaller *regions* can exist within larger ones, and different *regions* can overlap.

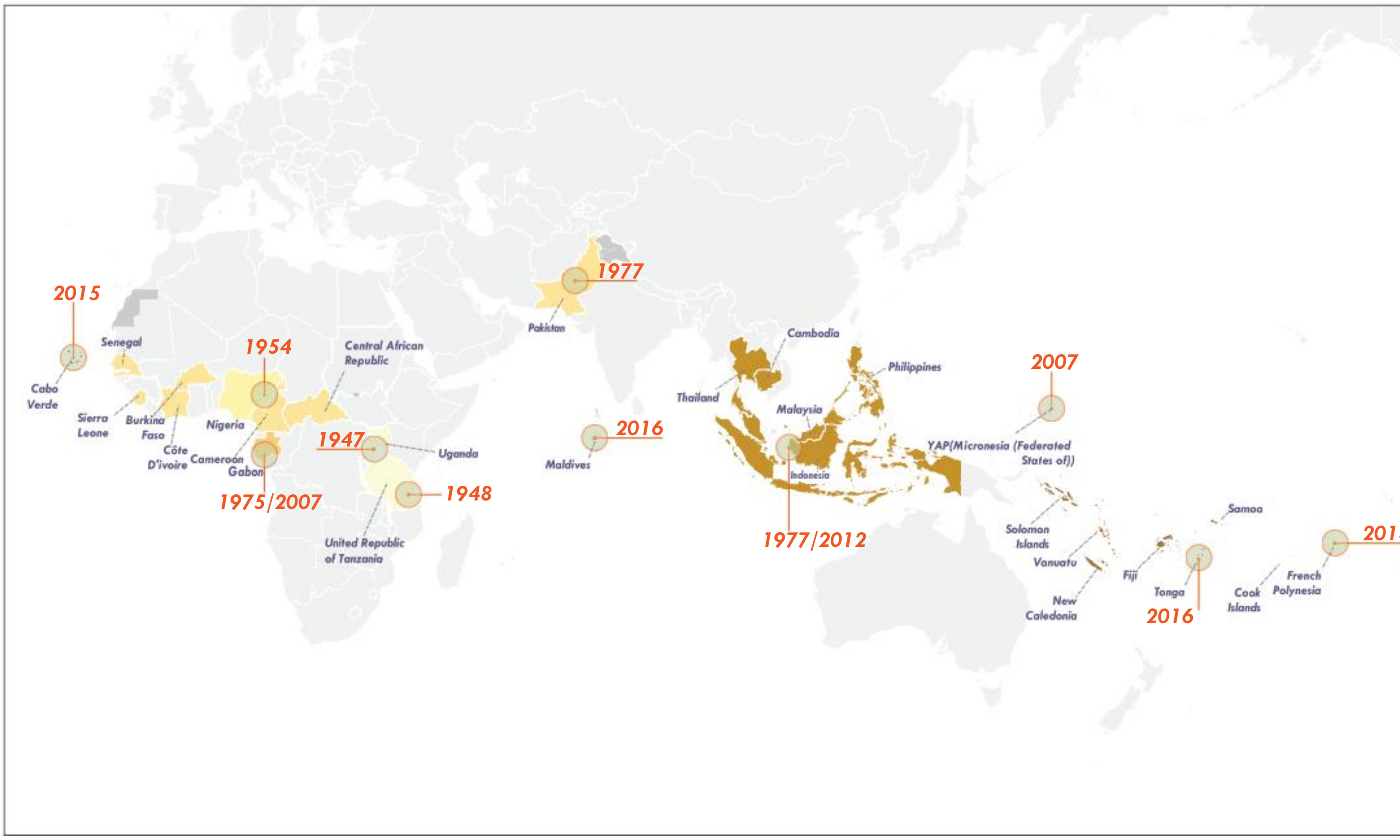
Region is important in terms of *scale*. *Regions* can be seen and defined at each of the local, national and international *scales*. Figure 1.12 provides examples of *regions* at a variety of *scales* that can be classified into various types. In this way, *region* itself can be used to represent a *scale*.

Hazard risk can define a *region* and, within that, levels of hazard risk can define *subregions*. Disasters, when they occur, define yet further *regions* being affected to varying degrees. The country information in Figure 1.13 could be used to define *regions* affected by the spread of the Zika virus over time.

▼ **Figure 1.12** Examples of *regions* at different *scales* and how they are defined

Region	***Scale* relationship**	**Defined by…**
Inter-tidal zone	Local	Physical
Chadstone Shopping Centre	Local	Land use
Otways rainforest	Local	Vegetation
Melbourne Central Business District	Local	Political/administrative, land use
Victorian Central Highlands	National	Political/administrative, physical
Great Victoria Desert	National	Climate, physical
South-eastern Australia	National	Location, common use
Amazon Basin	International	Physical
Tropics	International	Location, climate
Sub-Saharan Africa	International	Location, common use

▼ **Figure 1.13** Spread of the Zika virus, 1947–2016



▲ **Figure 1.14** Satellite images of the port of Beirut, Lebanon before and after the August 2020 explosion

Change

Change relates to the degree to which something alters, or is modified, over time. As phenomena studied in Geography are dynamic, they are often best understood by investigating how the focus of investigation has developed over space and time. It is also valuable to examine the effects and impacts of *change*, and this often relates to *sustainability*.

Change can be spatial and *place* related. This can include *changes* in the location (that is, *movement*), size, *distribution*, density or pattern of phenomena.

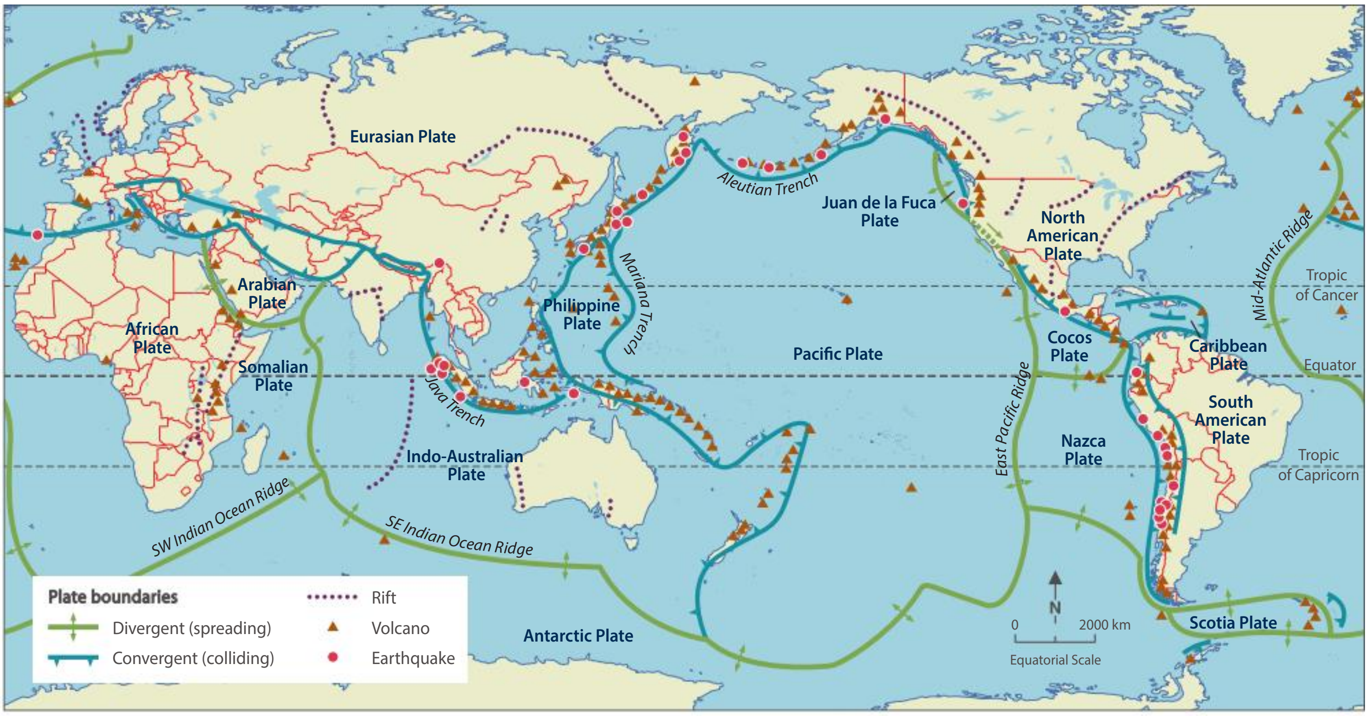
The transformation of the use, nature or quality of a *place* can also be identified. *Change* can be non-spatial and still be of relevance to Geography such as *changes* in land use policies or economic conditions. Varying occurrences of something over time can provide important information for geographers. Temporal *change* – or *change* over time – is one such example, such as the flow of water under different circumstances in Figure 1.3.

Rates of *change* are important. In Geography *change* can be studied in time *scales* which range from millions of years for geological, climate and landscape *change*, to a matter of a few years, months, days or even hours. The impact of the August 2020 Beirut explosion was immediate, and Figure 1.14 shows a satellite image of the physical and human *changes* that occurred in the city as a result of the explosion. *Change* might be relatively regular and predictable over time, such as some forms of natural climate variability or seasonal variation, or it might be a shift away from typical patterns or trends.

Process

Processes involve a series of ongoing events or steps that lead to the development, *change* or preservation of something. Often *processes* involve cause-and-effect relationships between things. *Processes* can operate within and between *places*, and at a variety of *scales*. *Processes* in the Earth's crust and landscape, in the oceans or atmosphere are at the heart of some hazards and disasters, while biological or human *processes* might create or make other hazards worse.

Complex interrelationships between different *processes* can impact on one another. A hurricane (as shown in Figure 1.11) is a *process* involving the ocean and its atmosphere – and depending on previous geographical patterns and historical trends this might represent an interruption to normal atmospheric *processes*. Human activities are bringing about climate *change*, which appears to be making the hurricane *process* more frequent and intense in part because of ocean warming.



▲ **Figure 1.15** The *process* of plate tectonic influences patterns of geological hazards on the Earth's surface

The *process* of plate tectonics results in increased chance of hazard events such as earthquakes, tsunamis and volcanic eruptions in particular *locations*, as seen in Figure 1.15.

Spatial association

It is common to find things occurring together on the Earth's surface. *Spatial association* is the degree to which two or more phenomena are similarly *distributed* or arranged on the Earth's surface. Where *distribution* patterns of phenomena are consistently similar, a strong or high degree of *spatial association* exists. For example, there is a strong *spatial association* between areas of the Earth with low rainfall and low population density. When one phenomenon has a high frequency and another phenomenon is lower in frequency there is a weak or low degree of *spatial association*. For example, there is a weak *spatial association* between urban areas and the *distribution* of native animals in Australia because urbanisation often destroys natural habitat. It is also possible for there to be no *spatial association* at all. The task of the geographer is to determine the degree of *spatial association* and explore potential underlying reasons for the existence of a relationship, or lack thereof.

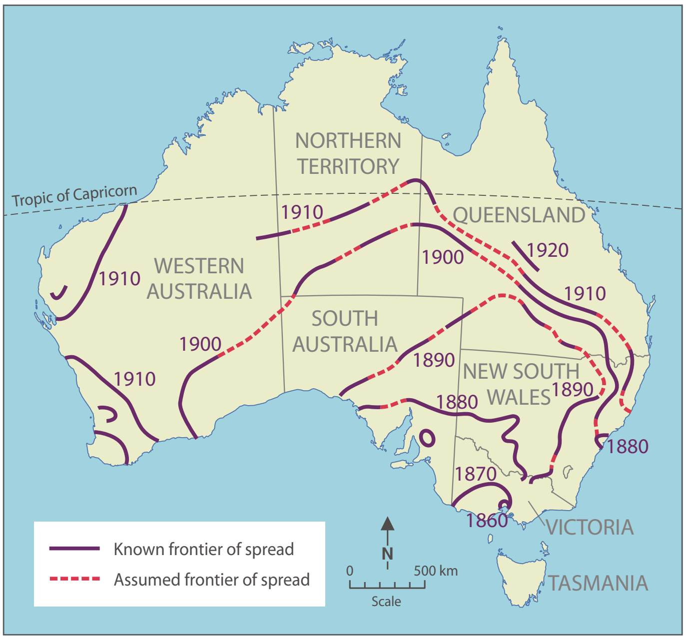
Spatial association can also be viewed through the perspective of impacts. The coincidence between phenomena spatially might occur by chance – or accident in the case of a hazard or disaster – but the fact that they do have overlapping *distributions* has consequences. Figure 1.15 shows the *distribution* of divergent and convergent plate boundaries as well as the *distribution* of volcanoes and recent major earthquakes. The map shows there is a strong *spatial association* between the location of plate boundaries and the location of volcanoes and recent major earthquakes. For example, a large number of active volcanoes exist on the north-western edge of the convergent Pacific Plate boundary where Japan has experienced many earthquakes with either a magnitude of greater than or equal to 7.0.

Sustainability

Sustainability is a different concept from the others and it encourages the formation of evaluations or judgements about current situations and their potential *change* into the future. *Sustainability* is the capacity of the *environment* and social systems to support people and other living things now and into the long-term future. It involves *environmental*, social, economic and political criteria to judge the wisest use of resources. This involves choices to ensure that the various benefits of resource use (such as income and employment) are gained only if this can be maintained by a healthy *environment*. Therefore, there may be conflict between what is judged to be *environmentally*, economically or politically *sustainable*.

People need to address various challenges arising from the issue of *sustainability*. These include sustaining enough scarce *environmental* services or resources to: reduce conflict or rising costs in particular *places*, allow equity between resource users in different *places*, leave adequate resources for future human generations rather than just exploiting them now, balance the needs of different species, and allow for *changing environmental* conditions in future.

Some hazards can have a dramatic effect on *sustainability*. People *changing* the *environment* can increase the severity of naturally occurring hazards such as flooding and bushfires. Human activity is responsible for intensifying climate *change*, which in turn leads to other hazard risks increasing and *changing* in *distribution* globally. Human activities have also been responsible for introducing invasive flora and fauna into locations, with subsequent *movement* throughout large *regions* over time. Figure 1.16 shows the northward *movement* of rabbits after their introduction in 1860 in Victoria. Figure 1.17 shows the extent of their current *distribution* across Australia. People are directly responsible for technological disasters such as oil spills, air pollution and radiation leaks. Are there *sustainable* decisions and behaviours that can reduce the occurrence, frequency and impact of hazards and disasters? These are questions geographers can help answer.



▲ **Figure 1.16** The *changing distribution* of rabbits across Australia after their introduction

▲ **Figure 1.17** Current *distribution* of rabbits in Australia

▶ ACTIVITIES

1. Identify what risk of harm tourists could face when visiting the Twelve Apostles (Figure 1.2).

Place

2. What is the difference between an absolute and relative location?

3. a. Refer to Figure 1.1. State the absolute location and provide a statement of the relative location shown.

b. Refer to Figure 1.4. State the absolute and relative location of Beirut, Lebanon.

4. Refer to Figure 1.3. Contrast the difference in run-off between a *place* with natural catchment compared to a *place* with an urban catchment. Explain why they might differ.

5. Examine Figure 1.4.

a. Outline the impact of the 2020 Beirut explosion on the residents of the city in terms of their 'sense of *place*'.

b. Describe how Beirut may have *changed* as a *place* after the explosion.

Scale

6. State the *scale* of the inset map shown in Figure 1.4 as a statement and a ratio.

7. Refer to Figure 1.7 to complete the following table. Insert the most appropriate *scale*.

Figure	Example	*Scale*
1.4	2020 Beirut explosion	
1.5	2019–2020 Australian fires	
1.11	2005 Hurricane Katrina	
1.13	1947–2016 spread of Zika virus	

Distance

8. Refer to Figure 1.11. Hurricane Katrina formed just south of the Bahamas and weakened to a tropical depression near Clarksville, in north Tennessee, USA. Use an atlas or Google Earth's *distance* tool to measure the *distance* travelled by this hurricane.

9. Refer to Figure 1.13 showing the spread of the Zika virus 1947–2016. What does the *distance* and time information tell you about the nature of this hazard?

Distribution

10. Refer to Figure 1.4. Describe the *distribution* of population with increasing *distance* from the explosion point.

11. Refer to Figure 1.5. Describe the *distribution* of 2019–2020 fires.

ACTIVITIES *continued*

Environment

12. Refer to the following figures and classify the type of *environment* shown as natural, human or mixed.

Figure	Natural, human or mixed *environment*
1.2	
1.3	
1.14	

13. Refer to Figure 1.5. Describe how the 2019–2020 fires disaster would have impacted both the natural and human *environments*.

Interconnection

14. Explain how drought conditions can *interconnect* with conditions suitable for bushfires.

15. Describe how a disaster can *interconnect* with the occurrence of disease.

Movement

16. Study Figure 1.11.

a. How has *movement* been depicted in this diagram?

b. Describe the *movement* of the path of Hurricane Katrina.

Region

17. Refer to Figure 1.13.

a. Complete the following table (the first date is completed for you):

Date	Location(s)	*Region(s)*
1947	Uganda	Africa
1948		
1954		
1975		
1977		
2007		
2012		
2013		
2014		
2015		
2016		

b. Describe the *regional* spread of the Zika virus.

Change

18. Describe the rate of *change* of the examples shown in the following Figures: 1.5, 1.13 and 1.14.

19. Refer to Figure 1.14. Describe the physical and human *changes* that you observe in an area of Beirut as a result of the explosion in August 2020.

Process

20. Refer to Figure 1.3. Explain how the *process* of urbanisation has caused a *change* in run-off contributing to flooding.

21. Refer to Figure 1.15. Describe the *process* of plate tectonics that results in the occurrence of earthquakes and formation of volcanoes.

Spatial association

22. Use Figure 1.15 to describe the degree of *spatial association* between plate boundaries and the location of volcanoes and the occurrence of earthquakes.

Sustainability

23. Refer to Figures 1.16 and 1.17. Outline how the spread of rabbits impacts on the *sustainability* of the *environment* and the economy.

What is geospatial technology?

All geography students need to have the ability to interpret spatial data – information that includes location and can be shown on maps. You may have used a form of spatial data when booking and tracking transport using Uber or when using Google Earth. Geospatial technologies are the digital tools for geographical inquiry that include software and hardware interacting with real world locations. This includes any form of technology that organises and collects data that is referenced to a point on the Earth's surface via latitude and longitude. Geospatial technologies enable the visualisation, manipulation, analysis, display and recording of spatial data. That data may have been observed directly by humans or it might have been obtained remotely including from oceanic buoys, drones, aeroplanes or satellites. It is important to be able to interpret and analyse spatial information as more decisions in our world are spatially based.

The different forms of geospatial technology are summarised in Figure 1.18.

▼ **Figure 1.18** Different forms of geospatial technology

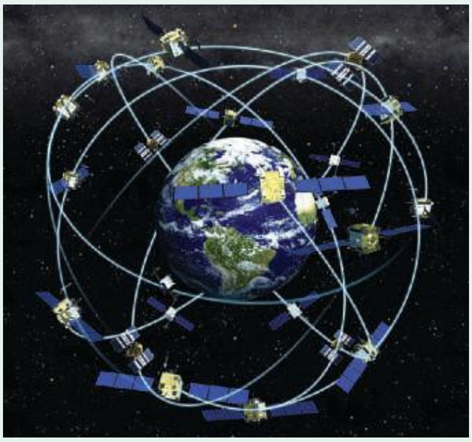
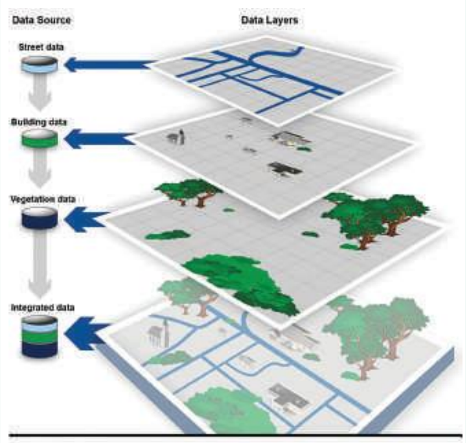
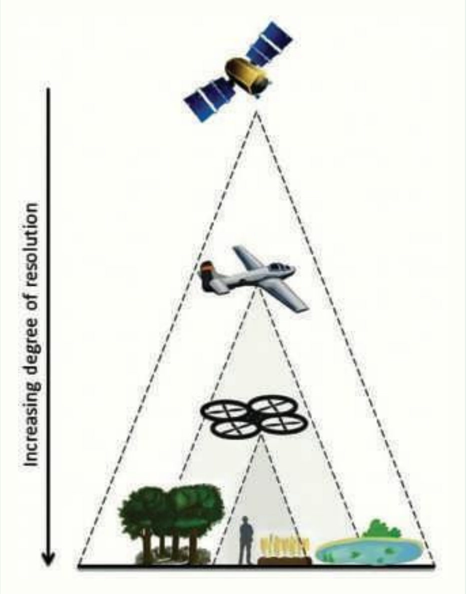
Geospatial technology	Explanation
GNSS Global Navigation Satellite System	Often inaccurately referred to as the Global Positioning System, this network is based on a system of at least 24 satellites that circle the Earth. The GNSS system can determine a user's position in terms of latitude and longitude as well as altitude. This enables users to identify their exact location on the Earth via a smart phone or in-car navigation unit. Once the system has determined a user's position, software can then calculate other information such as speed, bearing, track, *distance*, *distance* to destination, and many more features. GNSS forms the basis of modern mapping and can be used in mobile apps or for specific purposes such as tracking the *movement* of cyclones. 
GIS Geographic Information System	This is the most common geospatial technology tool used today. Geographic Information Systems use computer-based mapping software that collect, store and analyse previously unrelated information and display this information as easily-understood maps. The GIS program represents the data as layers of information that can be turned on or off, according to what the user wants to look at and the relationships they are trying to find. For example, layers could include road layout, buildings and vegetation *distribution*. Google Earth and ArcGIS are examples of GIS. Associated with this technology are many online interactive mapping applications usually focussed on a particular topic – for example, weather forecasting, town planning or monitoring emergencies.  Source: GAO. | GAO-15-193
Remote sensing	Remote sensing obtains information about the Earth's surface without being in contact with it. This involves data collected above the Earth from space or by an aircraft and includes satellite images and aerial photographs. A recent development in this area has been the development of drones that include cameras or sensors to record information. Remote sensors can be either passive or active. Passive sensors respond to external stimuli and record natural energy from the Earth's surface such as reflected sunlight or re-radiated heat (infra-red radiation). In contrast, active sensors use internal stimuli to collect data about Earth. For example, a laser-beam remote sensing system projects a laser onto the surface of Earth and measures the time that it takes for the laser to reflect back to its sensor (known as LiDAR or light detection and ranging). Remote sensing data is often then used to provide a base layer for a GIS map. Remotely sensed data is useful for hazard management and monitoring data about oceans and the atmosphere. 

Figure 1.19 The Operational Land Imager (OLI) on Landsat 8 captured lava flows from Fagradalsfjall, Iceland. This was the NASA Earth Observatory Image of the Day on 13 May 2021

Good sites for further information on geospatial technology

GNSS

- www.youtube.com/watch?v=CCKisghkcA4

  This YouTube clip by Geospatial Media offers a simple explanation of GNSS. (2.44 minutes)

GIS

- ESRI What is GIS?
  www.esri.com/en-us/what-is-gis/overview

  This site offers a clear explanation of how GIS works.

  Follow this up by selecting an example from the link to GIS showcase.

- National Geographic MapMaker Interactive:
  http://mapmaker.nationalgeographic.org/

  A very simple but useful GIS tool with some basic tools such as measuring *distance*, adding labels and place-marks.

Remote sensing

- NASA Earth Observatory
  http://earthobservatory.nasa.gov

  This site provides access to an enormous number of satellite images. The site provides featured images each day, as well as breaking news articles that feature satellite imagery. Current topical stories are also provided, with satellite imagery. Topics include climate *change*, natural disasters, deforestation, pollution and more.

Analysing and interpreting data

In many cases in Geography, analysing and interpreting data relates directly or indirectly to the key geographical concepts. Developing a conceptual understanding and applying concepts to information analysis is the basis of many activities in this textbook. Some questions or tasks will include a concept by name, while others imply the use of one or more concepts in your thinking.

Tips for using concepts:

- In written responses to tasks which name a particular concept, it is usually appropriate to use that concept by name in your answer.
- Conceptual understanding can often be demonstrated visually; for example, in a map, graph or diagram. Examples of concepts shown well on maps include *scale*, *distance*, *distribution*, *region*, *movement*, *change* and *spatial association*. Commonly graphed examples include *distribution*, *movement* and *change*, particularly those involving a time *scale*. *Process* might be appropriately shown in a flow diagram.
- Higher quality written responses often communicate clear conceptual understanding, without necessarily using the concept by name.
- Avoid using concepts in responses unnecessarily. Too much repetition does not always show an understanding of the concept.

Applying instructional terms in Geography

Throughout the chapters in this book, instructional (or directive) words are used in many activities. They specify how you should approach and complete a given task. Understanding these words and knowing what is expected of a response are important skills, and will improve the quality of your answers and enhance geographical understanding.

The table in Figure 1.20 provides explanations for instructional or directive terms found in this book, or likely to be used in class activities, assessments or fieldwork.

▼ **Figure 1.20** Explanation for instructional and directive terms

Analyse	Show the essence of something (e.g. a situation or a map) by breaking it down into separate points and critically examining the relationship between each part.
Annotate	Add labels, comments or explanatory notes to images, maps, graphs, diagrams or text.
Assess	Weigh up the value of or judge the strengths and weaknesses of something. Similar to 'evaluate', but more general.
Calculate	Use data or statistics provided in various forms to determine an answer.
Categorise	Arrange or group by distinctive characteristics.
Classify	See 'categorise'.
Compare	Show the similarities or differences when examining two situations, events, ideas, features or *processes*.
Consider	Think about what has been observed about something; be able to support observations using appropriate evidence.
Construct	Create, develop or draw a map, diagram, graph, flow chart or table.
Contrast	Highlight the differences when examining two or more situations, events, ideas, features or *processes*.
Describe	Provide characteristics of a situation explaining what is observed.
Discuss	Show understanding of a situation, where appropriate, by presenting both sides of a situation, issue or event. Include the strengths and weaknesses of available data. Usually involves more detail than 'explain'.
Evaluate	Weigh up and interpret a statement, viewpoint or situation and state a conclusion about its value or importance. Similar to 'assess', but with a focus on the outcome or result. Include consideration of different opinions.
Explain	Relate cause and effect. Give reasons why a situation exists or a *process* occurs.
Explore	Adopt a questioning approach, looking at all aspects of the situation, including points for and against. Similar to 'discuss'.
Identify	Establish the nature of a situation by distinguishing its features and naming them.
Interpret	Examine visual data such as a map, graph or diagram to make sense of what is being depicted and to draw conclusions.
Justify	Use examples or find sufficient evidence to show why, in your opinion, a viewpoint or conclusion is correct.
Outline	Summarise the main points of given information or events in a situation.
Predict	Suggest what may happen in a given situation based on evidence gathered.
Quantify	Use numbers or statistics to describe a phenomenon and support conclusions.
Rank	Arrange factors, outcomes or elements in order of importance.
Suggest	Present a hypothesis or theory about a particular situation.

2 Hazards and disasters: an overview

Geographers study hazards and disasters for many reasons:

- Hazards and disasters form part of the Earth's natural systems. The *processes* involved and their *interconnection* with human activity are areas geographers seek to understand.
- Geographers help interpret information about when and where hazards can develop and why hazard events and disasters can occur.
- Hazard events and disasters affect people *environmentally,* economically, socially and culturally in different ways at a range of locations and *scales*.
- The lessons learned from the study of one hazard or disaster may be applied to another situation as a way of reducing or avoiding risk or harm.
- Developing an understanding of risks from hazard events and disasters helps people to make effective decisions before and when events happen.

Everyone can face hazards every day: for example, preparing food, crossing a busy street, negotiating the crush at the school lockers or playing contact sport. These are hazards that have the potential to cause you harm; but, hopefully, they never will. We all try to adjust our daily activities in appropriate ways to avoid the risk of harm that similar hazards present.

Most people are aware of hazards that can affect a large area, with a potential to harm many people and the *environment*. Some of these hazards can be seen in the photographs in Figures 2.1 (a)–(d).

▲ **Figure 2.1 (a)** Storms producing strong winds and heavy rain can result in flooding, erosion and damage to property

▲ **Figure 2.1 (b)** Toxic wastes are difficult to handle, as well as to store or re-process

▲ **Figure 2.1 (c)** An airborne disease such as influenza, or a waterborne disease such as cholera, can easily spread within a community that lacks basic sanitation facilities

▲ **Figure 2.1 (d)** Volcanic eruptions can cause loss of life and can be destructive to property and the natural *environment*

Hazards, hazard events and disasters

Hazards, hazard events and disasters all have important different meanings. Hazards are situations with a potential to cause harm to people and/or to the *environment*. You can identify situations presenting hazards in Figures 2.1 (a)–(d) and 2.2 (a)–(c). A hazard event is when a hazard is realised. For example, the development of a low-pressure air system over the Pacific Ocean may be interpreted by meteorologists as a weather hazard if it further develops into a cyclone. If the cyclone does develop and moves onshore, and then produces destructive strong winds and heavy rains, a hazard event will have occurred. Similarly, living in a bushfire-prone area is a hazard for people. The bushfire itself is a hazard event that may become a disaster.

Some hazard events can become disasters. There are several ways this can be determined:

- A declaration is made by government authorities to enable assistance in dealing with the hazard event and its consequences.
- The human *environment* adversely affects people, especially their lives or their livelihoods.
- According to the Belgian-based international Centre for Research on the Epidemiology of Disasters (CRED), a disaster is a situation or event that overwhelms the local *environment* and requires national or international assistance for its recovery. To be listed in their disaster data base, a hazard event needs to have one of the following characteristics: 10 or more persons killed; 100 or more persons adversely affected; a state of emergency is declared by appropriate authorities; a call for international assistance is made.

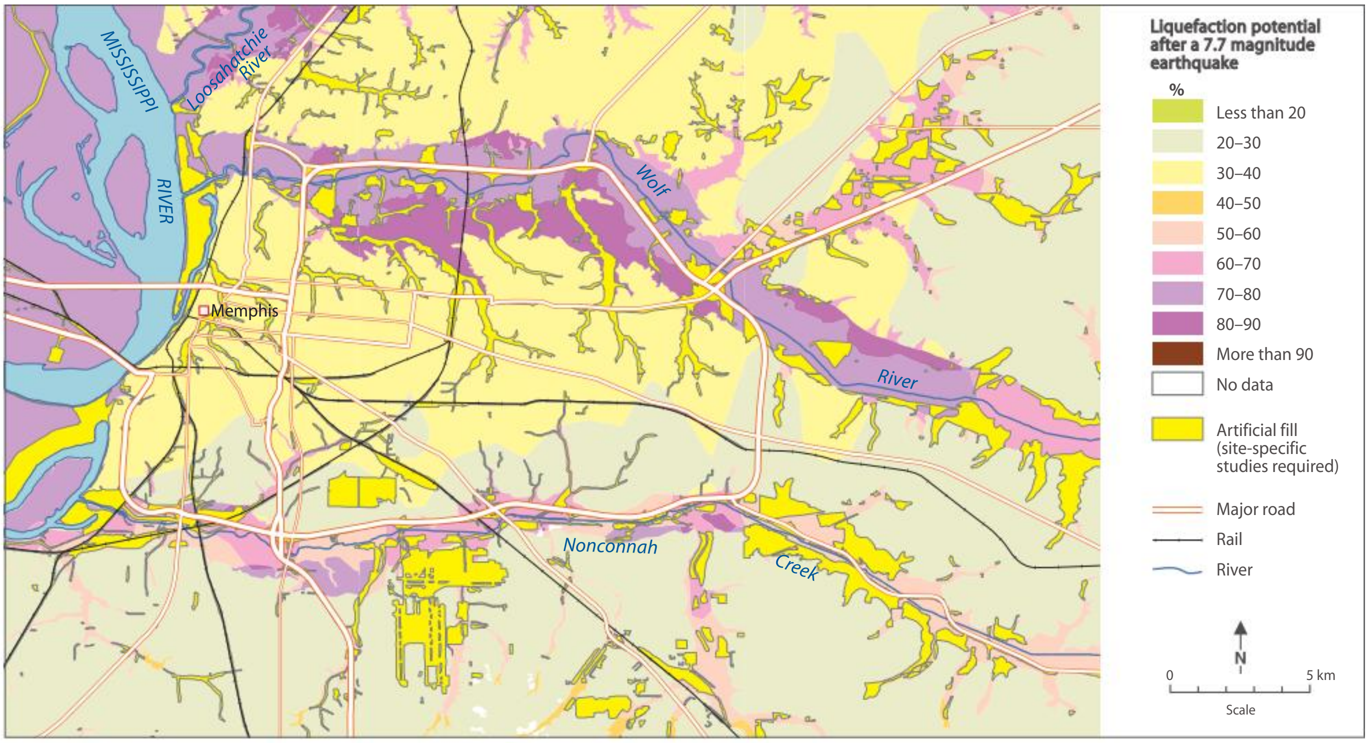
ACTIVITIES

1. Refer to Figures 2.1 (a)–(d). Suggest how each of these situations could become a disaster. Justify your position on each situation.
2. a. Do you experience any of the above-mentioned personal hazards? What other examples can you add to the list?
   b. How serious are these hazards to you and your immediate family and friends? Are they serious in the short term or long term?
3. Which methods outlined above do you think should be used to determine a disaster? Perhaps develop your own definition (with a justification, of course).
4. Visit the *Disaster Alert* website. Look at today's and other recent hazard events. Which category of events are most prominent? Describe their location. Which water-based events are shown? How do your answers *change* three to five days later?

▲ **Figure 2.2** **(a)** An oil spill on Thailand's coast mobilised hundreds of rescue workers

▲ **Figure 2.2** **(b)** Part of a Somali refugee camp in Kenya

▲ **Figure 2.2** **(c)** A winter hazard in Montreal, Canada



▲ **Figure 2.3** Liquefaction potential following a magnitude 7.7 earthquake in south-east Memphis, USA

Risks, hazards and hazard events

The risk of a hazard or hazard event can be considered as the probability of doing harm to people and, or, the *environment*. Figure 2.3 is an example of a risk map of liquefaction in south-east Memphis, USA. Liquefaction occurs when soil and unconsolidated rock acts as a liquid because of continuous earthquake *movement*. The map combines information about current and historic drainage, known areas of past liquefaction, soil type and depth. A series of maps based on different earthquake magnitudes provides a guide for planners and developers to direct new building of housing and infrastructure away from areas of highest risk. Maps such as this one have been produced in many parts of the world. They are examples of the application of geospatial technologies to geographic issues.

The factors affecting the level of risk at any location may vary considerably. These factors can be economic, social, political, *environmental* and cultural.

▼ **Figure 2.4** Tsunami warning sign, Chile

Most of these factors will inevitably *interconnect* with one another to some extent. In Memphis (Figure 2.3) there was a strong *environmental* factor causing risk: the possibility of earthquakes causing liquefaction. There were also other factors:

- economic – the value of existing infrastructure such as roads, underground cabling, and pipelines as well as buildings that could be damaged or destroyed
- social – long-established communities that could face loss of life or relocation after an earthquake
- political – the willingness and ability of local and state authorities to prepare for a hazard event.

Risk may appear to be very low because the likelihood of the hazard event occurring is also low. Future volcanic eruptions in western Victoria are possible but the likelihood and the associated risk is also very low. Some hazards are incremental, in other words, they build up over time to become harmful. Pollutants in the air (Chapter 6) or water may take many years to produce harmful effects in individuals. The risk probability is therefore low in the immediate term, but higher in the long term. Location may significantly affect the probability of risk. Storms with their associated winds and heavy rainfall may not necessarily be a harmful event. But in *regions* where construction has occurred on flood-prone lowlands, or on steep hillsides that have been cleared of most vegetation, the probability of risk increases. The cases of Bangladesh (page 26) and coastal Queensland (Figure 2.10) are two of many locations in this high-risk probability category. Risk identification and the determination of risk probability becomes very important in the management of hazard responses (page 36). Sometimes risk needs to be advertised to a local community and visitors to help manage people's behaviour, as in Figure 2.4.

Classifying hazards

Hazards are commonly classified by their causes. This approach produces four major categories of hazards.

1. Geological or geophysical hazards

These hazards include volcanic activity, earthquakes and tsunamis, all of which are *processes* generally associated with the dynamics of plate tectonics. Landslides, avalanches and subsidence are included in this category. These hazard events are mostly natural ones and have been operating on our planet for many millions of years. Human activity therefore makes only a minimal contribution to their cause. Some landslides are an exception: they can result from people clearing vegetation from steep slopes. Also localised small earthquakes may result from the introduction of huge reservoirs into locations over geological faults.

The *distribution* of the world's major geological hazards is shown in Figure 2.5. Chapter 3 examines these hazards in greater detail.

2. Hydro-meteorological hazards

These hazards are also referred to as atmospheric and climatological hazards. This category includes a wide range of hazards such as drought, floods, storms and bushfires.

Over many decades, hydro-meteorological hazards make up the largest proportion of all disasters registered by CRED. The *distribution* of the world's major atmospheric hazards is shown in Figure 2.5. Chapter 4 looks at these hazards in greater detail.

3. Biological hazards

These hazards are associated with life forms and their *processes*. They include infectious diseases such as HIV/AIDS, Ebola virus, COVID-19, malaria and influenza; animal-transmitted diseases such as rabies and avian flu; waterborne diseases such as cholera; plant invasions such as blackberries in Australia; and animal invasions such as cane toads and fire ants in Australia, and the Northern Pacific sea star in southern Australian waters.

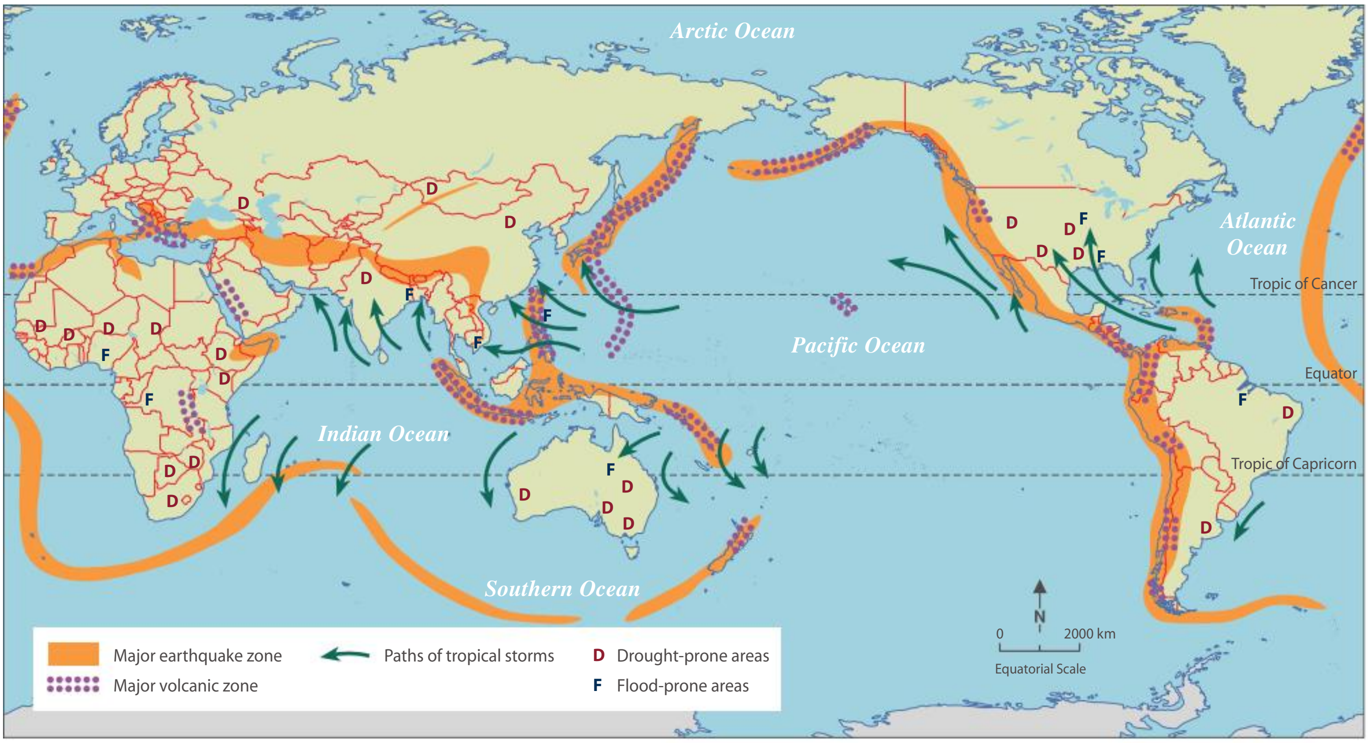
The *distribution* of some of the world's biological hazards is shown in Figure 2.6. Chapter 5 looks at biological hazards in greater detail.

4. Technological hazards

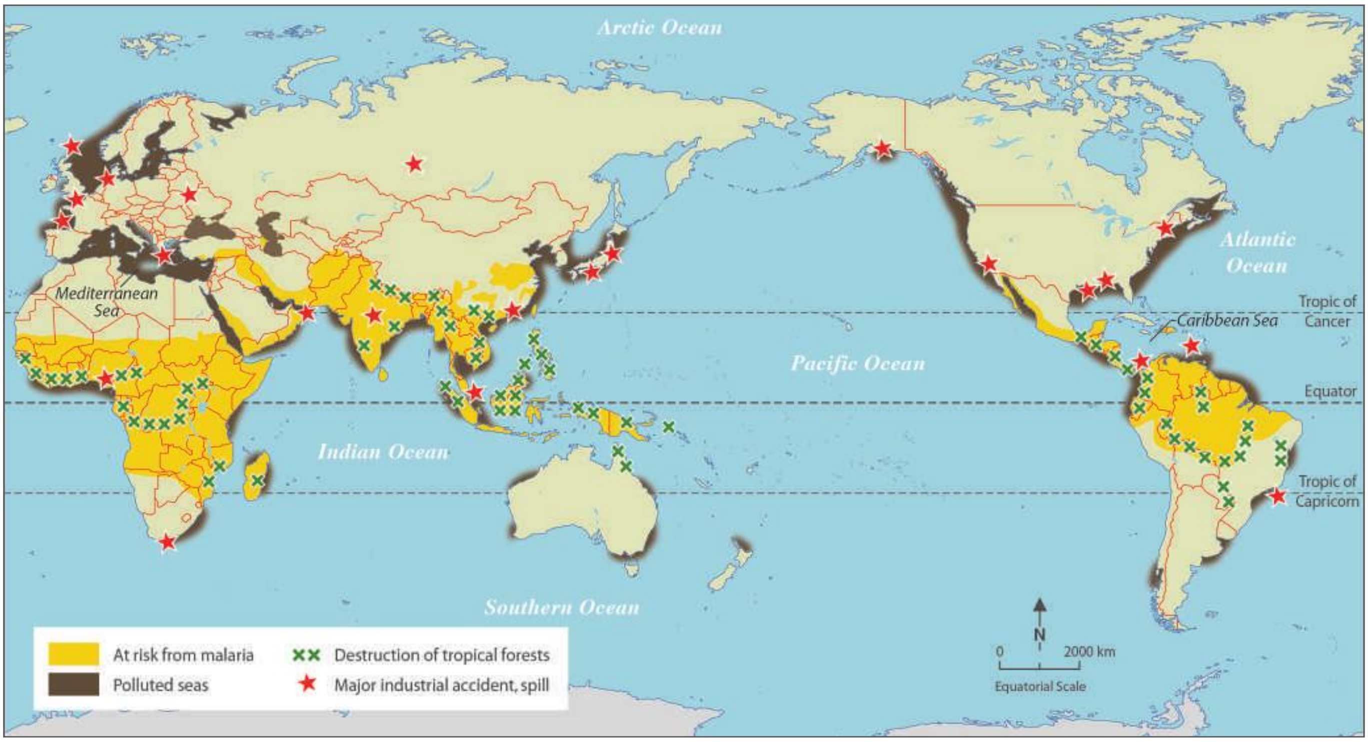
These hazards are sometimes referred to as anthropogenic hazards since their origins are connected to human activity. Human activities often *interconnect* with natural *processes* to produce hazards. For example, the spread of disease in human populations may be caused by poor hygiene and inadequate safe-water supplies. This broad category of hazards includes oil spills, air pollution, acid rain, and mining, and industrial wastes such as coal dust and asbestos fibres.

Increased carbon emissions from thermal power stations, factories and motor vehicles are now held responsible for enhancing the world's greenhouse effect. In turn, the world's climates, sea levels, soils and vegetation, together with human activities, are being affected. The *processes* of climate *change* are examined in greater details later in this chapter (page 29).

The global *distribution* of some major technological hazards is seen in Figure 2.6. In Chapter 6 you will discover more about technological hazards.



▲ **Figure 2.5** The *distribution* of major geological and atmospheric hazards



▲ **Figure 2.6** The *distribution* of some major biological and technological hazards and hazard events

Other hazard classifications

Hazards can be classified in other ways, such as the speed of their onset. Rapid-onset hazards such as volcanic eruptions, earthquakes, flash floods and bushfires can occur with little warning and can affect locations quickly. Increasingly effective monitoring, especially by meteorologists and volcanologists, is helping to reduce the surprise elements of some of these hazards. Many of the world's active volcanic *regions* such as Java (Indonesia), Honshu (Japan) and southern Italy are closely monitored for seismic activity that may be a prelude to a major event. Slow-onset hazards are ones that can take months or even years to develop. These hazards include drought, the spread of disease, the gradual accumulation of persistent poisons in soil, water or animals and sea-level rises linked to climate *change*. Slow-onset hazards appear to have a low risk of harm in the initial stages but over time can threaten harm to people and/or the *environment.*

Frequency of hazards can be used to classify hazards and disasters. The more significant the event, the less frequent is its occurrence, in general. A 1-in-100-year flood may be considered low risk, but its occurrence could be more damaging than an annual seasonal flood of one or two metres rise; and as people tend to forget infrequent hazards, the risk of harm to unprepared communities may increase when disasters eventually occur.

▶ ACTIVITIES

1. Refer to Figure 2.5.

- a. Which continent appears more likely to be affected by geological hazards: Europe, Africa or Australia?
- b. Which *regions* of the world are more likely to be affected by tropical storms: South America, Middle East or South-East Asia?

2. Classify each of the following hazard events as either geophysical, hydro-meteorological, biological or technological. Where you think a hazard event could fit into more than one category, explain your reasoning.

hail storm
rising sea levels
tsunami
chemical smog
lightning
airplane crash
avalanche
infectious disease
radiation leak
cyclone

3.

- a. Classify each of the images in Figures 2.1 (a)–(d) and 2.2 (a)–(c) into one of the four hazard categories.
- b. Discuss how each of these situations could have developed. If necessary, reclassify the images because of your discussion.

4. Refer to Figure 2.6.

- a. Name three *regions* where the clearance of tropical forest could pose a hazard to the human and non-human inhabitants.
- b. Which body of water appears to pose the greatest hazard: South Pacific Ocean, Caribbean or Mediterranean Sea?

5. In a group discuss which of the following situations are low risk hazards to you now. To whom, where and when could they pose high risks?

- annual influenza winter virus
- tsunami
- heat wave
- forest clearances in South-East Asia
- melting ice sheets in Antarctica and Greenland.

6. Some hazards and hazard events appear to fit into more than one category of hazard. Discuss the following scenarios

- Land clearance on steep slopes producing a landslide hazard: is this a geophysical hazard or a technological one?
- Current *changes* to the world's climates: are they largely induced by human activity? If so, into which category should this hazard be classified?

Interconnection and hazards

There is frequently considerable *interconnection* between hazards, hazard events and disasters. This may result in one occurrence generating others. The term compound disasters can be used to describe where one disaster creates another. For example:

- A wet spring in which grasses and trees have grown rapidly, followed by a hot dry season, frequently produces bushfire hazard events for much of south-east Australia. This is a combination of an atmospheric hazard event producing another atmospheric hazard event. The loss of animal habitats, lifeforms, farmland and housing raises the severity of the disasters.
- Heavy rains resulting from a tropical storm may result in the *movement* of soil and rock as a landslide on steep slopes that have been cleared of much of their vegetation. In turn, the landslide may block a river's flow causing local flooding. This is a combination of an atmospheric hazard event with a geophysical hazard event, with a role played by human activity.
- The Great East Japan Earthquake of 2011 had several *interconnecting* features which resulted in a major disaster. The very powerful earthquake produced little damage to infrastructure. It did, however, generate a powerful tsunami that devastated low-lying *regions* of north central Japan for up to 10 kilometres inland. Nearly 20,000 lives were lost. The tsunami severely damaged the Fukushima nuclear power plants, releasing toxic gases and forcing the evacuation of thousands of residents within a 20 kilometre radius of the power plants. Thus two geological events combined to produce a technological hazard event that rapidly turned into a disaster. Furthermore, the storage of large quantities of radioactive-contaminated material such as power plant cooling water and soil from nearby farmland creates a long-term incremental (or cumulative) hazard. These polluted materials will pose significant *environmental* and health management challenges long after the impact of the initial tsunami. Similar issues and challenges occurred after the disastrous 1986 explosion of the Chernobyl nuclear power plant in the Ukraine.

Hazards, disasters and natural *processes*

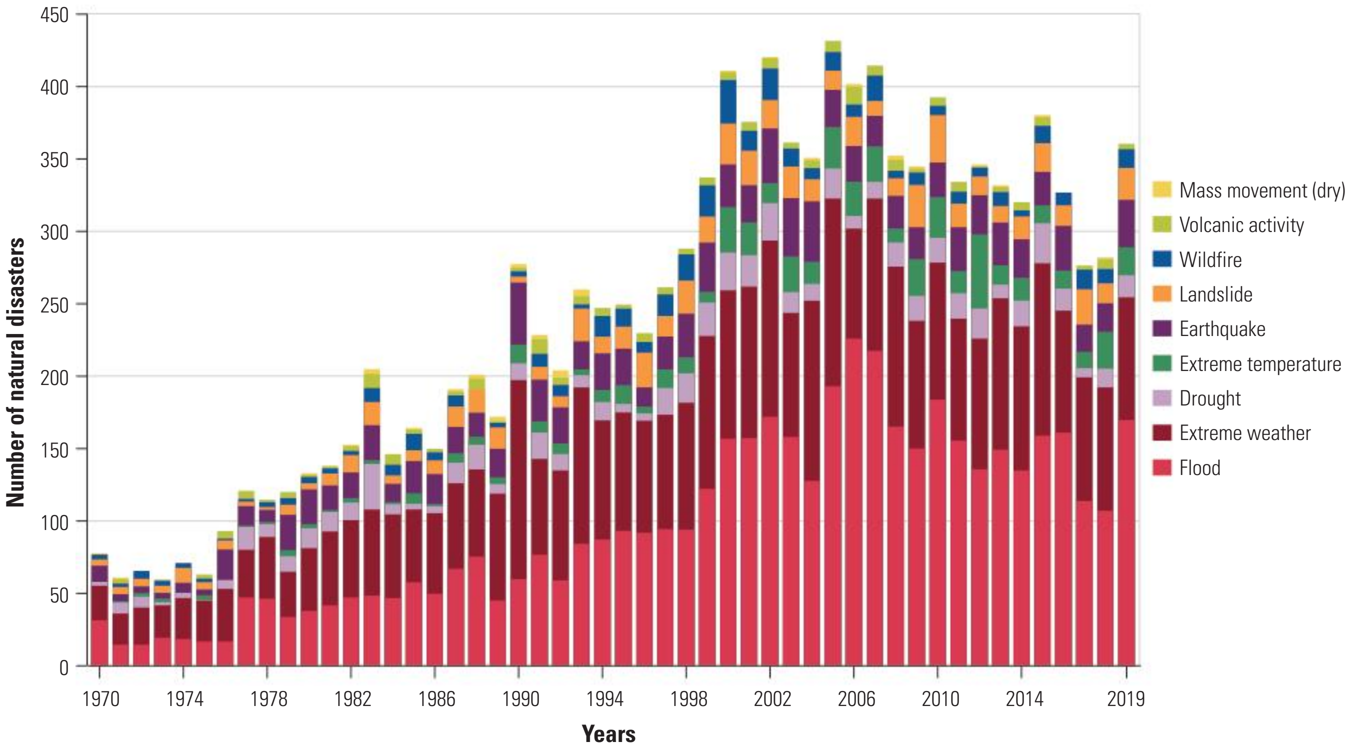
The natural *processes* that help form a hazard or a hazard event are part of the *processes* that have developed our planet as we know it. Earthquakes and volcanic eruptions have helped build mountain ranges and valleys. Landslides and avalanches have altered the shape and steepness of slopes. The Earth's atmospheric *processes* produce water that alters landscapes and provide water for life forms.

These *processes* operate almost continually but over different time and geographical *scales* and in different *locations*; and sometimes they are only noticeable when they threaten and affect lives or property. In the following chapters of this unit you will be able to investigate some of these *processes* in more detail.

Disasters

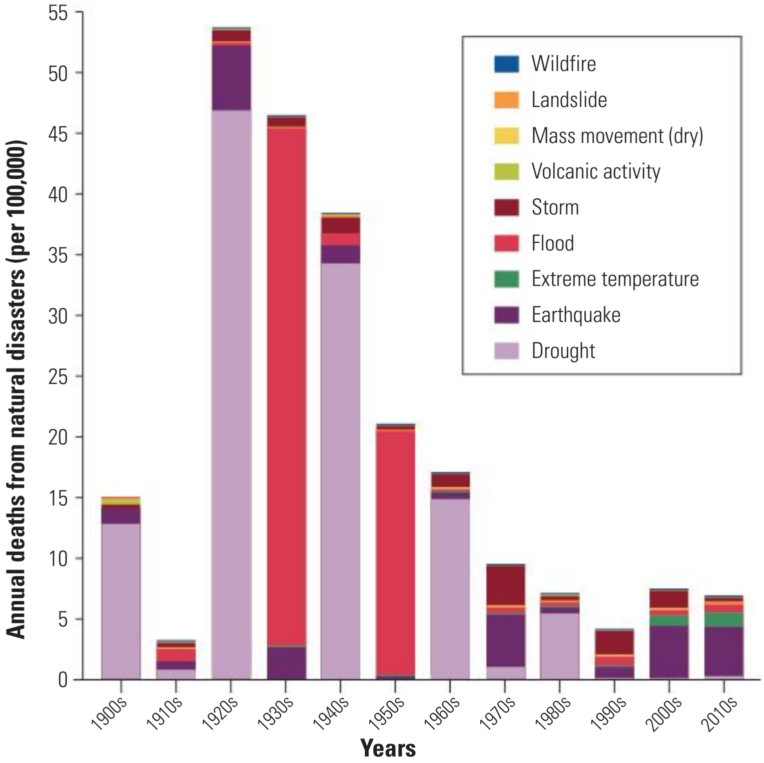
The Centre for Research on the Epidemiology of Disasters (CRED) in Belgium records and analyses disasters from all areas of the world. Its findings for 1970 to 2019 in Figure 2.7 are related to natural disasters from the geological and atmospheric categories (see Chapters 3 and 4).

▼ **Figure 2.7** Global reported natural disasters by type, 1970–2019



a

▼ **Figure 2.8** **(a)** Global annual deaths from natural disasters, by decade, 1900s–2010s



b

▼ **Figure 2.8** **(b)** *Distribution* of people affected and deaths from natural disasters, 2018

Most number of affected people, 2018		**Most number of deaths, 2018**	
India	23,900,348	Indonesia	4535
Philippines	6,490,216	India	1388
China	6,415,024	Guatemala	427
Nigeria	3,938,204	Japan	419
Guatemala	3,291,359	China	341
Kenya	3,211,188	Nigeria	300
Afghanistan	2,206,750	USA	298
USA	1,762,103	Pakistan	240
Japan	1,599,497	North Korea	237
Madagascar	1,472,190	Philippines	221

c

▼ **Figure 2.8** **(c)** *Distribution* of deaths from storms by income groups, 1995–2015

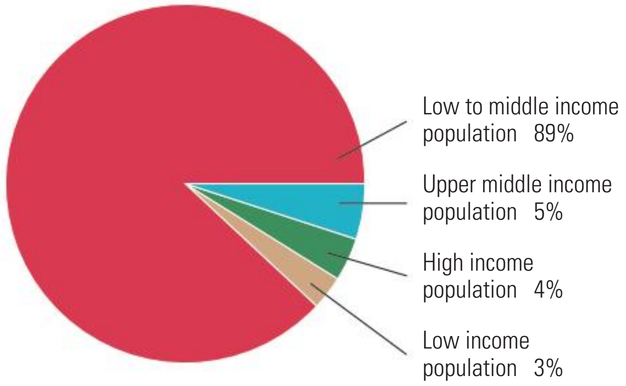


Figure 2.7 shows a marked increase in the number of disasters over six decades of data, mostly due to climate-related disasters such as droughts, floods and wildfires. The number of reported weather and climate-related disasters have more than tripled in the period. At the same time the number of geophysical disasters such as earthquakes and landslides has remained stable.

Since 2000, an annual average of over 300 natural disasters was registered by CRED. But as Figure 2.7 shows, there can be significant variations year to year in the number of natural disasters.

The damage caused by natural disasters each year is measured in billions of dollars. In the 2010s global damage costs averaged between US$100 to US$150 billion. These figures are well in excess of the annual averages of the 1980s when damage costs totalled less than US$50 billion. There have been some extreme variations year by year. A peak of US$350 billion was reached in 2011 following the Great East Japan Earthquake and subsequent tsunami.

Natural disasters can accentuate economic challenges at specific locations such as a suburb, city or *region*. Many small nations, such as Samoa, Vanuatu, Haiti, Madagascar and Mozambique, have limited economic development and resources. The cost of recovery and rebuilding from a single hazard event can overwhelm their financial and technological resources.

On average, natural disasters have resulted in the deaths of less than 75,000 people a year since 2000, as Figure 2.8 (a) shows. A far larger number of people were injured, made homeless or suffered severe shock. Figures 2.8 (b) shows the global disparity in where the natural disasters occurred and the location of their victims. Over 60 per cent of deaths from natural disasters occurred in low-income to middle-income countries such as India, China, Indonesia and the Philippines. Variations in the number of deaths between *regions* reflects a range of factors including the severity of the hazard event and the preparedness of the local population and authorities to deal with the immediate crisis and longer-term recovery. It is also determined by the number of people living in the *region* and its level of development. A less populated and less developed *region* may produce low damage levels compared to a more populated and more developed *region*. In these scenarios, there is a strong *spatial association* between population density, the level of development and the amount of likely damage. Figure 2.8 (c) provides some evidence for this association.

More and bigger disasters?

Analysts have begun to refer to some large-*scale* disasters, either natural or human induced, as megadisasters. To be considered a megadisaster, deaths totalling over 100,000 people need to occur from a single event. At this *scale* considerable damage is likely to have occurred to the *environment* and infrastructure. Megadisasters are not new in human history as Figure 2.9 indicates. The world's media frequently report disasters, both natural and technological ones. Sometimes they seem to be occurring with greater frequency and at greater magnitude than previously. Several *interconnecting* explanations can be given for this trend:

- The world's population has grown substantially from around three billion in 1960 to over 7.8 billion in 2020. Over 50 per cent of the world's population is urbanised and cities have grown considerably in size. A disaster, such as an earthquake or pollution of a water supply, affecting an urban area of less than one million people could have very different consequences to one affecting an urban area with over ten million people. Within low to middle income countries, there are many rapidly growing urban areas such as Jakarta, Mumbai and Lagos. Steep or flood-prone land, once rejected for housing and infrastructure, is being built on. These informal settlements, like the one in Figure 2.1 (c), are often built without basic infrastructure of drainage, water or electricity, or a secure building foundation. People using these areas may become at risk from landslides, avalanches, flooding or subsidence.
- Economic development of a *region* involves the construction of transport facilities, energy and water networks as well as industrial and service complexes. Large *scale* industrial developments in *places* such as China, India, Bangladesh, South Africa, Brazil and Mexico add to the potential risk of technological hazards. With greater wealth, people's homes become larger and filled with more valuable goods. If a hazard event affects such an area the likelihood of considerable damage is raised. Arguably, development should also bring better planning, prevention and mitigation for hazard events. This should reduce the risk of damage and death (see also page 36).
- Global media networks have rapidly expanded since the 1970s providing coverage of hazard events and disasters. Disasters in *regions* with more intensive media networks such as those in North America, Japan and Europe, are usually covered more frequently and in greater depth than ones in central Africa or west Asia. This increase in information about disasters raises the perception that there are more and more disasters occurring at any one time. The increases in registered natural disasters with CRED since the 1950s (see Figure 2.7) are partly due to the improvement in international communications.
- Climate *change* appears to be playing an important part in increasing the frequency of hazard events. In particular, atmospheric events (such as extreme weather involving storms, floods and droughts) are increasing in *distribution*, intensity and frequency. Climate *change* is predicted to produce rises in sea level of around one metre by 2100. This will be a further hazard risk for populations in low-lying coastal areas of the Earth. Coastal populations, like those in coastal Queensland in Figure 2.10, are particularly vulnerable to tropical storms and coastal flooding. Page 31 looks at this phenomenon in more detail, including the role played by human activity.

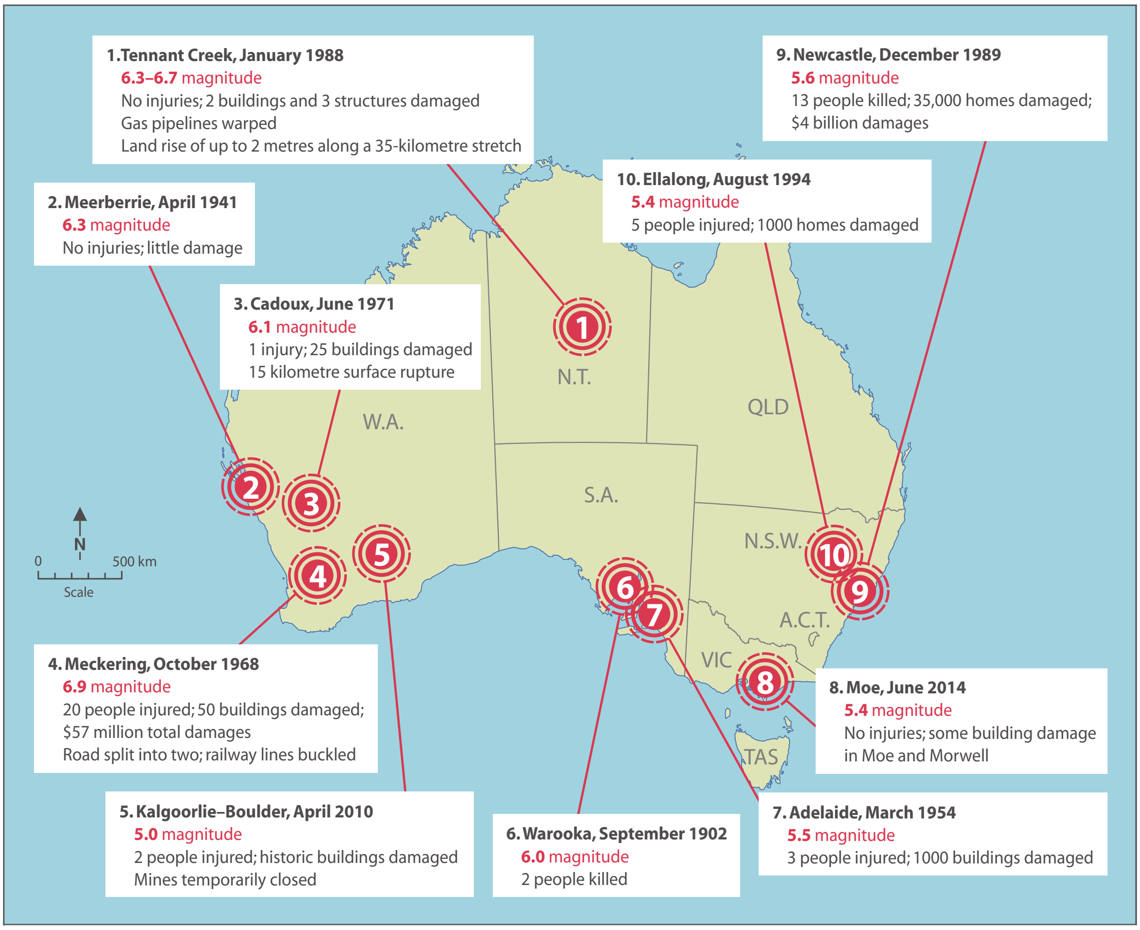
▼ **Figure 2.9** The world's megadisasters, by fatalities

Location	Cause	Date	Fatalities* (estimated millions)
Europe	Plague	1346–53	75–200
World	Spanish influenza pandemic	1918	50
Huang He River, China	Flood	1931	1–4
Huang He River, China	Flood	1867	1.5
World	COVID-19 pandemic	2020–21	3.8+
Huang He River, China	Flood**	1938	0.9
Shaanxi, China	Earthquake	1556	0.83
Bangladesh	Cyclone, Flood	1970	0.5–1.0
Haiphong, Vietnam	Cyclone, Flood	1881	0.3
Indian Ocean *region*	Tsunami	2004	0.28
Antioch (Antakya, Turkey)	Earthquake	526	0.25–0.3
Tangshan, China	Earthquake	1976	0.24
Haiyuan, China	Earthquake	1920	0.24
Aleppo (present-day Syria)	Earthquake	1138	0.23
Haiti	Earthquake	2010	0.22
Mount Tambora (present-day Indonesia)	Volcano	1815	0.2

* excludes war fatalities
** resulting from an act of war

Figure 2.10 A coastal population, in Queensland, that is vulnerable to tropical storms or coastal flooding

Figure 2.11 Selected Australian earthquakes



1. Tennant Creek, January 1988
6.3–6.7 magnitude
No injuries; 2 buildings and 3 structures damaged
Gas pipelines warped
Land rise of up to 2 metres along a 35-kilometre stretch

2. Meerberrie, April 1941
6.3 magnitude
No injuries; little damage

3. Cadoux, June 1971
6.1 magnitude
1 injury; 25 buildings damaged
15 kilometre surface rupture

4. Meckering, October 1968
6.9 magnitude
20 people injured; 50 buildings damaged;
$57 million total damages
Road split into two; railway lines buckled

5. Kalgoorlie–Boulder, April 2010
5.0 magnitude
2 people injured; historic buildings damaged
Mines temporarily closed

6. Warooka, September 1902
6.0 magnitude
2 people killed

7. Adelaide, March 1954
5.5 magnitude
3 people injured; 1000 buildings damaged

8. Moe, June 2014
5.4 magnitude
No injuries; some building damage
in Moe and Morwell

9. Newcastle, December 1989
5.6 magnitude
13 people killed; 35,000 homes damaged;
$4 billion damages

10. Ellalong, August 1994
5.4 magnitude
5 people injured; 1000 homes damaged

Always a disaster?

Not every hazard becomes a hazard event and not every hazard event becomes a disaster. The impact of hazard events varies greatly throughout the world and throughout time. They differ in the *change* they make to *environments*, the quantity of damage caused, the number of people killed or injured, and the time taken for a population and the *environment* to recover.

Some hazard events are simply that, with no disastrous impacts. For example, a tropical cyclone *moving* onto a coastal *region* may damage some vegetation and associated rain may cause flooding. But if few people live in the area and no life forms are threatened with extinction, it will probably not be considered a disaster. On the other hand, if the cyclone brings heavy rain that results in flooding into more populated *regions*, then the risk level rises, and a disaster may develop.

In other words, disasters result when hazard events adversely affect people and their activities. Hazard events have been occurring throughout the Earth's history and are often important natural *processes*. It is only when they negatively affect people that they have been considered disasters.

Hazards can bring benefits

Hazard events and disasters are frequently regarded by many people as something negative. But the *processes* linked to hazard events also bring benefits to people and the *environment* at local, national and global *scales*. Consider the following examples:

- **Bushfires.** Many native Australian plants have adapted to depend on bushfires to regenerate. This may be as new shoots from a tree's crown, from lignotubers at the base of a tree, or the opening of thick woody seeds onto ash-fertilised ground. Figure 2.12 is an example of vegetation regrowth one year after bushfires near Kinglake in Victoria. The new growth can provide habitats for birds and reptiles as well as provide an opportunity for new species of vegetation to invade; and fire often returns valuable nutrients to the soil. As a result, biodiversity may be stimulated by the hazard event. Chapter 4 examines the *processes* associated with bushfires in greater detail.
- **Floods.** Despite the devastation floods can bring to a *place*, they can produce positive aspects. The floodplains and deltas of the world, including those of India, Bangladesh, Myanmar and Vietnam, benefit from fine silt deposited by receding waters. This can increase the fertility of floodplains for farming. Furthermore, flood waters replenish rivers, lakes and ponds after dry seasons. A source for domestic and farm water is renewed. In drier areas, such as around Australia's Lake Eyre, renewed lakes become a breeding ground for wildlife, especially birds. Dormant seeds are germinated, and groundwater aquifers are recharged as water seeps into soil and rocks.
- **Volcanic eruptions.** These can produce extensive outpourings of lava and ash in many parts of the world. As these outpourings have weathered, their nutrients are released and, depending on the chemical composition of the ash and lava, fertile soils can result. These soils, combined with sufficient rain and warm temperatures, have become the basis for some of the world's most productive agricultural land. For example, the *region* around Naples (Italy) is a particularly fertile farming *region* for fruit, vegetables and flowers. Java and Bali (Indonesia) are in a productive rice, coffee and vegetable growing *region*. Figure 2.13 is a volcanic *region* near the Mayon volcano in the Philippines developed on volcanic soils.
- **Drought.** Much of the Australian continent experiences severe droughts. These negatively affect farming, manufacturing and urban life as well as our natural *environments*. Recurring droughts have stimulated more accurate long-term weather forecasting, the building of dams to ensure water supplies to rural and urban areas, and the development of dry-farming techniques to cope with water shortages. The impacts of climate *change* in Australia and elsewhere is spurring further research and development into drought tolerant plants and animals.

▲ **Figure 2.12** Vegetation regrowth 12 months after a major bushfire

▲ **Figure 2.13** Fertile agricultural land developed on volcanic soils in the Philippines

- **Research.** The risk of hazard events and subsequent disasters has prompted considerable research into causes, impacts and the means of reducing or removing the risk. This research occurs at many levels from local councils dealing with waste disposal to international bodies such as the Intergovernmental Panel on Climate Change (IPCC), which investigates the causes as well as the likely impacts of climate *change*. The development and application of geospatial technologies (see page 34) to produce modelling for prediction, recovery and mitigation of risks and hazard events is producing positive results.

ACTIVITIES

1. 'The total number of disasters, and their impacts, has steadily increased in the 21st Century.'

   Do you agree or disagree with this statement, and why?
2. Which two disaster types shown in Figure 2.7 have been most widely reported since 1970?
3. Refer to Figure 2.8 (a). In the period before the 1990s, which two disaster types were responsible for the largest number of deaths globally? Brainstorm reasons why this is no longer the case.
4. 'There is a *spatial association* between the location of the number of deaths from natural disasters and the location of the numbers affected.' Would you describe this *spatial association* as strong, moderate or weak? Be sure to give reasons for your evaluation.
5. Refer to Figure 2.9.
   a. Which continent has had a disproportionate number of high-fatality disasters?
   b. Which major disasters would have directly affected Australia?
   c. Are most disasters associated with geological, atmospheric, biological or technological hazards?
   d. Select one of the disasters in the table for further investigation. Discover the causes and impacts of this disaster. Evaluate how important human activity was in developing or preventing the seriousness of the disaster. How widespread and long lasting were its effects? What role did the national government and international governments play in dealing with the impacts of the disaster?
6. Look at the data in Figure 2.11.
   a. Which of these hazard events do you consider to be a disaster? What other information would help your decision?
   b. Rank the ten events from the most serious to the least serious. Discuss your ranking methods and the results produced with at least one other person.
7. 'Only people make a hazard event a disaster.'

   Discuss this statement using examples to support or reject this hypothesis.
8. Examine Figure 2.12.
   a. What benefits will the regeneration of vegetation shown in this photograph produce?
   b. What could interrupt this regeneration of the vegetation?
9. The volcanic eruptions that helped produce fertile agricultural land can result in other benefits. Discover these benefits through research starting with these key words: Vesuvius; Pompeii; volcanic minerals.
10. Brainstorm with another class member to think of benefits that could result from flooding.

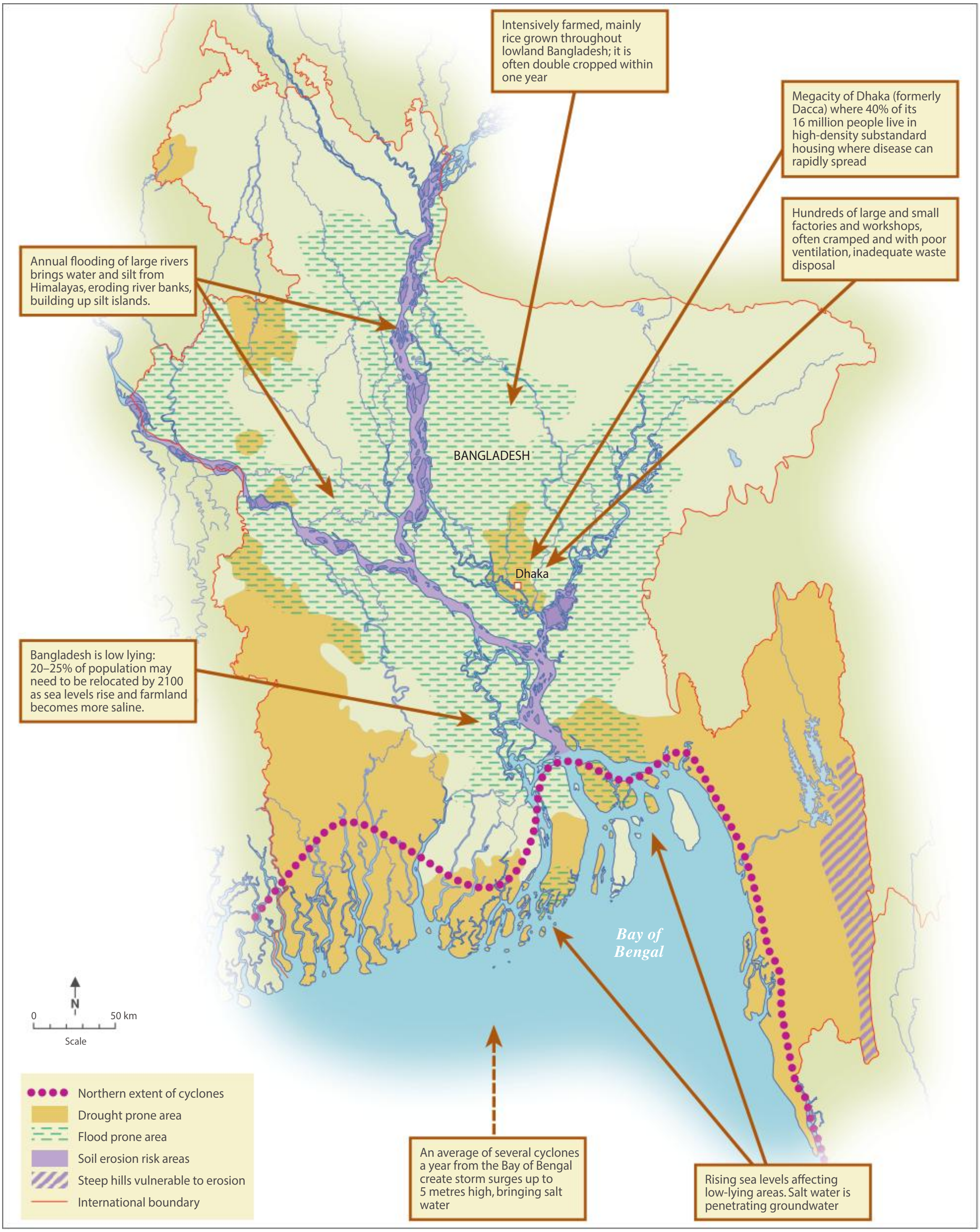
CASE STUDY Bangladesh: Managing hazards

Bangladesh is a small country (almost half the size of Victoria) in South Asia. In 2020 its 165 million people were some of the world's poorest with a Gross Domestic Product (GDP) per person averaging US$1250. Despite significant improvements since the 1980s, over 30 per cent of Bangladeshis live below national poverty levels. Bangladesh's *environments* and people are at risk from a large range of natural and human hazards. Figure 2.15 summarises the *distribution* of the causes of Bangladesh's major hazards. Most of the nation is an enormous floodplain (75 per cent is less than ten metres above sea level) formed from the Padma (known as the Ganges in India), Brahmaputra and Meghna rivers. Between June and September each year the *region* receives heavy monsoon rains. These rains are life-giving to farmers as they recharge rivers and ponds with water, provide water for cropping and deposit fertile sediments on the land.

▲ **Figure 2.14** Flooding affects Bangladesh's urban areas as well as its farmlands

These benefits can be countered by hazard events of flooding, erosion and the spread of disease. The 2016 flood map (Figure 2.16) shows the impact above average rains can produce. The flat, saturated land means flood waters are slow to drain away or seep into the soil. Damage to crops and the need to replant can have a negative impact on farming communities especially those with low or no surpluses of cash or food.

Many of Bangladesh's hazards are *interconnected* and can contribute to a series of further hazards. For example, loss of farmland due to flooding and erosion forces thousands of people to *move* from farming areas into urban areas. In the cities, living conditions may be cramped, poorly drained and unhygienic – ideal conditions for the spread of diseases such as diarrhoea, typhoid and malaria. Hazard events continue to be disastrous for Bangladesh but markedly less than



Intensively farmed, mainly rice grown throughout lowland Bangladesh; it is often double cropped within one year

Megacity of Dhaka (formerly Dacca) where 40% of its 16 million people live in high-density substandard housing where disease can rapidly spread

Hundreds of large and small factories and workshops, often cramped and with poor ventilation, inadequate waste disposal

Annual flooding of large rivers brings water and silt from Himalayas, eroding river banks, building up silt islands.

Bangladesh is low lying: 20–25% of population may need to be relocated by 2100 as sea levels rise and farmland becomes more saline.

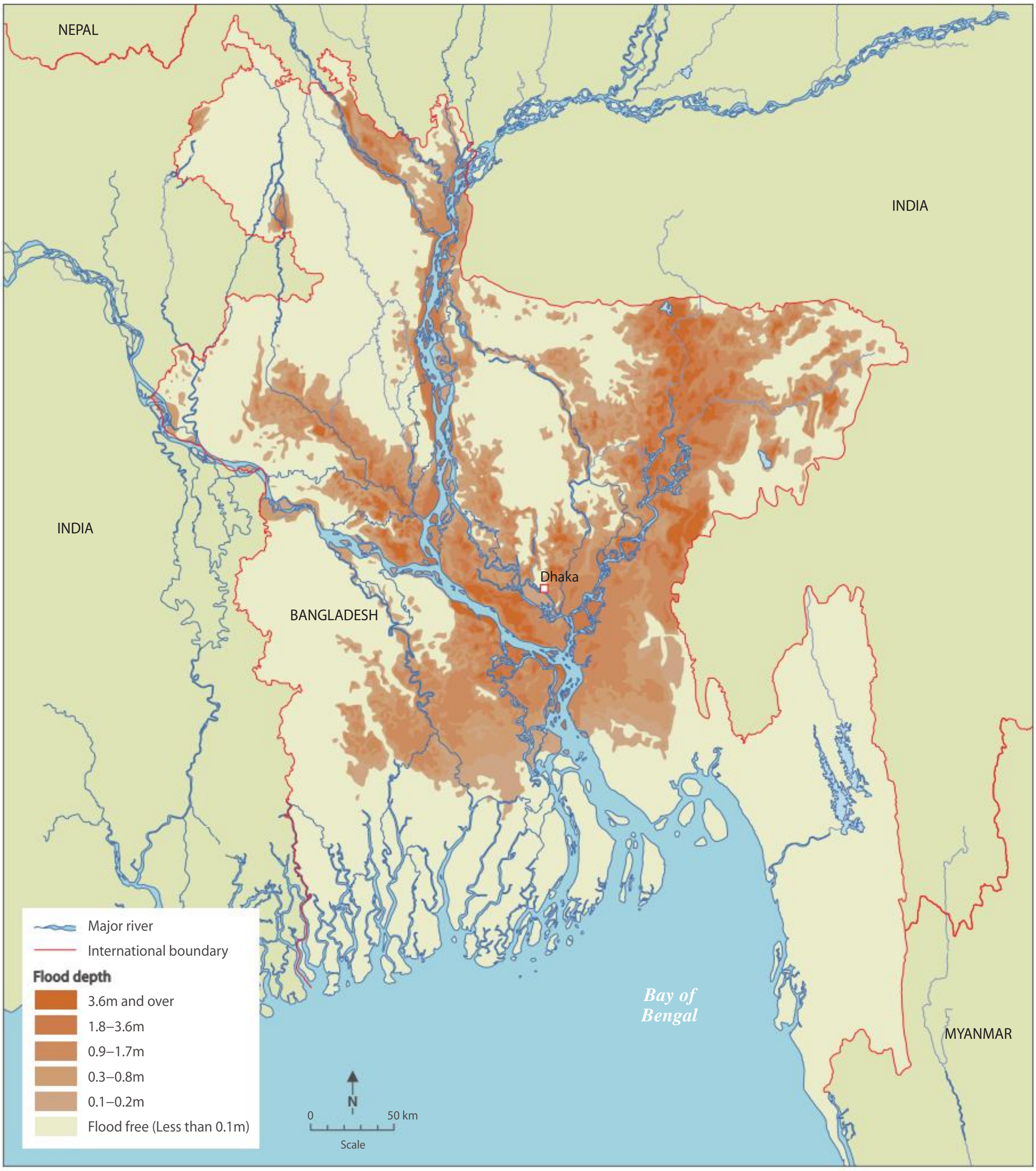
An average of several cyclones a year from the Bay of Bengal create storm surges up to 5 metres high, bringing salt water

Rising sea levels affecting low-lying areas. Salt water is penetrating groundwater

▲ **Figure 2.15** Bangladesh's hazards

30 to 50 years previously. Nonetheless, CRED (page 21) estimates that since the 1990s, Bangladesh's tropical cyclones have caused over 145,000 deaths, adversely affecting 40.5 million people and causing economic losses totalling over US$50 billion.

Thousands of killas, or secure concrete structures, in rural areas provide emergency shelters during cyclonic storms and flooding. The Bangladesh Meteorological Department, using a Cyclone Classifier Model, is able to issue information on wind speed, surge depth of coastal waves and potential damage to housing, embankments and cropland. Evacuation decisions can be made and relayed to the nation's 100 million mobile phone users. The armed forces are on alert for evacuation and delivery of relief supplies when a hazard event occurs. Reinforced river embankments are reducing the risk of flood inundation to rural areas, towns and cities.



▲ **Figure 2.16** The *distribution* of floodwaters, August 2016

ACTIVITIES

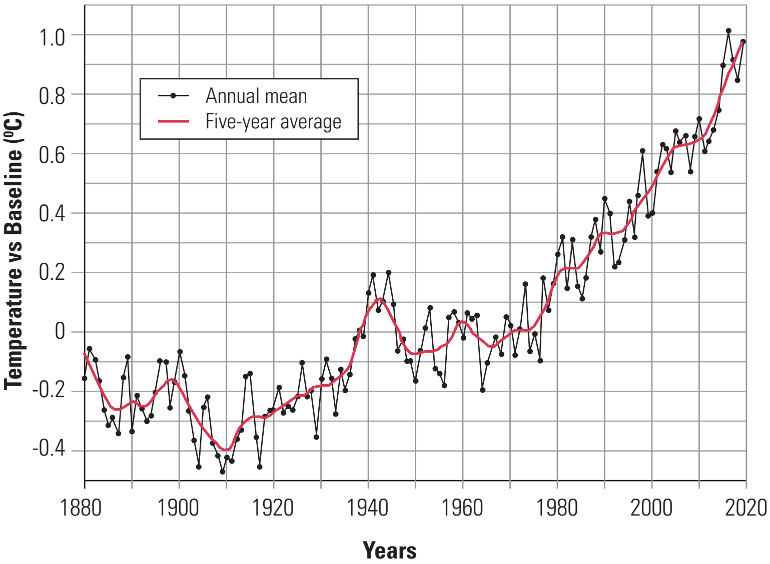
1. Use Figure 2.15 to identify at least six hazards facing Bangladesh. Classify these hazards into the groups outlined on page 19.
2. Discuss the level of *spatial association* that exists between Bangladesh's high population density and the level of risks from hazards faced by its populations.
3. Referring to Figure 2.14, describe the hazard event and suggest its likely causes.
4. How might the *interconnection* between extensive flooding in Bangladesh's farmlands lead to other hazards?
5. Discuss which technological hazard appears to be most damaging to Bangladesh.
6. Locate the BBC Two documentary *Tropic of Cancer*, Episode 5, and watch the opening section on Bangladesh. What hazards and hazard events can you identify? What responses to these situations have developed? Do you think these responses will be effective in the long term?

Climate *change* and hazards

What is climate *change*?

Climate *change* is a *process* that refers to *change* in global climates and patterns in the long term. For example, approximately 20,000 years ago the Earth was experiencing a major ice age. Enormous ice sheets covered large areas of North America, Asia and Europe. Ice held so much water as solids that sea levels were up to 125 metres lower than the present day. From around 15,000 years ago the Earth's atmosphere began to experience warmer and wetter periods. Sea levels rose as vast ice sheets and mountain glaciers melted and as warmer ocean surface waters expanded. In this period Tasmania and New Guinea became separated from the Australian mainland. Globally, there were significant *changes* in the *distribution* of different types of landscapes, vegetation cover and animal species. This cycle of intense global cooling and warming is one of many climate *changes* that have occurred throughout Earth's history.

▼ **Figure 2.17** Global temperature *changes*, annual and five-year averages, 1880s–2020



Since the 1800s and corresponding with the Industrial Revolution and its wider use of fossil fuels, Earth has been experiencing rising average annual surface temperatures. Figure 2.17 shows this upward trend in temperature *changes*. Each decade since the 1880s temperatures have risen by an average of 0.07°C. But since 1981 the rate has averaged over twice that rate. Nine of the ten warmest years on record have all been since 2005.

Natural causes of climate *change*

There are several natural causes contributing to climate *change*.

a. Variations in solar output

The amount of solar radiation received by the Earth varies. Milankovitch's theory, developed in the 1920s, hypothesised that variations in the Earth's orbit and tilt of its axis produced regular short and long term variations in climate by affecting the amount of solar radiation reaching the Earth's atmosphere. Past ice ages, warming periods (interglacials) and unseasonal weather were the result. The Intergovernmental Panel on Climate Change (IPCC) believes that Milankovitch cycles contribute little to the current period of rapid warming.

b. Volcanic activity

Gases, ash and dust from volcanic activity (Figure 2.18) can spread into the atmosphere across many thousands of square kilometres. Apart from the potential risks to people and *environments* (see Chapter 3), these particles block the sun's rays and reduce *regional* and global surface temperatures by several degrees. This reduction may last a few weeks or even years. The 1991 eruption of Mount Pinatubo in the Philippines is estimated to have cooled global temperatures for two to three years by approximately 0.4°C.

◀ **Figure 2.18** The 2010 eruption of Iceland's Eyjafjallajökull volcano poured around a megaton of material into the stratosphere but this was insufficient to impact on *regional* climates

c. Oceanic circulation *changes*

Changing ocean currents impact on the exchange of heat between oceans and the atmosphere. In the Pacific *region*, the impact of El Niño can produce wetter and milder seasons for the western Pacific and drier and hotter seasons for the Australasian *region*. These events can last several years before reversing locations. On a global *scale*, past *changes* to the thermohaline oceanic circulation have brought about major shifts in global climate, sometimes rapidly and at other times much more gradually. A large-*scale* melting of Greenland's ice cap could dump trillions of tonnes of cold fresh water into the North Atlantic Ocean. This would affect water salinity and temperature, thereby disrupting ocean circulation and *changing* climates in Northern Europe and other parts of the globe.

Human activity as a cause of climate *change*

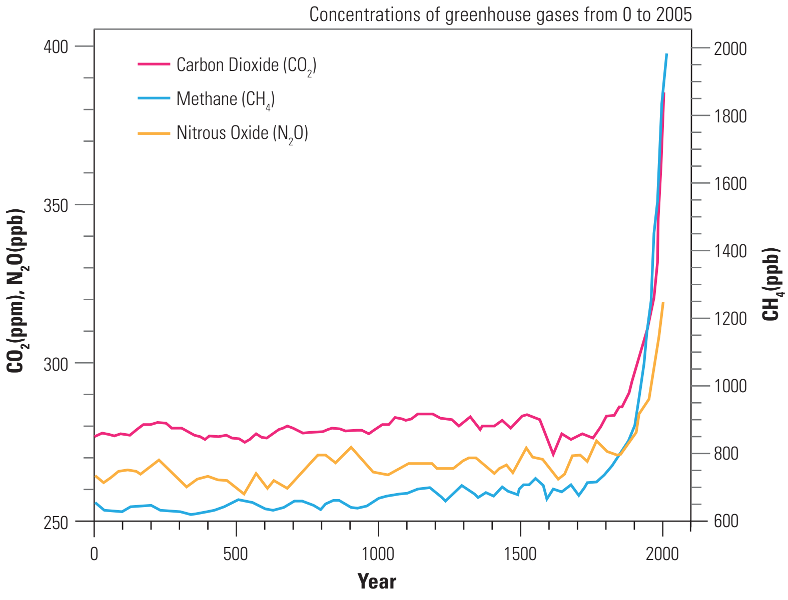
▶ ***Changing*** **atmospheric gases**

The energy needed for industries, transportation, housing and commercial activities has mostly come from the burning of fossil fuels. These fossil fuels, especially coal and oil, contribute to the increase in greenhouse gases in the atmosphere when burnt. These gases are mainly carbon dioxide, methane, fluorocarbons and nitrous oxides (see Figure 2.19). With a greater concentration of greenhouse gases in the atmosphere, more long wave radiation is absorbed, warming the Earth.

▶ ***Changes*** **in land cover**

Forests can absorb billions of tonnes of carbon dioxide, thus taking much of the greenhouse gases emitted elsewhere. Once forests are cleared and replaced with farmland, industry and urban structures, there are fewer plants to absorb carbon dioxide. Cleared land allows carbon in the soil to react with oxygen in the atmosphere to produce carbon dioxide. Since the 1980s global rates of deforestation have slowed. In the 2010s an average of around three million hectares a year was still being cleared. The greatest losses have been in the tropical forests of Central and South America, South-East Asia and Africa. Clearance of swamps and melting of permafrost in tundra disturbs the methane cycle releasing increased amounts of methane, another significant greenhouse gas.

▼ **Figure 2.19** *Changes* in atmospheric gases



▶ ***Changes*** **in land use**

Increases in population have led to more land being used for agriculture, industry and urban facilities. Agriculture, according to the United Nations Food and Agricultural Organization (FAO) is estimated to produce between 14 and 18 per cent of the Earth's greenhouse gases. The world's one billion cattle are major producers of methane (mostly from burping), each averaging over 250 litres a day. Organic matter from plants decomposes and produces methane. Inorganic fertiliser can release nitrous oxide. Farm machinery is manufactured and operated using fossil fuels.

The *change* from rural to urban land use, as in Figure 2.20, is a global *process*. More than 50 per cent of the global population is urbanised. Urban areas create heat islands with concrete and asphalt surfaces absorbing then reradiating heat and raising local temperatures by several degrees. Urban residents rely on manufactured energy for heating, cooling, lighting, cooking, transport and work. Traditionally the sources of this energy have come from burning fossil fuels.

▶ ACTIVITIES

1. Describe the trend in global surface temperatures between the 1880s and the 1950s using Figure 2.17. How does this compare to the period after the 1950s?
2. Research to discover which of the following areas were largely covered with ice more than 20,000 years ago:

   Australia; Canada; Iceland; India; Scandinavia; South Africa
3. Which of the natural causes of climate *change* is least likely to affect Australia? Be sure to say why.
4. Investigate what is meant by thermohaline oceanic circulations. Why could *changes* in one part of the Earth's oceans affect all other parts?
5. What are fossil fuels? Why have people needed to use them in such large quantities?
6. Explain how large-*scale* forest clearances in Brazil could contribute to increases in global temperatures.
7. The area in Figure 2.20 is *changing* to an urban-industrial one. What contributions could this *place* make to the Earth's greenhouse gases? Are there alternatives?

Impacts of climate *change*

Changes in climate conditions raise the risks of hazard events including:

- more frequent and more intense storms
- rising sea levels that would flood low lying coastal areas and cause increased soil salinisation there
- loss of farmland and natural habitats as temperatures and rainfall regimes *change*
- pressure on water supply to urban populations
- the possibility of increased spread of diseases.

a. Sea level rise

With the upward trend in global temperatures, the melting of ice sheets in Antarctica and Greenland, as well as thousands of land glaciers, is accelerating. Melt water flowing from the land to the sea is raising sea levels. In addition, higher temperatures in the atmosphere is causing ocean waters to expand. The IPCC estimates that under current conditions an average rise of 1.1 metres is probable by the end of the century. Rising sea levels raise the risk and likelihood of hazard events for low lying areas and islands. Vulnerable populations include those living in Bangladesh (see page 26), southern Vietnam (Figure 2.29), Florida, Kiribati and the Maldives. Cities most vulnerable to sea level rise include New York, Fort Lauderdale, Shanghai, Bangkok and Alexandria. As many as 1.4 billion people could be displaced by 2060, according to analysis from Cornell University in the United States. The combination of rising sea levels with more frequent and more intense storms raises the risk of coastal erosion. Figure 2.21 is one of many examples already occurring on low lying coastal areas.

b. More extreme weather

Extreme weather events include heat waves, prolonged droughts, storms and floods. Meteorologists believe the increase in extreme weather events is associated with higher land and sea surface temperatures resulting from global warming. The higher temperatures result in more water vapour and latent heat in a warmer atmosphere. This combination leads to greater frequency and intensity of storms. Chapter 4 looks at this phenomenon in greater detail.

c. *Changing* growing seasons

Higher temperatures may enable some growing seasons for natural vegetation and crops to lengthen. *Places* that have present day milder climates could find this advantageous. But it may be a disadvantage if the increase in temperature is spatially associated with drier conditions. Much of Australian grain and livestock farming operates in marginal and unreliable rainfall areas. Prolonged droughts combined with higher temperatures could force many farmers out of business. In addition, the amount of grain, meat and other agricultural products available for sale could be threatened.

The Arctic *region* covers extensive areas of Siberia, Alaska, northern Canada and Greenland. Figure 2.22 is representative of one very small part of this *region*. Much of the ground is permafrost meaning the subsurfaces are frozen soil and plant matter. Only low and sparse vegetation can be supported. With rising temperatures,

▲ **Figure 2.20** Land use *change* in Malaysia

▲ **Figure 2.21** Part of New Caledonia's Pacific coast that is suffering from rising sea levels and more frequent strong storms

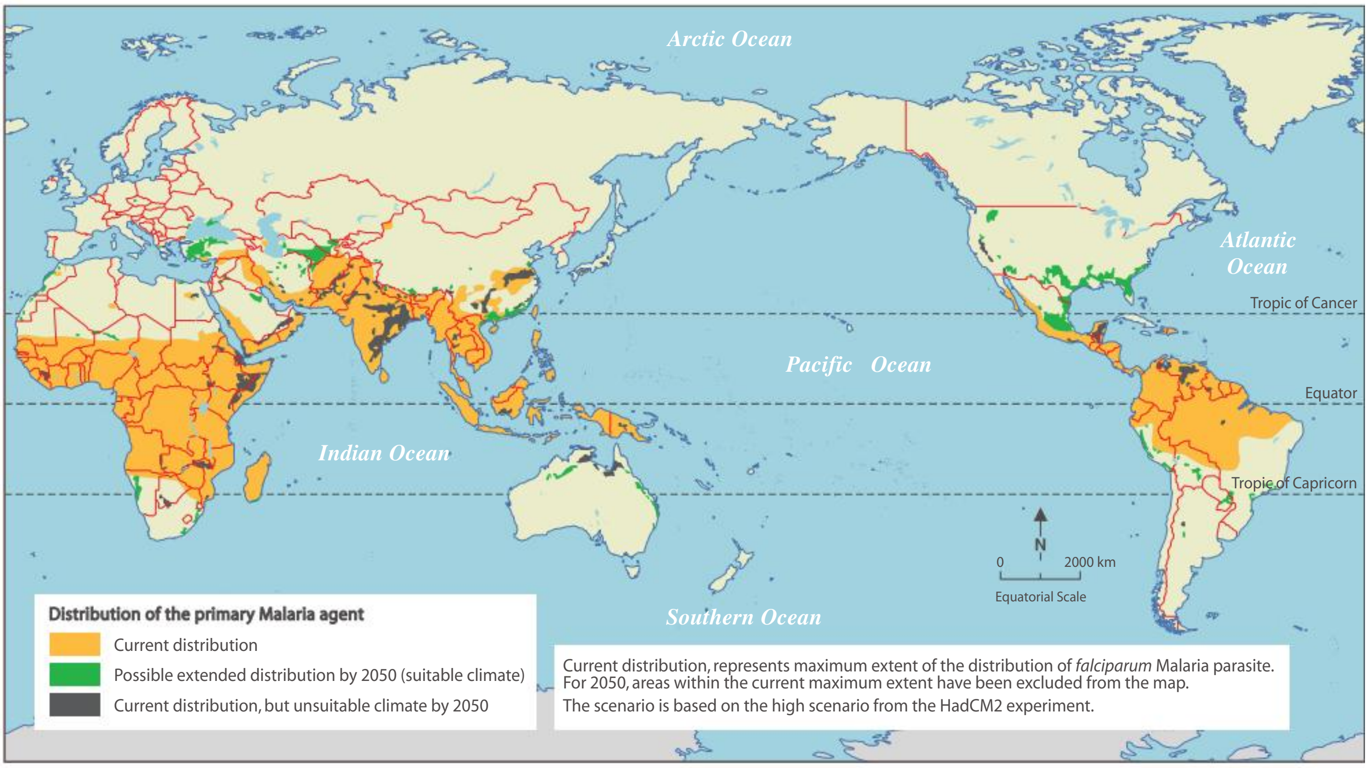
▲ **Figure 2.22** The ground in *region* of Oymyakon in Siberia, Russia is permafrost the frozen lower ground levels are melting and releasing stored carbon into the atmosphere. The IPCC estimates that permafrost *regions* may be storing 1600 gigatons of carbon – twice the amount already in the atmosphere. A further hazard *interconnected* with rising temperatures in these *regions* has been the phenomenal increase in insect numbers, particularly mites and mosquitoes. The natural *environments* of animals such as the Arctic fox and polar bear are being threatened.

d. Spread of infectious insect-borne diseases

Insect-borne diseases are ones transmitted to humans or animals by insects. The increase in warmer and wetter conditions in some parts of the Earth are extending breeding conditions for some insects, notably mosquitoes. Malaria, which kills over 400,000 people annually is spread by mosquitoes. The disease has been reported in areas where previously it was undetected: the highlands of east Africa, and the foothills of both the Himalayas and Andes mountain ranges. Figure 2.23 shows the current and projected *distribution* that is possible as climate *changes*. Malaria may be expanding into some of these areas due to non-climatic factors: insect resistance to eradication methods, poor implementation of control programs and inadequate local health services.

Dengue fever infects around 400 million people annually, resulting in advanced illness in 100 million and killing between 20,000 and 25,000 people. Perhaps 40 per cent of the world's population lives in areas at risk from dengue fever. It is caused by a virus transmitted to humans from the bite of an infected mosquito. Like malaria, its *distribution* has *changed*. During this century it has appeared in Europe and North America. Nepal reported cases of dengue fever for the first time in 2004.

▼ **Figure 2.23** Malaria's *distribution* in the late 2010s and its possible *distribution* by 2050



Distribution of the primary Malaria agent

🟧 Current distribution
🟩 Possible extended distribution by 2050 (suitable climate)
⬛ Current distribution, but unsuitable climate by 2050

Current distribution, represents maximum extent of the distribution of *falciparum* Malaria parasite.
For 2050, areas within the current maximum extent have been excluded from the map.
The scenario is based on the high scenario from the HadCM2 experiment.

ACTIVITIES

1. Select one of the cities or *regions* mentioned in the text that is at risk from sea level rise. Research to discover how serious the problem is and what is being done about it.
2. Which areas of Australia are regarded as being at high risk from sea level rise? Try the Geoscience Australia website as a starting point to your investigation.
3. a. Explain how the *interconnection* between sea level rise and increased storm activity could be devastating to a low-lying coastal area such as that in Figure 2.21.
   b. Would the situation in Figure 2.21 have been a rapid onset *process* or a gradual one? What other information would you need to know to be more certain?
4. What possible opportunities could there be for farmers in a drier and warmer southern Australia or in a wetter and warmer northern Australia?
5. Why could the Arctic's rising temperatures and increasing carbon and methane releases from the ground become a hazard event or a disaster for:
   a. people wanting to build infrastructure or live in an area like Figure 2.22?
   b. other parts of the Earth?
6. a. Identify five *regions* from Figure 2.23 where malaria could spread to by 2050.
   b. Estimate as a percentage of the existing areas, the increase in areas vulnerable to malaria by 2050.
   c. Are the major areas of current malarial infection still projected to remain so in 2050?
7. 'Malaria and dengue fever are on-going disasters on a global *scale*.' How far do you agree with this statement?

Responses to climate *change* hazards and disasters

The *scale* and complexity of challenges arising from the impacts of climate *change* is obviously immense. To counter these impacts authorities have responded in several ways. Policies have been developed on an international *scale* as well as by national and local authorities. As well millions of companies, organisations and individuals have implemented their own action plans.

International responses

The United Nations has been instrumental in developing initiatives responding to the impacts of climate *change*. International agreements are primarily aimed at reducing the levels of greenhouse gases in the atmosphere, but reductions in deforestation are also targeted. Unless these international agreements are ratified by each national government, they will have limited effect. Over the past decades these agreements have attempted to become increasingly comprehensive and demanding. This corresponds with the increase in global greenhouse emissions and the urgency shown by IPCC and other research reports.

- The Kyoto Protocol was drawn up in 1997 and came into effect from 2005. It required the most developed countries to reduce their greenhouse gas emissions by at least 5 per cent of their 1990 levels. Countries were encouraged to take on emission reduction projects, such as tree-planting, in less economically developed countries. Despite some successes since the Protocol was first realised, global emissions had increased by more than 30 per cent 15 years later.
- The Copenhagen Conference of 2009 attempted to improve on the Kyoto Protocol. Its accord aims to keep global temperatures within 2°C of those before 1850. Agreements were made on target reductions for each country. Financial aid was offered to developing countries to assist in reducing current and future emissions.
- The Paris Agreement of 2015 with 189 signature countries aims to rapidly reduce emissions to specific targets lower than ones set previously. Climate resilient development, such as renewable energy projects, became a keynote of its aims.

None of the international agreements can be enforced, except by national governments within their own territory. Some countries, such as the United States – a very large greenhouse gas emitter, chose to withdraw from the Paris Agreement, but this decision was reversed early in 2021 after a *change* in government.

The United Nations has been responsible for setting up the Intergovernmental Panel on Climate Change (IPCC). The IPCC brings together the work of hundreds of scientists, including meteorologists, oceanographers, glaciologists, geographers and other specialists who work in different parts of the world. Their reports should allow national policy makers to make clearer and more effective decisions on what to do *regionally* and locally. Their regular updates have often been controversial such as the level of predicted sea level rises, the areas at greatest risk from rising sea levels and storms, as well as the suggested rates needed to lower greenhouse gases in the long term.

National and *regional* responses

For international agreements to succeed, national governments need to implement their own policies. Inevitably the paths taken by countries will vary. Several countries and *regions* aim to be carbon neutral soon: European Union (2050), California (2045), Canada (2050), Iceland (2040). Other countries such as the United States, Saudi Arabia and Russia are still increasing their greenhouse gas emissions more than recommended Paris Agreement targets.

There are many significant successes. For example, Morocco's Noor Ouarazazate solar farm (Figure 2.24) covers the size of 3500 football fields and generates carbon-free electricity to approximately three million people. The low-lying island nation of Maldives is protecting its main island with an enclosing concrete wall as protection against erosion and tsunamis (Figure 2.25). China has become the world's largest manufacturer of solar technology and batteries and the largest manufacturer of electric vehicles. But it is still the world's biggest consumer of coal.

Australia has a national target of a 26–28 per cent reduction from its 2005 greenhouse gas emissions level. The target has been criticised from within and outside Australia as being far too low.

▲ **Figure 2.24** Part of Morocco's drive to achieve 50 per cent renewable energy by 2040 is developing solar energy plants

▲ **Figure 2.25** Male is Maldives' capital city and is protected from ocean-based hazard events by extensive three-metre-high walls

▼ **Figure 2.26** Providing charging facilities for electric vehicles in car parks is a common sight in many European cities

▼ **Figure 2.27** Alexandria, Egypt's second largest city, is at risk from sea level rises and storms that originate in the Mediterranean Sea

Critics argue that the severity of climate-based hazard events such as droughts, bushfires, heatwaves, coastal erosion from sea level rise and storms, and the loss of significant areas of the Great Barrier Reef due to warming and acidification of ocean waters, necessitates more ambitious targets. There is currently no plan to phase out coal-fired power stations or to cut back on coal exports to other countries largely on the basis that such cuts would reduce traditional jobs and income in the mining and transport industries especially in rural *regions*.

Local responses

Local responses include those made by state or provincial governments and local council authorities. Throughout the world many thousands of local responses exist. They range from recycling of household waste, purchasing and favouring electric vehicles (Figure 2.26), planning and building coastal defences (Figure 2.27), planting trees, passing laws on vegetation clearances and developing urban buildings that reduce energy needs.

▶ ACTIVITIES

1. Discuss the advantages and disadvantages of reaching international agreements on measures to reduce the impacts of climate *change*.
2. Similar efforts to Morocco's promotion of renewable energy is found in many other parts of the world. Investigate where in Australia and California this is happening. What impact do you think it is making in reducing greenhouse gas emissions?
3. With the aid of diagrams or a flow chart, explain how extending forest areas could help reduce climate *change* risks, such as sea level rise.
4. Debate the contention that electric cars are a viable option to reduce greenhouse gas emissions worldwide.

Geospatial technology and hazards

Many of Earth's locations are at risk from a hazard event that could take lives and seriously damage property and the natural *environment*. These risk estimates are based on past frequency and strength of hazard events within a *region*, together with relevant additional information such as weather forecasts or seismic recordings of Earth *movements*.

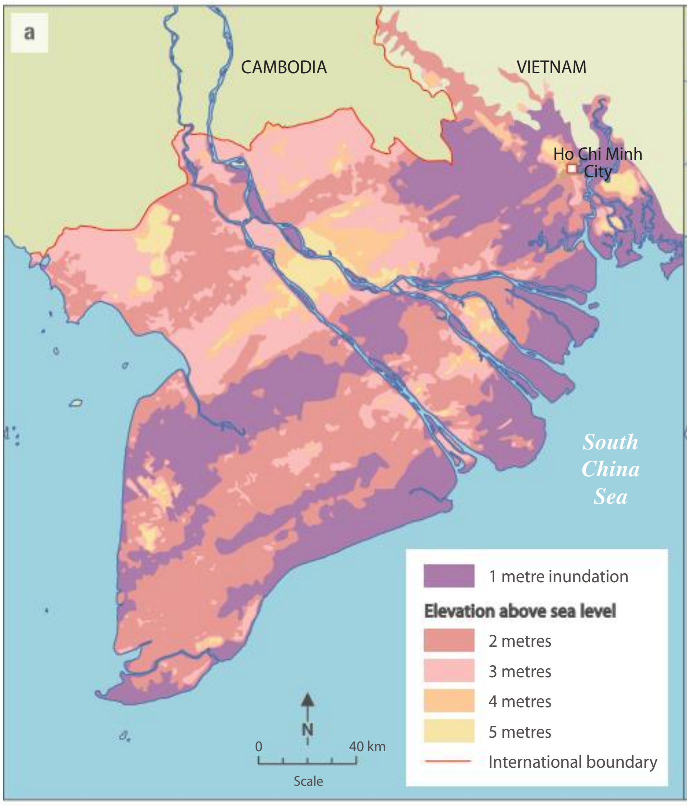
Increasingly, the use of geospatial technology is providing an effective tool for investigating past disasters, trying to predict and/or reduce the negative impacts of hazard events. For example the Hawaii-based Pacific Ocean Warning System collates data from a network of pressure sensors including deep-ocean detectors, seismographs and satellite imagery to monitor and forecast the strength and direction of *movement* of tsunamis. It issues warnings when appropriate, as well as coordinating technological developments throughout the world. Spatial information allows for planning risk management strategies such as developing building codes, planning relevant infrastructure and educating local communities.

Figure 2.28 is part of a map series produced from information recorded by drones flown over Vanuatu in March 2015. Cyclone Pam left about 75,000 people homeless and caused widespread damage. Drones proved of greater value than satellite imagery since cloud cover was so heavy. Drones could be angled to record the damage to buildings. The information plotted was interpreted to assess damage to houses, crops and to determine if locations were accessible to road vehicles. Once plotted, authorities could assess which were the most seriously affected areas and the quickest way to deliver relief. Additional information, such as a *region's* demographic characteristics and the availability of trained personnel can be overlaid or correlated with the damage map. This information could then strengthen relief work decisions.

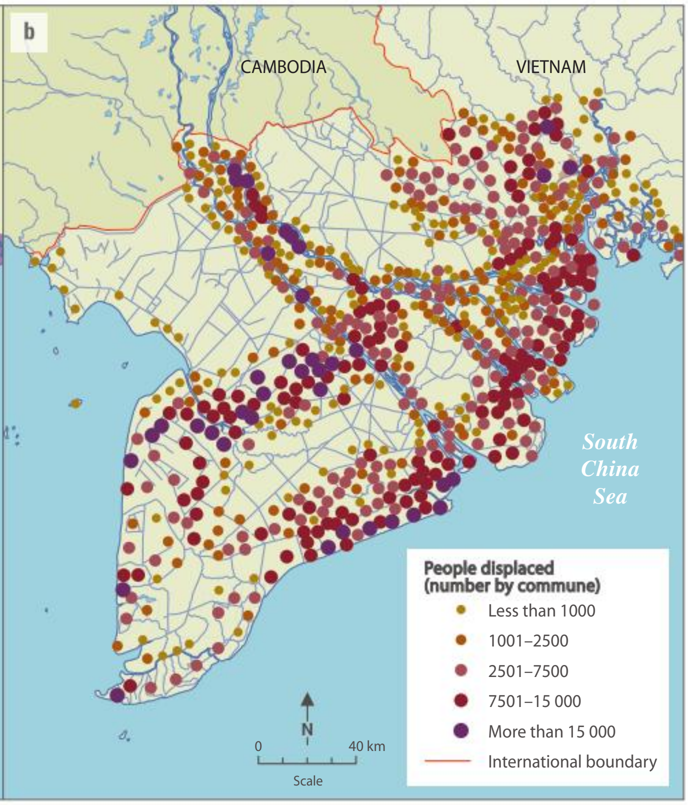
Landslides are a particular hazard in *regions* of hills and mountains that have been cleared of much of their vegetation cover. A series of thematic maps based on satellite images and Geographical Information Systems (GIS) can be produced. These thematic maps cover remaining vegetation, variations in slope and soil type. Predicted rainfall quantities and frequencies are modelled onto these maps. Such modelling can provide early warning of where slopes can become destabilised after rain falls. The necessary preventive measures can be put into place as a result. Authorities in Thailand, Malaysia and the Philippines are increasingly using this technology.

A similar technique has been used to produce Figure 2.29 (a) and (b). Instead of landslides, the focus is the impacts of sea-level rise in the Mekong Delta *region* of Vietnam. Additional maps detailing local variations in drainage and height are designed to add greater accuracy to the modelling.

▲ **Figure 2.28** Map of Cyclone Pam damage, Vanuatu, 2015. Red structures are heavily damaged, blue structures moderately damaged and yellow structures undamaged



▲ **Figure 2.29 (a)** The predicted impact of a one-metre sea level rise in the Mekong Delta *region* of Vietnam



▲ **Figure 2.29 (b)** The number of people likely to be affected by a one-metre sea level rise in the Mekong Delta *region* of Vietnam

Responding to hazards, hazard events and disasters

People respond to hazard events in various ways. For people living in a hazard-prone area there are several broad reactions:

- **Fatalistic.** This approach accepts hazard events as unavoidable. It may be because the events do not greatly affect them, that the event soon passes, or that the processes are seen as supernatural and beyond human control. Communities with limited education and access to external assistance, as well as past experiences of hazard events, believe there is little that can be done about hazard events. This approach has been noted in mountainous areas of Pakistan and Afghanistan after earthquake events.
- **Acceptance.** Many people believe that the risk of living in a hazard-prone *region* is outweighed by the benefits of living in those areas. The urban fringes of most Australian cities are prone to bushfires, especially in the summer and autumn seasons. Yet people continue to want to live in these locations, placing high value on their immediate *environments* (Figure 2.31). Southern California is one of the world's most earthquake-prone *regions*. People still continue to migrate into the *region* believing the lifestyle and work opportunities outweigh the potential disadvantages.

▼ **Figure 2.30** Poverty and low levels of education help produce a fatalistic approach to hazard events

CAREER PROFILE

Sam Hillman

Project Officer – Application Development Bushfire Monitoring, Evaluation and Research, DEWLP

From working on the side of volcanoes in Patagonia, to flying drones across the desert landscapes of the Mallee, to being a part of a team of people executing planned burns in the Otways – Geography, and in particular, the applications in spatial information, have taken me to some diverse parts of the world.

Growing up, I really enjoyed hiking, bike riding and just being outdoors. I studied Geography during VCE and could see that this was the subject that would lead me to where I wanted to be. It is Geography that enables you to make some sense of the world. During my undergraduate degree at The University of Melbourne, I enjoyed being able to study physical Geography – fantastic field trips to New Zealand provided the best lecture theatre to study the impact of climate change and the retreat of glaciers. From glaciers to fires, I then completed a Masters in Spatial Information at RMIT University which focussed on new ways of measuring fuel hazard for fire behaviour.

Following the conclusion of the Masters program, I gained a position in the Science Graduate Program with the Department of Environment, Land, Water and Planning (DELWP). From district to state level operations, I have relished the opportunity to participate in fieldwork activities, from koala monitoring in Cape Otway, fuel hazard monitoring around the state, planned burning and fire response activities and presenting at conferences in the USA. I am developing mobile applications to improve the safety of fire fighters and producing mapping products for the state. This position allows me to combine an interest in Geography and technology, and hopefully have a positive impact for DELWP firefighters and the community.

By studying Geography, a whole world (pun intended) of opportunities has indeed become possible.

- **Adaptation.** People who live in a hazard-prone area but are well prepared for any event can be called adaptive (Figure 2.32). The preparation measures may be personal (for example, a specially designed or modified house, an evacuation or emergency plan of action) or community based (for example, risk assessments from authorities, enforced planning laws, well-equipped rescue and relief teams, advanced technology monitoring). This approach is costly but the most effective in avoiding or reducing damage to property and the loss of lives. Businesses also adapt by factoring in risks to their costs and income, including through insurance policies.

Atmospheric hazard events are mostly very well monitored in Australia. The Bureau of Meteorology (BOM) issues warnings several days in advance and in turn supplements these with regular and local developments. Emergency teams, such as the Country Fire Authority (CFA) in Victoria, are alerted. Prior to an atmospheric hazard event, communities are encouraged to prepare for the event by securing loose rubbish and building materials and to minimise outdoor activity.

In the following chapters of this unit, you will find many variations in response to hazards, hazard events and disasters. They range from attempts at prediction, monitoring events and, increasingly, strategies that reduce the impact of events and even prevent them from happening at all.

▲ **Figure 2.31** Melbourne's outer suburbs are a very attractive option for many households despite a hazard risk from bushfires

ACTIVITIES

1. Refer to Figure 2.3.
   a. Which natural features are located closest to the areas with a more than 60 per cent potential for liquefaction?
   b. Identify the main roads on the map. What potential earthquake hazards are there for these roads, especially at the intersections? What could you advise authorities to do in the event of an earthquake? What would you advise in the longer term?
2. Compare Figure 2.29 (a) and Figure 2.29 (b).
   a. Which districts appear most vulnerable to a one-metre sea-level rise?
   b. Which of these identified districts have greater than 1500 households that could be displaced?
   c. Apart from inundation, suggest what effects a sea-level rise could have on agricultural activities in the Mekong Delta *region*.
   d. How secure from this hazard does Vietnam's largest urban area of Ho Chi Minh City appear to be?
3. Why do you think people continue to live in areas prone to hazard events such as flooding or earthquakes?
4. Suggest why more people do not *move* away from hazard-prone areas.
5. How might subsistence farmers in Papua New Guinea react differently from commercial farmers in Australia to prolonged drought conditions?

▲ **Figure 2.32** Emergency warning systems and operation teams are well established in many communities indicating an adaptation approach

3 Geological hazards and disasters

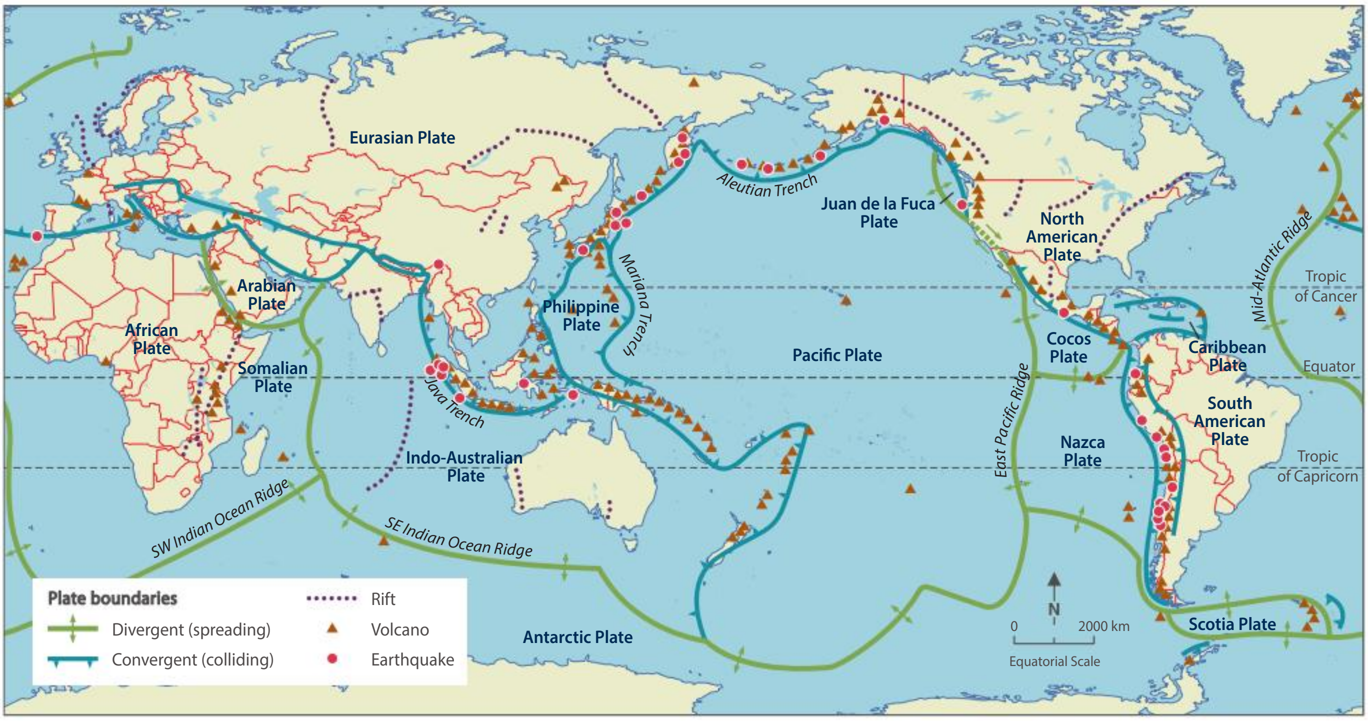
What are geological hazards and disasters?

Volcanoes, earthquakes, landslides and erosion are all geological *processes* that occur throughout the world (Figures 3.1 and 3.2). They are only considered natural hazards or hazardous when they have an impact on people and/or the *environment* – or have the potential to do so. When geological hazards occur as hazard events they can be responsible for immense loss of life and destruction of property in which case they would be classified as a disaster. In the last century, for example, more than one million people worldwide were killed by earthquakes. On 25 April 2015, an earthquake measuring 7.8 on the Richter Scale struck east of the Gorkha District in Nepal. Approximately 9000 people were killed and 22,000 were injured.

Even with present-day technology, most geological events cannot be predicted with any accuracy or prevented. Nevertheless, many areas predisposed to such events can be identified and appropriate mitigation measures can be adopted to reduce potential damage. In Japan, for example, huge shock absorbers, walls that slide and Teflon foundation pads that separate the buildings from the ground all contributed to medium-rise and high-rise buildings remaining upright after the country's largest earthquake in March 2011 (page 48). In *regions* where known hazards exist, for example, Mount St Helens and the San Andreas Fault in the United States, instruments have been installed that can give an indication of impending activity. The Pacific Tsunami Warning System (PTWS), comprising 26 participating international member states, monitors seismic activity in the Pacific Basin.

▼ **Figure 3.1** Classification of geological hazards

Type of geological hazard	Examples of geological hazards
Volcanic eruptions	There are many types of volcanic eruptions with varying impacts. Examples of active volcanoes include: Mount St Helens (north-west USA), Mauna Loa (Hawaii, USA), and Bardarbunga (Iceland).
Earthquakes	These occur along fault lines and release an enormous amount of energy. The Great East Japan Earthquake of 2011 and the Indian Ocean Earthquake of 2004 are examples.
Tsunamis	These giant waves are a result of an oceanic volcanic eruption or earthquake and can be immensely destructive. The powerful Sumatra–Andaman Earthquake (known also as the Indian Ocean Earthquake) on 26 December 2004 triggered tsunamis that destroyed many coastal *regions* of South and South-East Asia.
Landslides	These hazard events are associated with natural *processes* such as earthquakes, rainfall and coastal erosion. However, mining and other types of excavations can also cause landslides. A magnitude 5.1 earthquake on the north side of Mount St Helens triggered a landslide which travelled at 170 to 250 km/h, the largest in recorded history.
Avalanches	An avalanche is the sudden downhill *movement* of snow. In April 2014, 16 Nepalese guides were killed when an avalanche struck Mount Everest Base Camp.
Sinkholes	A sinkhole is a hole in the ground caused by some form of collapse of the surface layer due to erosion or drainage of water. It usually occurs in limestone formations. Human activities like mining, construction or other types of excavation work can result in small or large holes in the ground. Broken water pipes can also cause sink holes. In February 2014 a sinkhole in Bowling Green, Kentucky, swallowed eight Corvettes at the National Corvette Museum.

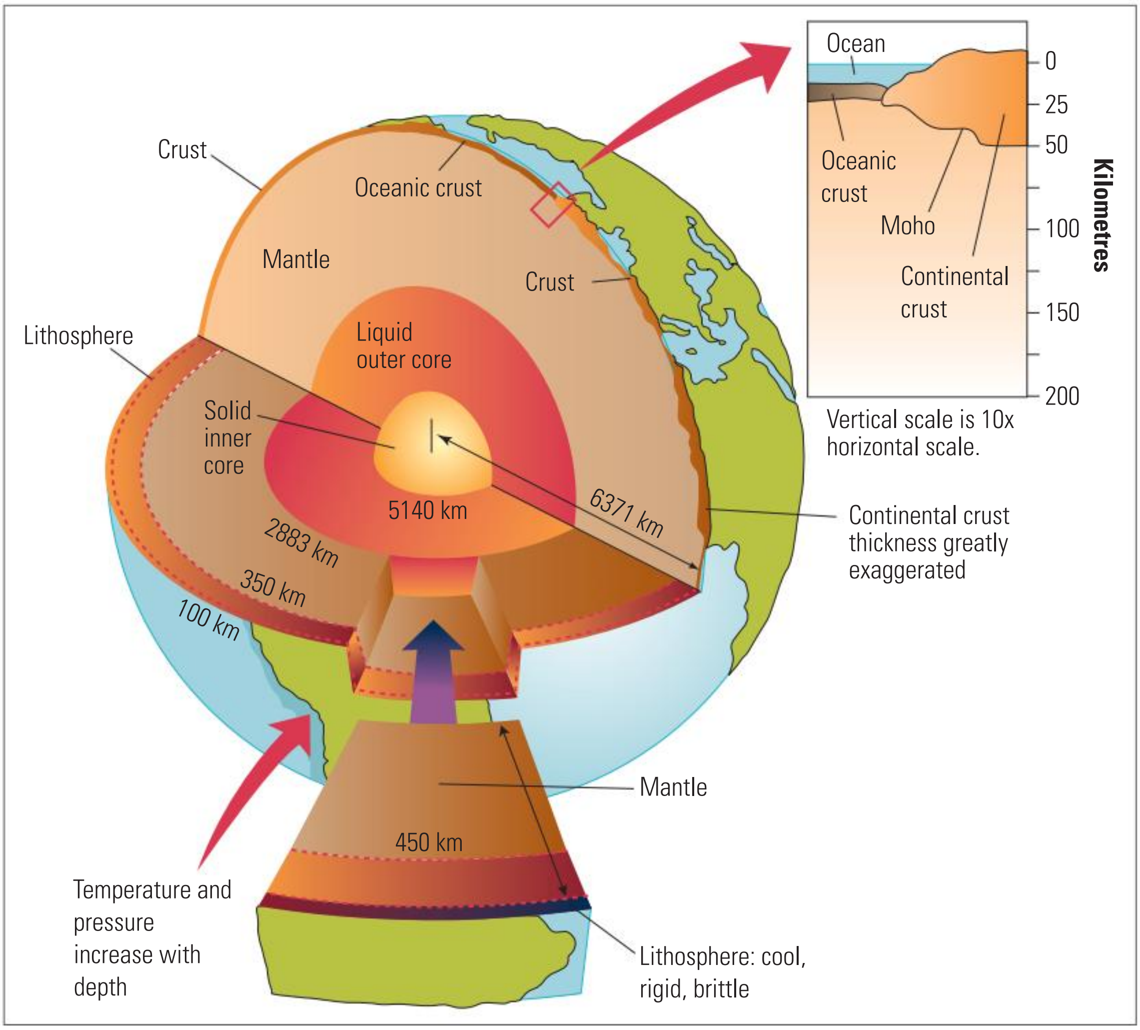


▲ **Figure 3.2** Global *distribution* of selected geological hazards

What are the geographical characteristics of geological hazards?

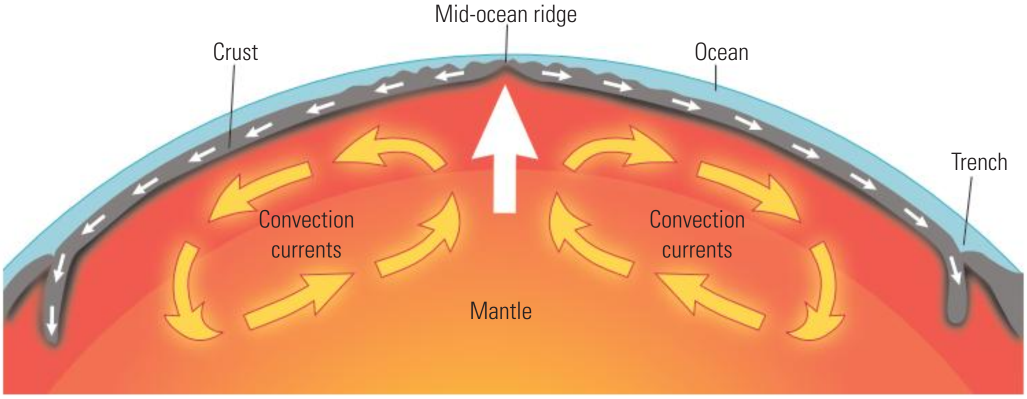
The Earth is made up of four main parts: an inner core which is believed to be solid; a liquid outer core made of iron and nickel; a mantle, composed of molten rock rich in iron and magnesium; and a thin crust (the lithosphere), as shown in Figure 3.3.

The crust can be divided into two types: oceanic and continental. The continental crust consists of rocks that are light, in both colour and density. These rocks, which consist of mainly granites and vary in thickness from 10 to 30 kilometres, are known as sial;



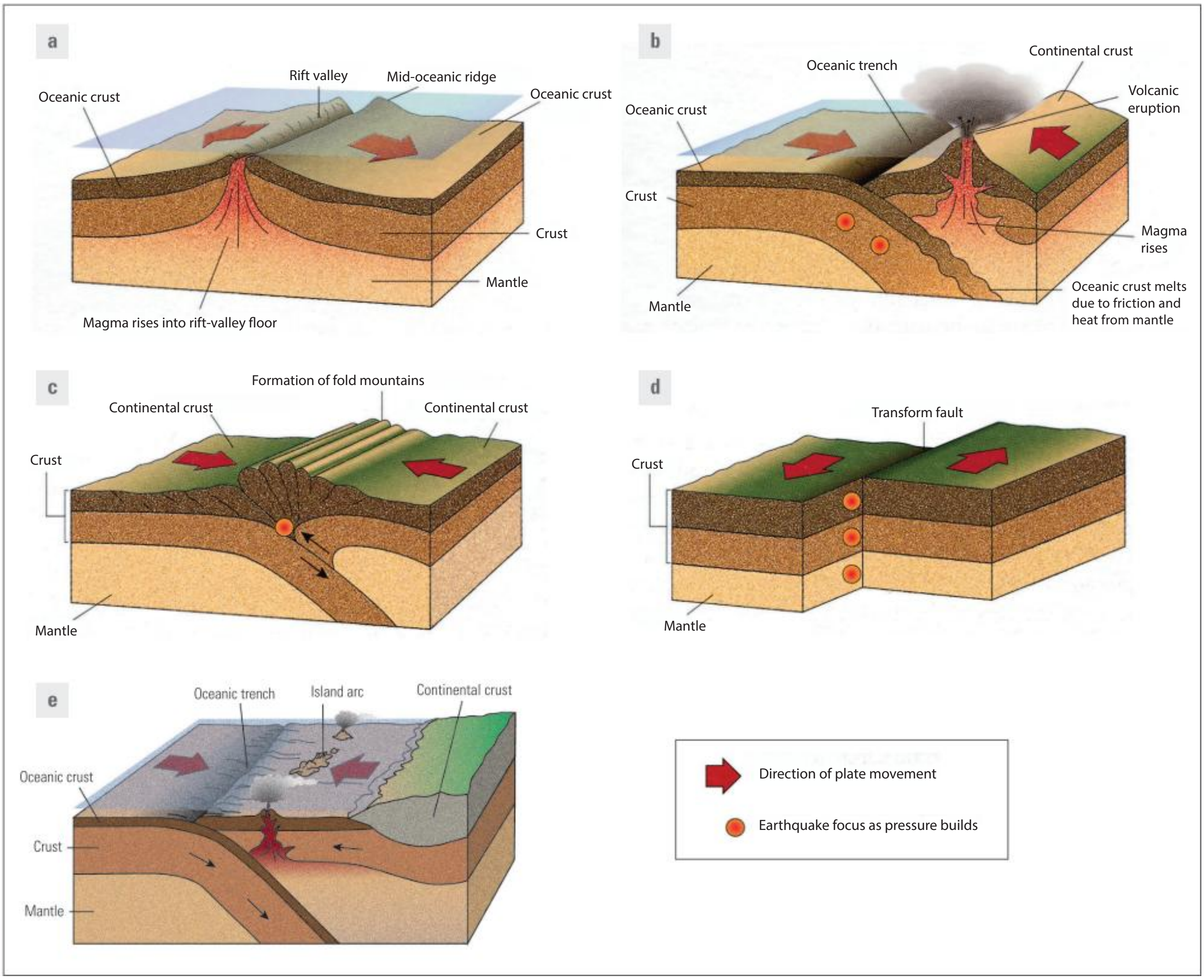
◀ **Figure 3.3** A cross-section through the Earth that is, silica and alumina. The oceanic crust, which forms the floor of the oceans, is much thinner, on average six kilometres thick; it is heavy and denser, and consists mainly of basalt or sima, made of silica and magnesium. The mantle on which the crust 'floats', over a period of many years, can become quite viscous as a result of increases in the Earth's temperature with increasing depth. This hotter material rises to the surface while the cooler liquid sinks; as it sinks, it heats up and rises again. A continuous cycle is established: hot liquid rising and cold liquid descending. This *process* is known as convection currents (Figure 3.4). It is these currents which cause the relatively light tectonic plates located on the crust to *move* across the Earth's surface contributing to the *process* called continental drift.

The *distribution* of the plates is shown in Figure 3.2. It is near the plate margins or boundaries that most of the Earth's major earthquakes, volcanic activity, and folding and faulting of rocks occur. As convection currents rise in the mantle, the plates are forced to move either away from each other, towards each other or simply move past each other (see Figure 3.5).



▶ **Figure 3.4** Diagram showing convection currents which drive the plates on top of the mantle

▼ **Figure 3.5** Types of plate *movement* **(a)** Divergent plate *movement* – constructive margin e.g. Pacific Plate and Antarctic Plate to south of Australia **(b)** Convergent plate *movement* – destructive margin e.g. Pacific Plate under Eurasian Plate to east of Japan **(c)** Convergent plate *movement* – collision margin e.g. Indian Plate into Eurasian Plate **(d)** *Movement* of plates past each other – conservative margin e.g. along San Andreas fault line, California USA **(e)** *Movement* of oceanic plates – constructive margin e.g. the formation of the Aleutian Islands, US and Russia



Where a continental plate and an oceanic plate collide, the oceanic plate, which is heavier, is forced to sink into the mantle and a subduction zone (trench) or a convergent plate boundary is formed. The friction that results from one plate being pushed under the other releases pressure and this may cause earthquakes. As the oceanic plate is forced deeper into the mantle, it begins to melt and releases gases. These gases and magma rise to the Earth's surface where they may result in a volcanic eruption. These margins are also known as destructive plate margins. Some volcanoes that form along subduction zones include Mount St Helens in the United States, Mount Etna in Italy (Figure 3.6) and Soufrière Hills in Montserrat.

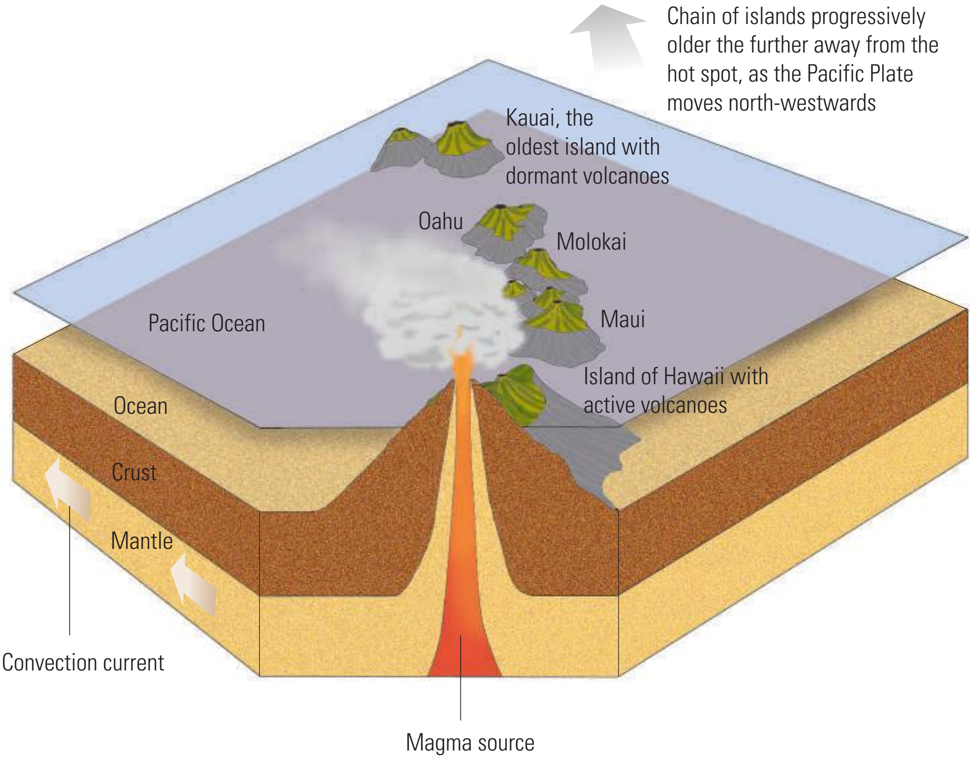
Where two oceanic crusts meet, the result is similar to where an oceanic and continental plate meet. The older, denser plate is forced under the less dense plate into the mantle; an ocean trench is the result and a line of volcanoes emerges from the convergence. These volcanoes form island arcs. This occurs in the west Pacific where the Philippine Plate is being forced under the Okinawa Plate forming the Ryukyu Trench and the Ryukyu Islands (Figure 3.7).

When two continental plates collide, the resulting landform is fold mountains. The Himalayas in Asia are a result of the collision of the Indian and the Eurasian plates. However, high mountains are not the only result of this collision. These *regions* on the Earth's surface are also susceptible to the most violent earthquakes: Izmit, Turkey, in 1999, and Gujarat, India, in 2001 are just two examples.

Some volcanic activity can also be found away from plate margins. The Hawaiian Islands, which are situated in the middle of the Pacific Ocean, far from the margins of the Pacific Plate, sit on top of a hot spot (Figure 3.8). Magma, driven by a particularly strong convection current in the mantle, rises and erupts through a weakness in the crust and forms the volcanoes which make up the Hawaiian Islands.

▲ **Figure 3.6** Mount Etna sits on the boundary between the African Plate and the Eurasian Plate

◀ **Figure 3.7** Ryukyu Islands have formed at the convergence of the Philippine and Eurasian plates



◀ **Figure 3.8** Hawaii sits on top of a hot spot. As the Pacific Plate continues to move north-west the main island moves off the hot spot and a new island is created

As this *process* continues, a volcano develops on the sea floor. Eventually it builds, rises above sea level and forms an island. As the Pacific Plate continues to move towards the north-west and pass over the hot spot, new volcanoes are created.

Eruptions from both Mauna Loa and Kilauea, Hawaii, have caused millions of dollars in damage in recent years, as homes, buildings and roads have been destroyed and rebuilt and destroyed. Lava flows have *changed* the shape of the coastline and added new land. These flows have also encouraged tourism to the island, which helps generate considerable income that compensates for some of the economic damage.

▶ ACTIVITIES

1. Refer to Figure 3.2. Describe the *distribution* of the geological hazards – volcanoes and earthquakes.
2. Are these geological hazards randomly *distributed*? Justify your response.
3. a. On a copy of Figure 3.2, which shows the *distribution* of selected geological hazards and the Earth's tectonic plates, label each plate as either oceanic or continental.
   b. Referring to Figure 3.5, briefly describe what is happening at each plate margin. Name the type of crust involved and the direction of *movement* of the plates.
4. Referring to Figure 3.2, describe the degree of *spatial association* between plate margins and geological hazards.
5. While studying geological hazards and disasters in this chapter, keep a diary of these events as they occur in the world. To help you, type the following into a search engine: Live Earthquakes Map, Volcano Discovery and National Tsunami Warning Centre. You may like to work in groups.

Geological hazards – volcanoes

What is a volcano?

A volcano is a crack, fracture, or vent in the earth's surface which allows molten material (called magma) from the earth's interior to escape to the surface through eruptions. The magma that erupts from the volcano is called lava. Viscous lava builds up around the vent to form a cone, whereas more fluid lavas may spread far from a vent without building up to form a cone. The eruptions are generally classified into several different types, generally named after particular volcanoes, but there are two major types: explosive and effusive. Explosive eruptions are characterised by a short, violent burst of viscous magma. They produce tephra, and clouds of hot ash, gas and rock that sometimes flow almost like liquid. The second type is an effusive eruption which is characterised by an outpouring of lava without any significant explosion.

▼ **Figure 3.9** Hazards caused by volcanic eruptions

Geological event	Hazards they cause
Volcanic eruption	Tephra falls (ash, pumice, scoria) and ballistic projectiles Lahars (mud flows) and floods Lava flows and domes Poisonous gases

What causes a volcano?

As mentioned, volcanoes are a result of magma coming to the earth's surface through fissures in the crust. These fissures or cracks are generally located at plate margins. These margins are known as either a constructive boundary or divergent plate boundary (Figure 3.5 (a)). The Mid-Atlantic Ridge of which Iceland is a part and the East African Rift Valley system are both *regions* where the plate boundary is being forced apart and volcanic activity is common.

▼ **Figure 3.10** The ten largest eruptions in history

	Location	Date	Type of plate margin	Type of eruption	Why is it considered a major disaster?
1	Mount Tambora, Indonesia	1816			
2	Krakatau, Indonesia	1883			
3	Mount Pelée, Martinique	1902			
4	Vesuvius, Italy	79AD			
5	Kilauea, Hawaii (US)	1983 – ongoing			
6	Nevada del Ruiz, Colombia	1985			
7	Mount St Helens, United States	1980			
8	Mount Pinatubo, Philippines	1991			
9	El Chichon, Mexico	1982			
10	Mount Unzen, Japan	1792			

The volcanoes listed in Figure 3.10 are considered the most significant as they have not only caused the deaths of tens of thousands of people, but they have also caused major *environmental changes* such as climate *change*, *changes* to topography in the *region* and *changes* to the size of the volcano, and, in some cases, caused tsunamis.

What are the impacts of volcanic eruptions?

Volcanic eruptions can have catastrophic consequences on people and the *environment*. However, volcanoes can also have a positive impact. (See Figure 3.11.) It is these positive impacts that may help explain why people choose to live near volcanoes.

▼ **Figure 3.11** Positive and negative impacts of an eruption

Positive	Negative
▶ During the Earth's early geological history, volcanoes released most of the carbon dioxide that allowed plants to flourish and also formed the natural greenhouse effect that allowed complex life forms to evolve. ▶ Different type of landscapes created by erupting volcanoes may attract tourists, bringing in income to the *region*. ▶ The lava and ash deposited during an eruption can create fertile soil good for agriculture. ▶ The heat generated near the volcano can provide the potential for geothermal energy.	▶ Many lives may be lost and people often have to be evacuated. ▶ Ash discharged into the atmosphere can have negative consequences on the ozone layer and impact on climate by reducing the temperature. ▶ Volcanic ash emitted into the atmosphere can be disruptive and hazardous to aircraft. ▶ Ash can be hazardous to the health of humans and animals. ▶ Landscapes and natural scenery can be altered. ▶ Ash and mud can mix with water or melting snow, and become lahars. Lahars are very fast-moving mud flows. ▶ Lava flows and lahars can destroy settlements and agricultural fields.

▶ ACTIVITIES

1. Referring to Figures 3.2 and 3.10, give two examples of active volcanoes that are located at two of the plate margins that generate volcanic activity.

2. a. Referring to Figure 3.10, copy and complete the table columns.

   b. Explain why some volcanic eruptions are very explosive and more of a hazard and others less explosive. In your response use the following terms: viscosity, gas content, pressure.

3. The Kilauea volcano in Hawaii erupted on 3 May 2018 (see Figure 3.12). Conduct some investigation on this eruption including its causes and impacts on people and the *environment*.

4. Select a specific, recent volcanic eruption and conduct further research. Produce a report, an annotated visual display or a web page to illustrate the characteristics of the eruption. Include the following points:

   - location – show on a map
   - are any tectonic plates involved, and if so what type of *movement*?
   - the date of the eruption/s
   - the type of eruption/s or hazard
   - the impact of the disaster on people and the *environment* (social, economic and *environmental* effects)
   - the responses to the disaster from government and non-government organisations.

5. a. Research the types of landforms that are a result of the eruption of the volcano you have chosen in question 4.

   b. Using annotated sketches and diagrams, describe and explain the formation of the specific features.

◀ **Figure 3.12** Taken from a helicopter overflight of the lower East Rift Zone of Kilauea volcano on 19 May 2018 showing the lava flows

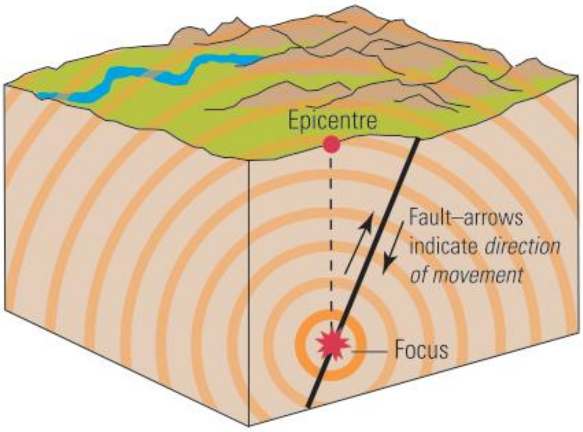
Geological hazards – earthquakes

Earthquakes represent a major hazard to people living on or near plate margins. When an earthquake occurs, it releases an enormous amount of energy that can create hazard events and potentially form disasters (see Figure 3.13).

▶ **Figure 3.13** Hazard events that are a result of earthquake activity

Geological event	Hazards caused
Earthquake	Ground shaking / tremors Surface faulting Landslides and liquefaction ▶ Rock avalanches ▶ Rapid soil flows ▶ Rock falls Tsunamis Loss and damage to property and infrastructure

▼ **Figure 3.14** The fault, epicentre and focus of an earthquake



What is an earthquake?

Most large earthquakes occur when the tectonic plates of the Earth's crust, which are in constant *movement*, shift, bump or grind past one another (see Figure 3.5). As these individual plates either converge (collide), or diverge (move apart) they create internal stress at the edges where they meet, becoming one major cause of the formation of fault lines. When the stress is great enough, the energy is suddenly released and the crust breaks or shifts, causing an earthquake. Another major cause is the *movement* of plates over hotspots (Figure 3.8) – here the rock melts when heat moves upward, and the surrounding, weakened lithosphere bends upwards.

The energy released from the earthquake radiates outward from the fault in the form of seismic waves like ripples in a pond. The seismic waves shake the earth as they move through it. The location below the Earth's surface where the earthquake begins is called the focus, and the *place* directly above on the Earth's surface is called the epicentre (Figure 3.14).

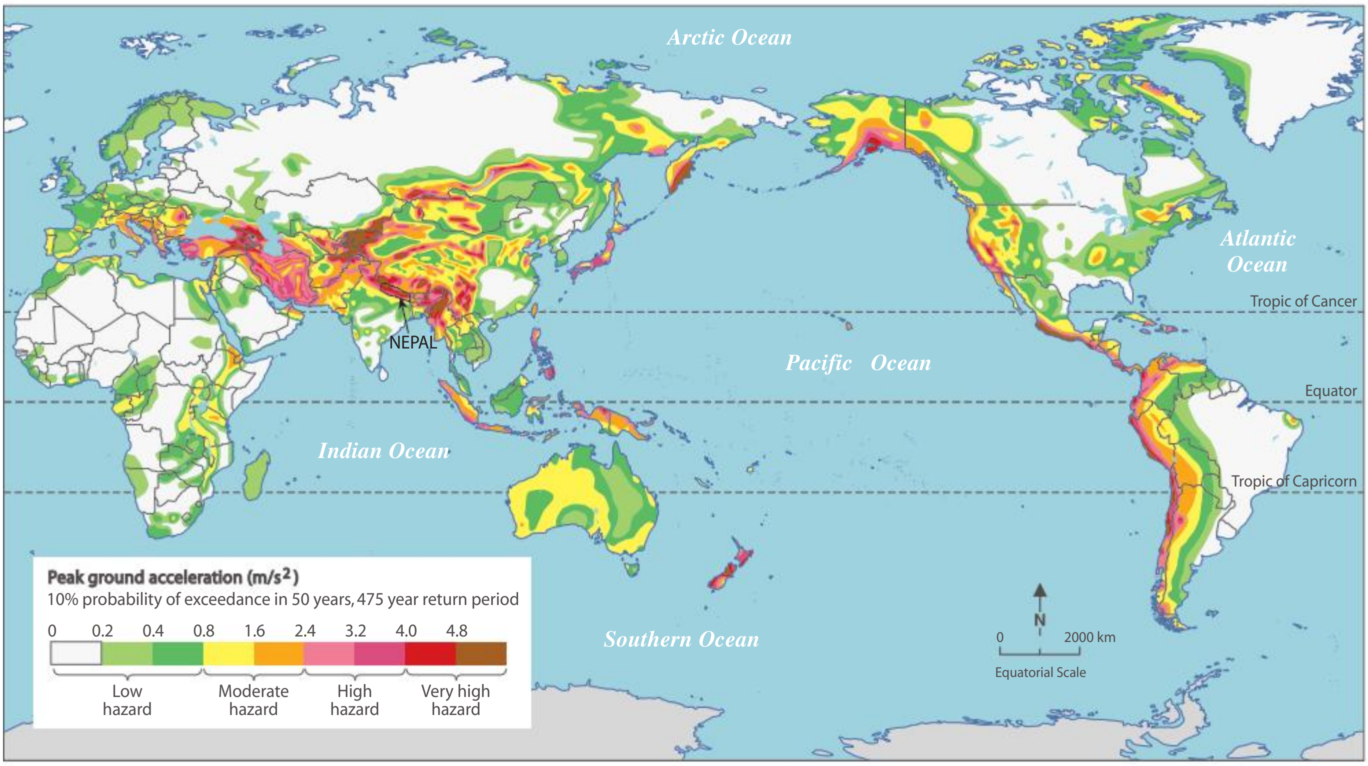
The maximum *movement* of the earthquake is then used to calculate its magnitude which signifies the amount of energy released. The strength, or magnitude, of an earthquake is measured using a Richter Scale which was developed in 1935 by Charles F. Richter. The *scale* is based on a logarithm of the amplitude (height) of waves recorded by the seismograph and is numbered 0–10. Due to the logarithmic basis of the *scale* a magnitude 5 earthquake is 10 times greater than a magnitude 4. Earthquakes below magnitude 8 can still be highly destructive depending on the *region* in which they occur and, according to the United States Geological

▼ **Figure 3.15** A table of the Richter Scale of earthquake intensity*

Intensity	Description	Estimated average frequency
1	Detected only by seismographs	Continual/several million per year
2	Felt slightly by some people. No damage to buildings	Over one million per year
3	Slight – similar to the vibrations of a passing truck. Often felt by people, and rarely causes damage.	Over 100,000 per year
4	Moderate – noticeable shaking of indoor objects. Felt by most people in affected area. Generally damage ranges from none to minimal.	10,000–15,000 per year
5	Strong – can cause damage to poorly constructed buildings. Felt by everyone.	1000–1500 per year
6	Destructive – damage to moderate number of well-built structures, with moderate to severe damage to poorly constructed buildings. Felt up to hundreds of kilometres from epicentre. Some deaths may occur.	100–150 per year
7	Disastrous – causes damage to most buildings; railways bent. Landslides on steep slopes. Felt across great *distances*, with major damage limited to 250 kilometres from epicentre. Significant death toll.	10–20 per year
8	Very disastrous – major damage to buildings; bridges destroyed; all services out of action. Death toll in the thousands.	One per year
9	Catastrophic – near or total destruction. Ground rises and falls, with permanent *changes* in ground topography. Death toll can surpass 100,000.	One per 10–15 years

*Based on United States Geological Survey (USGS) documents

▼ **Figure 3.16** Global Seismic Hazard map



Survey (USGS), an average of 17 earthquakes occur between magnitude 7 and 7.9 globally each year. Generally, the more shallow the focus, the greater the shaking at the Earth's surface. When the earthquake focus is deeper, the seismic waves have to travel further through the Earth and hence lose their power (Figure 3.15).

The majority of the world's earthquakes occur on the Ring of Fire, also known as the Circum-Pacific Belt (see page 51). In fact, 90 per cent of the world's earthquakes occur here. The Ring of Fire is a horse-shoe-shaped belt of seismic activity which stretches approximately 40,000 kilometres around the Pacific Ocean. The *region* is susceptible to disasters because it is here that a number of tectonic plates overlap.

The most violent earthquakes occur in the subduction zone or the destructive margin (see Figure 3.5 (b)). When this *movement* occurs on the ocean floor, a tsunami could result.

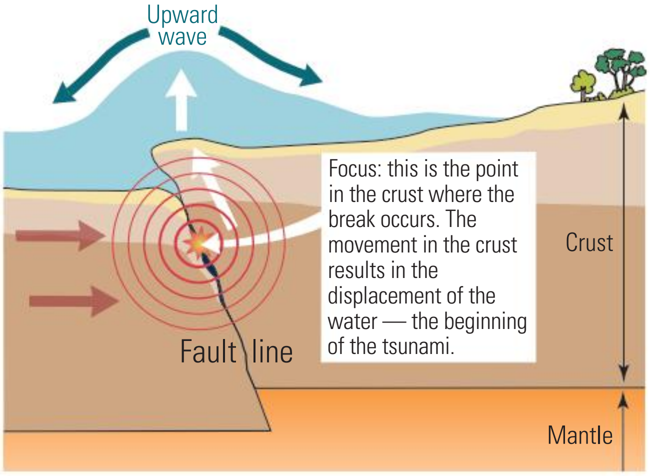
Earthquakes may occur as a result of human activities such as mine blasts and nuclear experiments. In fact, on 9 September 2016 seismometers (instruments used to record the *movement* of the earth as it shakes and then plots the vibrations on a seismograph) began squiggling madly from South Korea to Russia and Japan. Seismic waves were recorded as they passed through and shook the ground. It appeared that a magnitude 5.2 earthquake had passed through the *region*. Seismologists deduced that the shake had originated at North Korea's nuclear weapons test site.

As part of the United Nations International Decade for Natural Disaster Reduction, the Global Seismic Hazard Assessment Program (GSHAP) collated data which highlighted the *regions* where there is an increased risk of seismic activity (Figure 3.16). Although the GSHAP ran from only 1992 to 1999 the data presented is relatively accurate overall.

A closer look at the Figure 3.16 map reveals that Nepal and parts of northern India are areas that experience higher risk of strong earthquakes. Earthquakes consistently occur in the *region* with the strongest earthquake recorded being in 1934 Bihar–Nepal earthquake, which measured 8.2 and killed around 10,000 people. In April 2015, Nepal experienced another earthquake which measured 8.1 killing approximately 9000 people, injuring 22,000 more, destroying 600,000 structures in Kathmandu and other nearby towns, and displacing 2.8 million people. The earthquake triggered an avalanche on Mt Everest killing 21 people and another huge avalanche inundated the Langtang Valley, where 250 people were reported missing. The Nepali government estimated that the overall damage was about $10 million, half of their GDP of $19.2 million.

Tsunamis

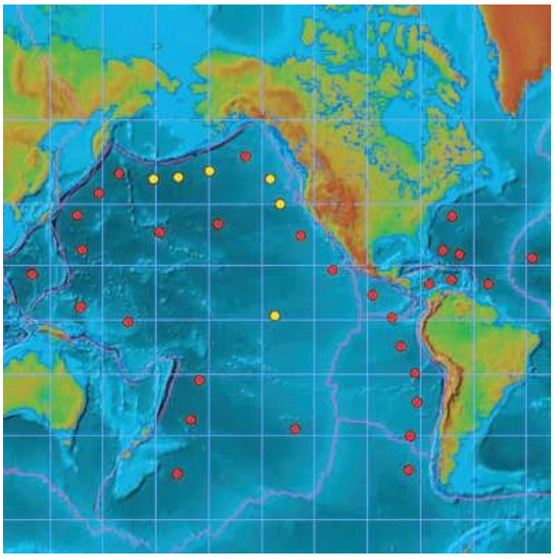
A rare but devastating result of some earthquakes or volcanic eruptions at sea is a tsunami. A tsunami is a huge wave, usually caused when earthquake or volcanic activity happens on the ocean floor (Figure 3.17).



▲ **Figure 3.17** How a tsunami works

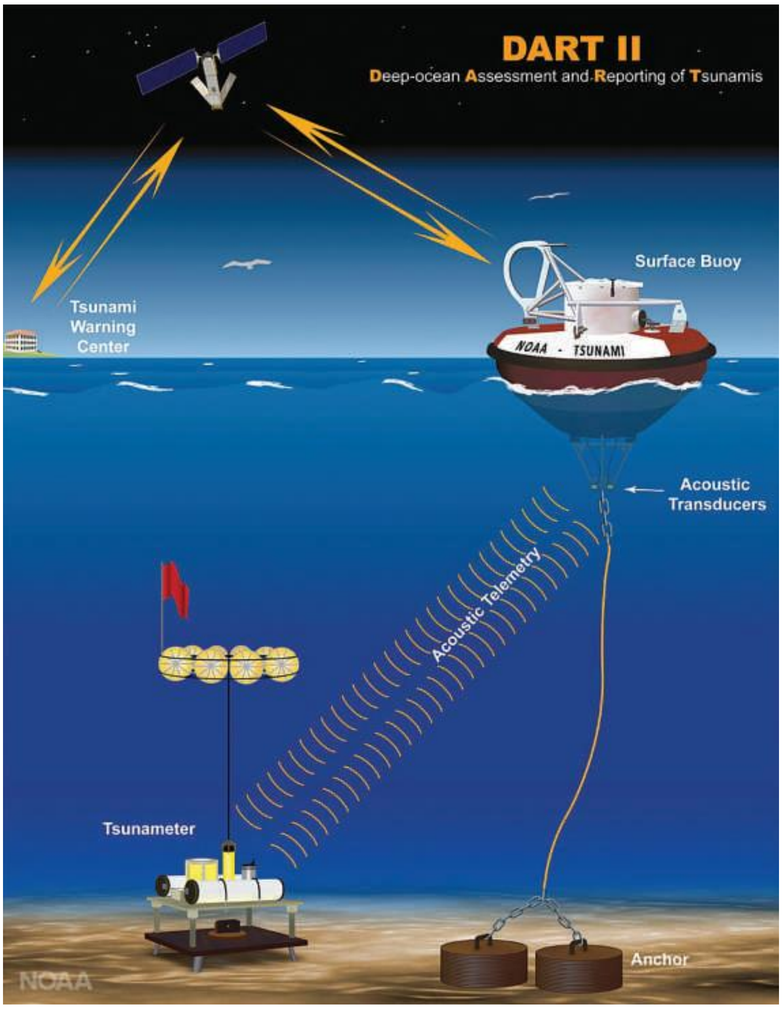
The water is displaced under the ocean, and this displaced water then forms a giant wave. When the wave reaches shallow water the height increases, the wave slows down and then rolls into shore creating a huge wall of water as seen in Figure 3.17.

Tsunamis, like earthquakes, can be difficult to predict. However, the most obvious sign of a tsunami approaching is the temporary retreat of water from the coast. In 2004, it was this rare occurrence on the beaches in southern Thailand that prompted the fatal behaviour by some people, especially children, to collect stranded fish on the exposed beach.



▲ **Figure 3.18** Map showing the *distribution* of DART buoys in the Pacific Ocean. The yellow dots mark the location of existing DART buoys. The red dots are buoys that are proposed for an expanding tsunami warning system

▼ **Figure 3.19** This diagram shows how tsunami wave information in the deep ocean is transmitted from DART systems via satellite to NOAA's tsunami warning centres



The uncertainty associated with tsunamis occurring in the Pacific, as mentioned earlier, has prompted the establishment of a sophisticated monitoring system in the *region*. In 2008, the US government finished setting up a series of 39 buoys in the Pacific, Atlantic, Caribbean and the Gulf of Mexico (see Figure 3.18). These stations consist of a sensor anchored to the sea floor and a receiver attached to the buoy. A sound wave constantly transmits data from the sea floor to the surface, and then satellite links relay the data to the National Oceanic and Atmospheric Administration (NOAA) warning centres (Figure 3.19). This system is capable of detecting all *changes* in sea level larger than one millimetre. Nevertheless, to be effective the system needs to be monitored closely, buoys kept operational, and warnings heeded.

What are the impacts of earthquakes?

Earthquakes can destroy settlements and kill people. Aftershocks (shaking of the lithosphere that occurs after the initial *movement*) can cause even more damage than the initial quake.

On 6 February 2018, a magnitude 6.4 earthquake struck Taiwan's coastal city of Hualien. According to Xinhuanet (Chinese news agency), 285 people were recorded missing or unaccounted for, at least 180 were injured and 17 deaths reported. Numerous buildings collapsed (Figure 3.20) and Taiwan's Central Emergency Operation Centre reported that 31,000 households were without water. Aftershocks continued for weeks.

One of the most destructive earthquakes of recent times occurred in the Indian Ocean off the west coast of Northern Sumatra, Indonesia, on 26 December 2004 (Figure 3.21). The earthquake registered 9.1 on the Richter Scale and was reported by the the USGS as the third largest in the world since 1900. The earthquake caused the entire planet to vibrate by at least two centimetres. The large tsunami created by the earthquake spread across the Indian Ocean and resulted in the deaths of 227,898 people in northern Sumatra, Thailand, India, Sri Lanka and the Maldives. There were 1.7 million people displaced and there was severe damage to property. The damage bill was estimated at more than US$10 billion. In this case, the tsunami was the greater disaster despite the *scale* of the earthquake.

On 28 September 2018 a magnitude 7.5 earthquake and resultant tsunami on the Indonesian island of Sulawesi resulted in over 2000 deaths, several thousand missing and caused widespread destruction.

Factors that could be taken into account when assessing the impact of an earthquake can be:

- short-term/long-term
- social
- economic
- *environmental*
- positive/negative (Figure 3.22).

▼ **Figure 3.20** Rescue services search for people in a damaged building in Hualien, eastern Taiwan, 9 February 2018

▼ **Figure 3.21** North-eastern Indian Oceanic plates responsible for the Indian Ocean Earthquake, 26 December 2004

Scientists at the US National Earthquake Information Center record over 20,000 earthquakes each year and estimate that many more occur globally. Many earthquakes are barely noticeable. However, some earthquakes, such as the Great East Japan Earthquake of 2011, released huge amounts of energy, killing thousands of people and destroying large areas of land. Despite this destruction, earthquakes can also have positive benefits for people; refer to Figure 3.22.

▼ **Figure 3.22** Positive and negative impacts of earthquakes

Positive	Negative
▶ Provides a picture of what is happening underground. ▶ Formation of mountain ranges such as the Himalayas and other landforms. ▶ By measuring vibrations made by small earthquakes, geologists can find aquifers, oil and natural gas deposits, and other important resources.	▶ Many lives can be lost. ▶ Damage to property and infrastructure – loss of power, fire, contaminated water and the spread of disease. ▶ Economic hardship – extremely costly to rebuild. ▶ Flooding and widespread destruction caused by tsunamis ▶ Landslides are triggered on unstable slopes.

▶ ACTIVITIES

1. Refer to Figure 3.18, map showing the location of buoys in the Pacific Ocean.
   a. Describe the *spatial association* between the location of the buoys and the Ring of Fire.
   b. Why do you think the original buoys were placed in the northern and central *region* of the Pacific Ocean?
   c. Identify and explain the reason/s for the expansion of the detection system.
2. Tsunami prediction is complicated by several factors which include the size of the underwater earthquake, the speed and direction of the earth *movement*, and the orientation and slope of the coastline. However, one of the major problems is the evacuation of the people. What are some of the problems associated with the evacuation of the people ahead of a tsunami?
3. In pairs, carry out the following tasks on the Indian Ocean Earthquake that occurred on 26 December 2004.
   a. Refer to Figure 3.21. Using appropriate websites (for example the NASA website), describe the *movement* of the plates which caused the tsunami. Explain the *process*.
   b. What were the characteristics of the earthquake and the subsequent tsunami?
   c. Consider the factors affecting the impact of the earthquake (some of which have been mentioned in the text) and create your own table which classifies them as either positive or negative and short-term or long-term.
   d. What *changes* occurred to the *environment*?
   e. What were the responses to the disaster – from government and non-government organisations? Evaluate the effectiveness of these responses.
   f. Choose another recent earthquake (for example, the earthquake which rocked western Turkey and Greece, 30 October 2020 which measured 6.6). On a blank map of the *region*, mark the location of the earthquake and include the following:
      - plates involved and the type of *movement*
      - date of the earthquake (the aftershocks)
      - impact on people and the *environment* (social, economic and *environmental* effects)
      - responses from government and non-government organisations and the effectiveness of these responses.

CASE STUDY Japan – a land prone to geological hazards

Japan is the most geologically hazard-prone *region* on Earth. About 1500 earthquakes occur in the country every year. Minor tremors occur on a daily basis. Deadly earthquakes occur on average every 20 to 30 years. Japan is located on the Pacific Ring of Fire, a narrow band around the Pacific Ocean where about 90 per cent of all the world's earthquakes and 75 per cent of the world's active volcanoes are also located.

Japan is located at the junction of four tectonic plates (see Figure 3.23) – the Eurasian, Philippine, Pacific and North America plates (the blue lines show the edges of the plates). These plates grind past each other or are subducted into the mantle, and the resultant build up of stored energy creates a huge potential to trigger volcanic eruptions, deadly earthquakes and fatal tsunamis.

Great East Japan Earthquake

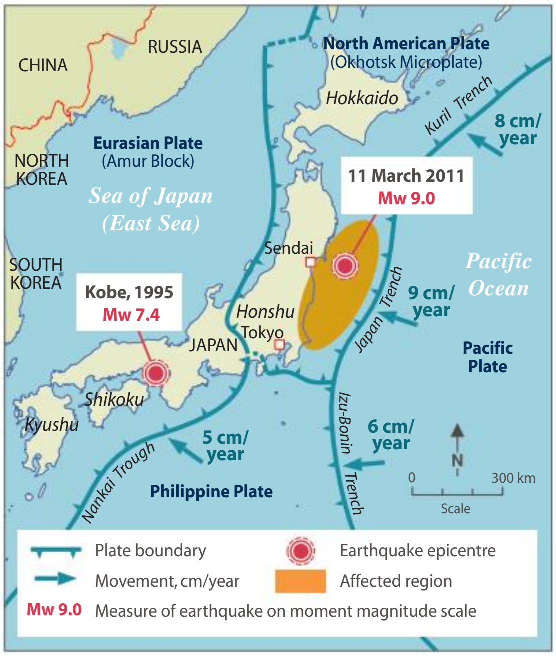
On 11 March 2011, an earthquake with a magnitude of 9.0 struck the north-east coast of Honshu, Japan. This event is known as the Great East Japan Earthquake (or as Tōhoku Earthquake). It was the result of a sudden release of energy from where the Pacific Plate was being forced under the North American Plate (Figure 3.24). The blue arrows in Figure 3.23 show the *movement* of the Pacific Plate at the subduction zone.

What was the impact of the earthquake and the subsequent tsunami?

The earthquake moved parts of the north-eastern Japanese coast by about two metres towards Hawaii, shifted the Earth on its axis by about 0.2 millimetres and shortened the Earth's day by a few microseconds, according to geophysicist Richard Gross.

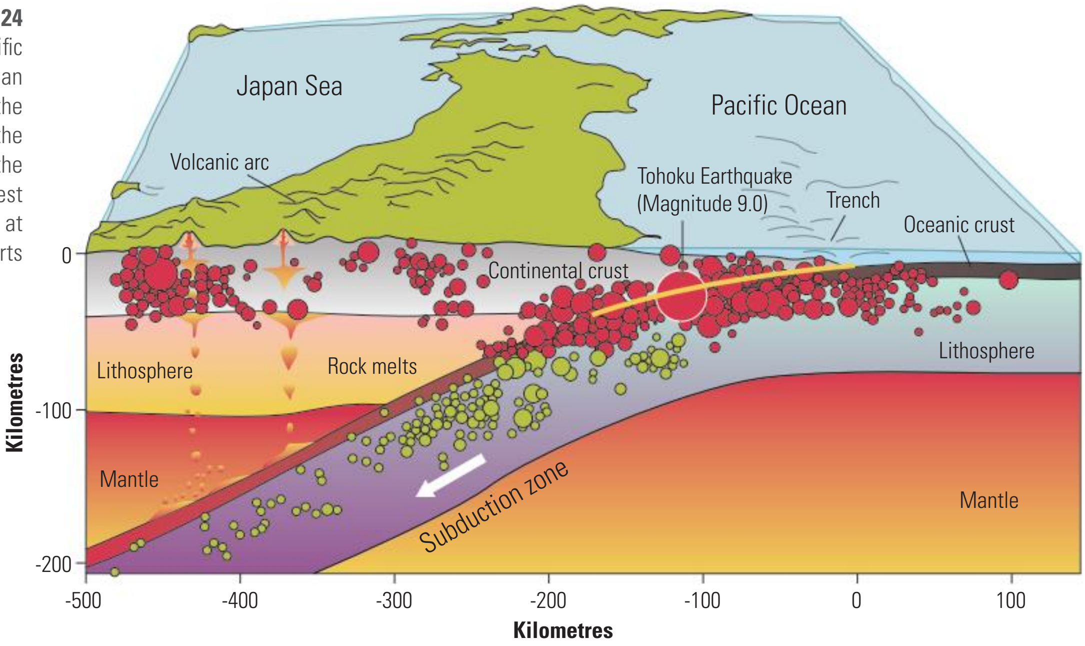
During the quake, seismic waves travelled outward in all directions from the focus, resulting in severe shaking in Japan. Japanese buildings, due to their stringent building codes, sustained surprisingly little damage. Sensors on bridges and other infrastructure fed information into data centres which immediately halted train and plane *movements,* and cut electricity generation. A tsunami was triggered as the North American Plate rebounded, ocean water was pushed upwards creating the initial waves which travelled both back to Japan and out into the Pacific. Some of the resulting waves were as high as 39 metres and travelled up to 10 kilometres inland, where destruction can be seen in Figure 3.25.

Although Japan is relatively well prepared for such hazards, they were not prepared for the size of the earthquake and tsunami that hit the north-east coast on 11 March 2011, and the subsequent disaster. This disaster caused around 20,000 deaths, and over 125,000 buildings were damaged or destroyed, with an estimated overall cost in excess of US$300 billion.



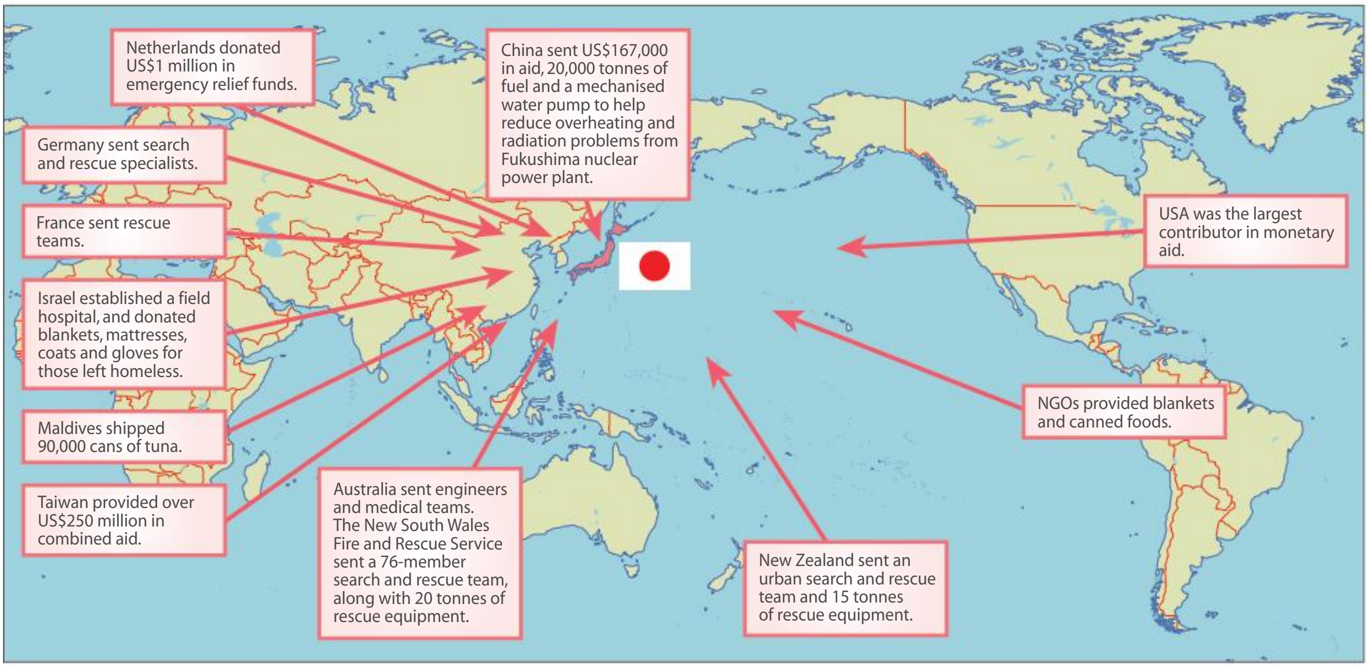
▲ **Figure 3.23** Map showing the four tectonic plates around Japan

▶ **Figure 3.24**
A block diagram showing the Pacific Plate sinking into the North American Plate. The slip occurred along the yellow line; the red dots represent the earthquakes; the larger the dot the greater the magnitude. The largest red dot was the focus – the point at which the earthquake starts



▼ **Figure 3.25** Satellite images taken **(a)** before and **(b)** after the earthquake and subsequent tsunami show how an area of Sendai has been stripped bare. Buildings and trees have been swept away from the city in north-east Japan, which has a population of more than one million

▼ **Figure 3.26** Offers of help came from all over the world in response to the disaster



Netherlands donated US$1 million in emergency relief funds.

China sent US$167,000 in aid, 20,000 tonnes of fuel and a mechanised water pump to help reduce overheating and radiation problems from Fukushima nuclear power plant.

Germany sent search and rescue specialists.

France sent rescue teams.

USA was the largest contributor in monetary aid.

Israel established a field hospital, and donated blankets, mattresses, coats and gloves for those left homeless.

NGOs provided blankets and canned foods.

Maldives shipped 90,000 cans of tuna.

Taiwan provided over US$250 million in combined aid.

Australia sent engineers and medical teams. The New South Wales Fire and Rescue Service sent a 76-member search and rescue team, along with 20 tonnes of rescue equipment.

New Zealand sent an urban search and rescue team and 15 tonnes of rescue equipment.

What were the responses to this disaster?

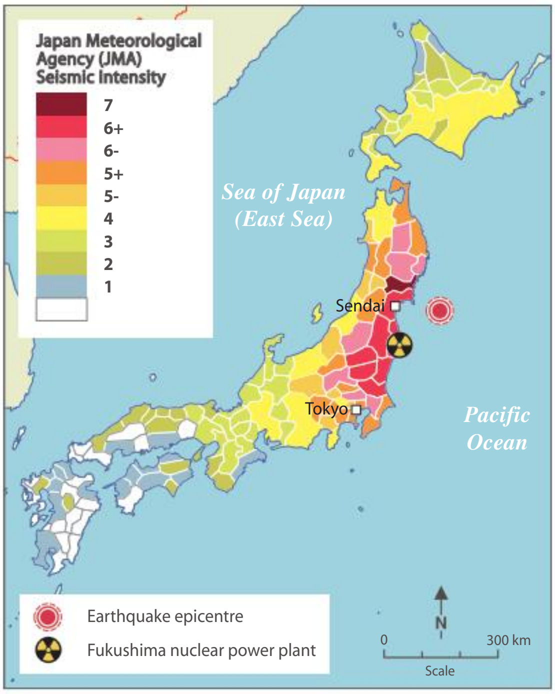
Numerous Non-Government Organisations (NGOs) contributed to the relief efforts in Japan, not only through the provision of money and relief workers, but also in the form of non-perishable items such as blankets, canned foods and children's essentials. A selection of these responses can be seen in Figure 3.26.

Japan's Volcanoes

Due to its location at the junction of the four tectonic plates previously mentioned, Japan is also prone to volcanic activity with over 100 active volcanoes (Figure 3.28). The main island of Honshu alone has 47 active volcanoes, including Mount Fuji.

On the smaller island of Kyushu is Sakurajima volcano. Sakurajima is referred to by many experts as the 'Vesuvius of the east', due to its high level of volcanic activity. It once was an island, but lava flows in its 1914 eruption caused it to connect to the mainland.

Every year, thousands of small eruptions throw up ash over the surrounding countryside. The city of Kagoshima, as part of its preparedness plan, has built



▲ **Figure 3.27** Map showing the intensity of the earthquake and tsunami in the north-eastern *region* of Japan special volcano shelters where people can take shelter from the hazard of falling debris. A major eruption, however, could have catastrophic consequences.

In fact, the volcano heralded in the New Year of January 2015 with a series of loud explosions, emitting ash plumes up to three kilometres into the atmosphere.

In September of 2014, Mount Ontake (or Ontake-san) erupted and killed 47 people, the majority of these were bushwalkers. Mount Ontake is the second-highest volcano in Japan and located on the main island of Honshu, 200 kilometres west of Tokyo. Figure 3.29 shows the layers of ash that blanketed the area. At the time seismologists had noticed increased seismic activity in the *region* ahead of the eruption but were still unprepared for what ensued. Mount Ontake is one of Japan's 110 active volcanoes and the eruption was regarded as one of the worst volcanic disasters in Japan for 90 years.

Experts warned that the eruption was ongoing.

▲ **Figure 3.28** Map showing the major volcanoes of Japan

▶ **Figure 3.29** Mount Ontake, Japan

▶ ACTIVITIES

1. Why is Japan so prone to hazards?
2. a. Refer to Figure 3.23. In which direction are the plates *moving*?
   b. Explain why you think the plates are *moving* in that direction.
3. a. What were the impacts of the Great East Japan Earthquake?
   b. Organise the impacts of this disaster into a table:

	Positive impacts	**Negative impacts**
People		
Environment		

   c. From the table you have completed, identify the long-term and short-term impacts.
4. Both the beaches in Sendai, Japan (Figure 3.25) and in Banten Province, Indonesia (Figures 3.36 (a) and (b)) show evidence of devastation caused by their respective tsunamis.
   a. Compare the destruction that occurred in both areas. You might need to do further research on both areas to complete this question.
   b. Explain why there appears to be a huge difference.
5. In Sendai, why was the tsunami, and not the major earthquake, the main cause of the disaster?
6. Refer to Figure 3.16, map showing the intensity of potential earthquakes and Figure 3.27, map showing the intensity of the earthquake and tsunami that hit the north-eastern *region* of Japan. Describe the *spatial association* between the potential intensity map of the north-eastern *region* of Japan and the actual intensity of the earthquake of March 2011.
7. How prepared was the Japanese government for such an event?
8. Japan accepted some help but was reluctant to accept aid from certain countries. Research the responses by government and non-government organisations. Why were some accepted and others not?
9. a. Draw an annotated diagram and describe the features associated with a destructive plate margin.
   b. For one of these features, explain the *processes* that have led to its formation.
   c. Explain one way in which an area close to a destructive plate margin may be of economic value.
   d. With reference to one or more areas that you have studied, explain how people can exploit the economic resources that can be found at destructive plate margins.

▶ CASE STUDY The Ring of Fire

As mentioned earlier in this chapter, the Ring of Fire or Circum-Pacific Belt is a *region* which almost surrounds the Pacific Ocean (Figure 3.30). It is a *region* prone to tectonic activity and it is where several geological features are common. These features include volcanoes, ocean trenches, mountain trenches, hydrothermal vents and sites of earthquake activity.

Seventy-five per cent of the world's volcanoes, or approximately 450 of them, extend from the southern tip of South America, north along the west coast of North America, across the Bering Strait, south through Japan and on to New Zealand. The western edge of the Ring of Fire tends to be more active. Some of the volcanoes include Mount Ruapehu in New Zealand, with annual minor eruptions, the island volcano of Krakatau in Indonesia (which destroyed the entire island in an eruption in 1883 and has continued ever since with minor eruptions and formed Anak Krakatau) and Mount Fuji, in Japan.

The eastern section of the Ring of Fire includes the volcanic areas of the Aleutian Islands, the Cascade Mountains of the United States (which includes Mount St Helens), the Trans-Mexican Belt and the Andes Mountains of South America.

Popocatépetl, part of the Trans-Mexican Belt, is one of Mexico's most active and dangerous volcanoes with 15 recorded eruptions since 1519. Popocatépetl poses the greatest risk to the 20 million people living in the surrounding *region*.

The activity that occurs in the Aleutian Islands is often difficult to monitor without the assistance of satellite imagery, infrasound and seismic sensors. Bogoslof Island, one of the largest of a cluster of small, low-lying islands which make up the summit of a large submarine volcano, began its eruption sequence in mid-December 2016 and intermittently through to May 2017. This volcano is frequently altered by both eruptions and erosion, and has undergone dramatic *changes* over time.

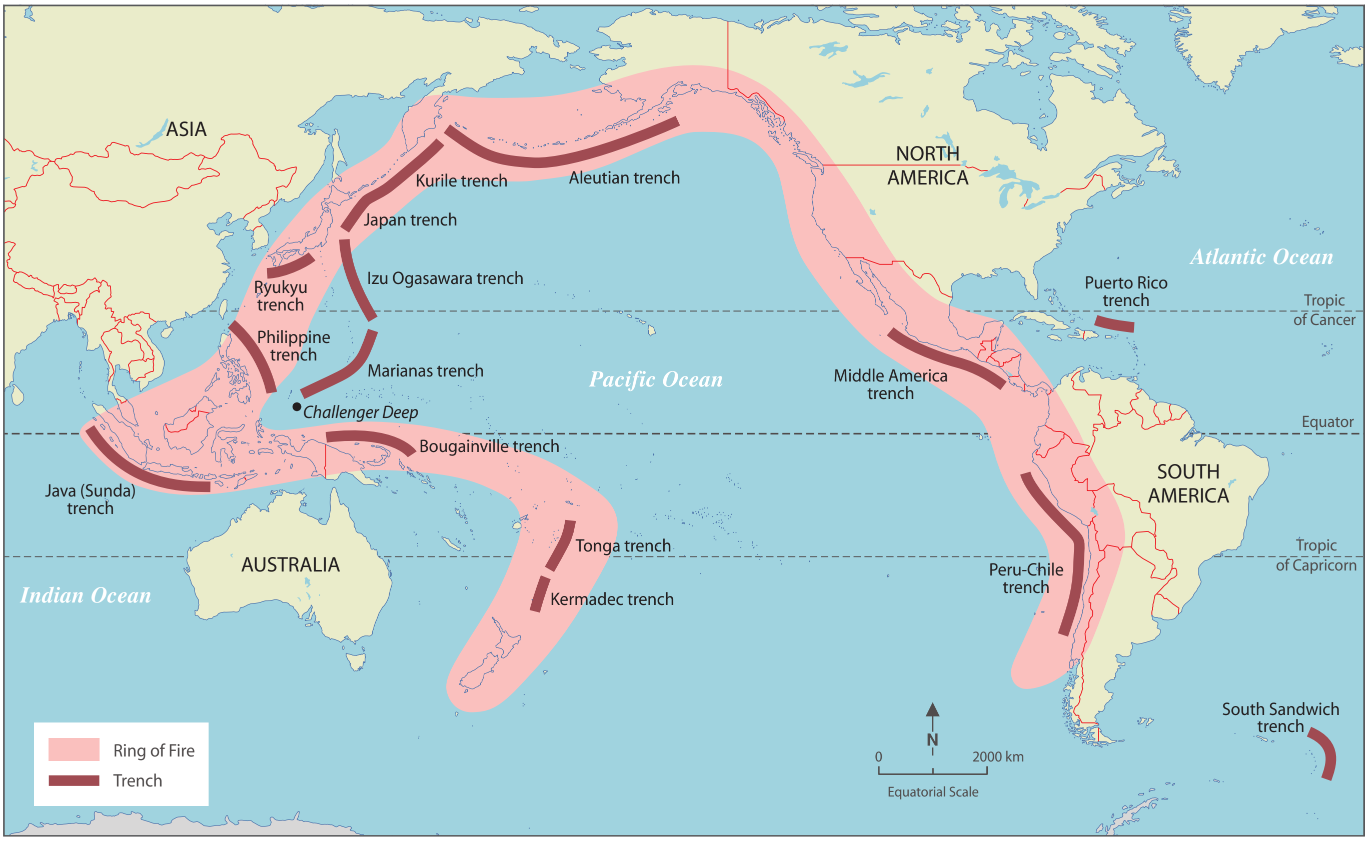
The most significant hazard of the Alaskan volcanoes are the ash clouds and ashfall impacting air traffic. The volcanoes are located under major aircraft routes through which many planes fly on a daily basis.

In November 2016 significant seismic activity was experienced along the Ring of Fire, particularly in Japan and New Zealand. The earthquakes in Japan and New Zealand occurred because they are on the borders of Pacific plates. It is here where various plates move, slide and grind past each other.

On 22 November 2016, a 6.9 magnitude earthquake struck off the coast of Japan and tsunami waves soon followed (Figure 3.31). Japan is particularly vulnerable as it is located at the junction of four major tectonic plates. The earthquake and subsequent tsunami were a result of the North American and Pacific Plate colliding.

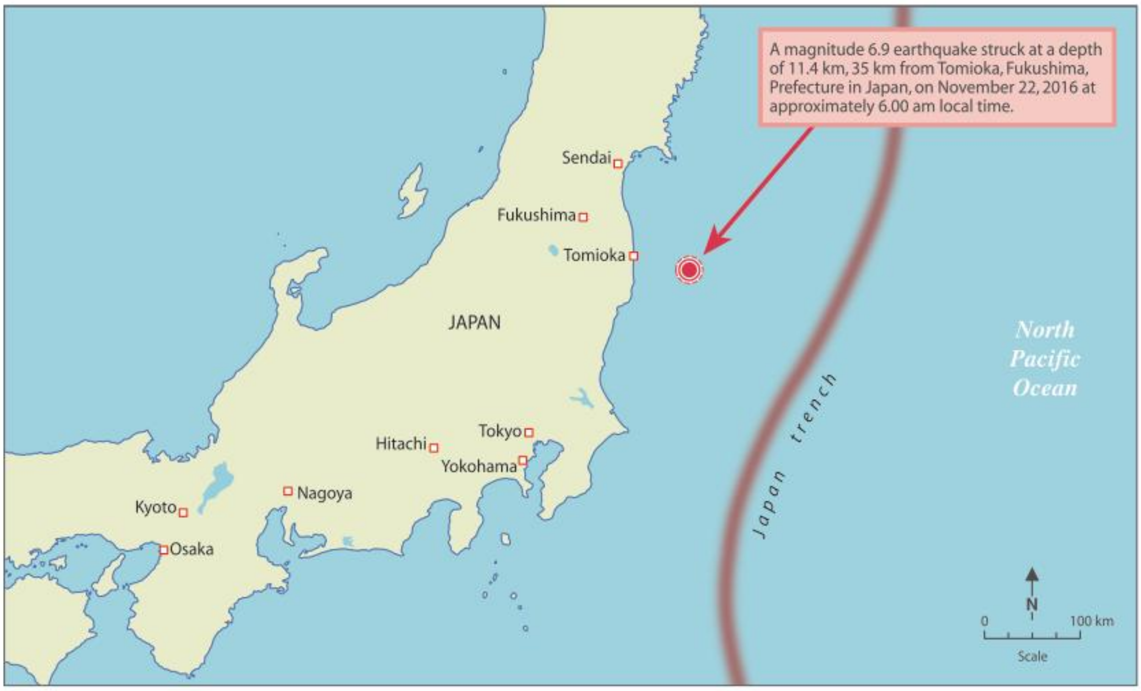
Not long after, New Zealand's North Island was shaken by an earthquake that measured with a preliminary magnitude of 6.1 to 6.3. This earthquake occurred less than one week after a powerful tremor centred in the upper South Island rocked the country and killed two people.

In January 2018 four geological disasters jolted the Pacific Rim, including a magnitude 7.9 earthquake in Kodiak, Alaska; a 6.4 earthquake on the Indonesian



▲ **Figure 3.30** The location of the Ring of Fire

▼ **Figure 3.31** A magnitude 6.9 earthquake struck Fukushima Prefecture, Japan



CAREER PROFILE

Dr Adele Bear-Crozier

Volcanologist, Geoscience Australia

As a volcanologist I get to travel the world, climbing volcanoes and collecting rock samples which can help determine how big and how often eruptions have occurred in the past. I then use the data collected in the field to run computer models and try to work out where volcanic hazards might occur in the future and what impact they will have on communities living at risk.

I use my understanding of Geography every day whether it be mapping sample locations on active volcanoes using GPS, reconstructing past volcanic landscapes from eruption deposits or modelling future impacts on communities through the development of volcanic hazard maps.

I work in a multidisciplinary team of seismologists, tsunami scientists, meteorologists, demographers and built-environment spatial scientists, all of whom have a background in Geography which is an important part of any earth scientist's training.

I loved all the science subjects in high school including Physics, Chemistry and Biology but Geography seemed to me an excellent way to apply science to real world problems, not just theorise, and this led to my career in earth science.

Geographers working in volcanology can find themselves working outdoors monitoring active volcanoes in observatories worldwide – or in university and government institutions where science is applied to solving real world problems such as helping communities in developing countries prepare for, or recover from, volcanic eruptions. Or like me, they can do both!

island of Java and the eruption of Mount Kusatsu-Shirane in Japan. On 22 January, Mount Mayon in the Philippines sent lava more than 600 metres into the air resulting in more than 61,000 people forced to evacuate from nearby villages as thick smoke descended the mountain (Figure 3.32).

In mid-February 2018 a “flurry of earthquakes” hit the Pacific Plate. These earthquakes occurred near Japan, Guam and Taiwan. A series of tremors shook the island of Guam; tremors reaching magnitude 5.7, 5.6 and 4.9. Japan experienced a 4.8 magnitude earthquake and two 4.5 quakes, and as mentioned earlier, Taiwan’s earthquake measured 6.4 magnitude.

During the height of the New Zealand tourist season, in December 2019, Whakaari or White Island volcano, off the coast of the North Island, erupted without warning, killing 22 people and injurying several others.

Earthquake activity occurred in Indonesia between January–June 2021 with the country experiencing 15 earthquakes over a magnitude of 5.0. The deadliest was a magnitude of 6.2 in January causing 105 deaths.

Krakatau

Indonesia, an archipelago made up of over 17,000 islands and with a population of 240 million, is another country susceptible to earthquakes and volcanic eruptions as it too is located on the Ring of Fire.

Krakatau’s first major eruption occurred in August 1883. It was one of the deadliest and most destructive volcanic events ever recorded in history. The volcano blew apart the surrounding islands and collapsed into its crater forming a caldera. The explosions were so violent that they were heard in Perth, Western Australia, over 3000 kilometres away. Over 36,000 deaths were attributed to the eruption and the subsequent tsunamis that it created (see Figure 3.33). The remnant crater sits near the Sunda Trench (Figure 3.34), an active subduction zone, formed where the Australian Plate is *moving* under the Sunda Plate. This subduction zone is responsible for creating the island of Sumatra, the active volcanoes and calderas fed by the rising magma, and the frequent earthquakes and tsunamis.

▲ **Figure 3.32** Lava and clouds of ash and smoke are erupting from Mt Mayon, Philippines, 16 January 2018, six days before its major eruption

◀ **Figure 3.33** Map showing the original size of Krakatau before the eruption

▼ **Figure 3.34** Location of the Sunda Trench

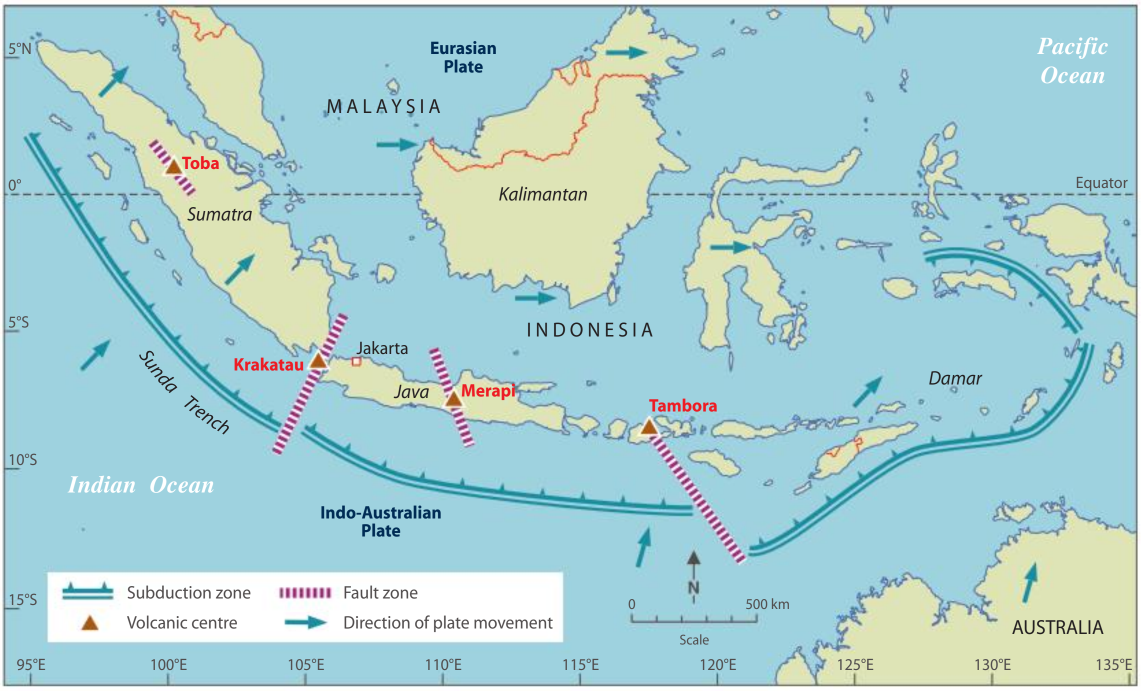
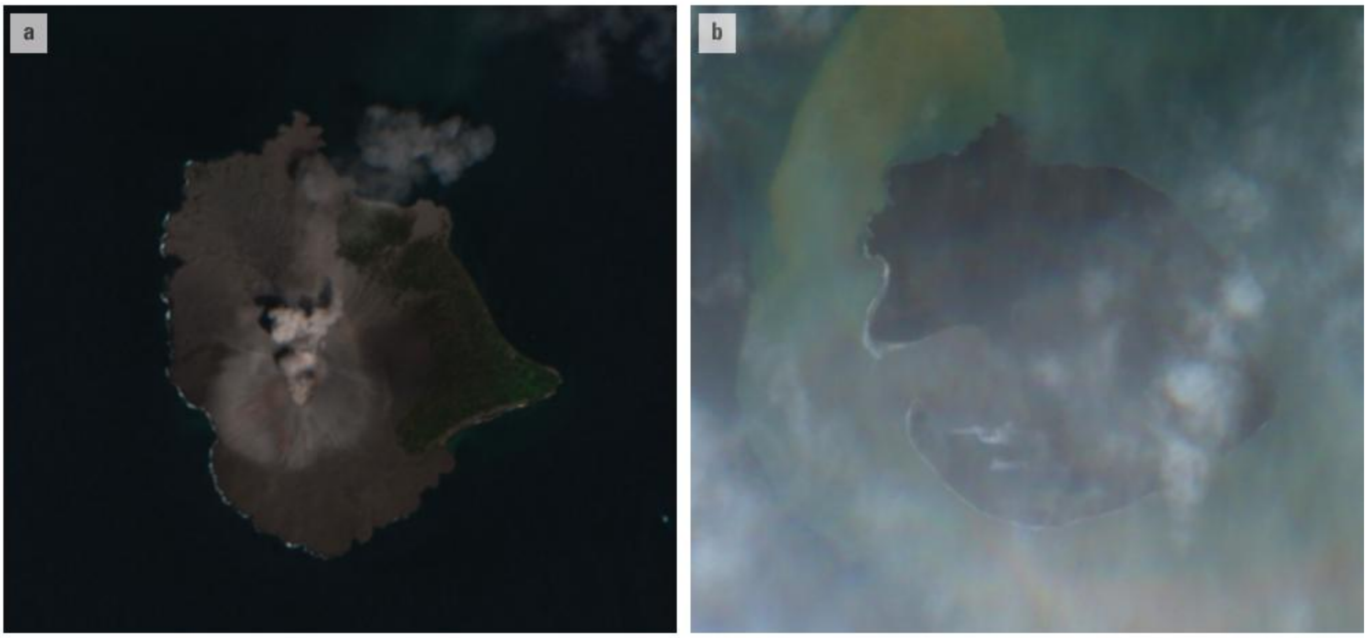


Figure 3.35 Satellite imagery showing **(a)** before the eruption, 16 November 2018 and **(b)** one week after the eruption, 29 December 2018



Within the crater of Krakatau, on the north-east margin of the caldera, Anak Krakatau (Child of Krakatau) has been forming (Figure 3.33). It first breached the ocean surface in 1927 and has experienced frequent eruptions since then. On 22 December 2018 Anak Krakatau experienced a major lateral collapse of its south-west flank. What was once a crater had opened up and formed a small bay, as can be seen in Figures 3.35 (a) and 3.35 (b).

The Centre of Volcanology and Geological Hazard Mitigation (CVGHM) under the Geological Agency of the Indonesian Ministry of Energy and Mineral Resources examined satellite images of Anak Krakatau and stated that the volcano went from 430 metres above sea level to 110 metres and between 150–170 million cubic metres of material slipped into the sea. The collapse of the volcano triggered a tsunami which flooded the coast of west Java and south-east Sumatra. According to Indonesia's disaster agency, the tsunami killed over 400 people, 13,000 were injured, 33,000 were displaced and forced to seek temporary accommodation, and thousands of buildings were destroyed (see Figure 3.36 (a) and (b)).

The tsunami came a few days before the 14th anniversary of the 26 December 2004 tsunami, one of the deadliest in history that claimed over 200,000 people in several countries around the Indian Ocean, more than half of whom were Indonesian.

As mentioned earlier in this chapter, the Ring of Fire has a sophisticated monitoring system which measures even minor *changes* in sea level. Although these warning systems are in place, Indonesia is a very large, dispersed and diverse country that is exposed to many natural hazards, and according to Professor Greg Foliente who is the deputy director of the Centre for Disaster Management and Public Safety (CDMPS) at Melbourne University, the area that needs to be covered is too vast. The head of Indonesia's Meteorology, Climatology and Geophysics Agency, Dwikorita Karnawati, said that the tsunami was caused by volcanic activity not an earthquake, so it could not be detected by the agency's sensors, which monitor the conventional earthquakes in the *region*.

Figure 3.36 **(a)** A coastal village ravaged by the tsunami. **(b)** Tsunami destroys hotels along Panimbang Beach, Banten Province, Indonesia

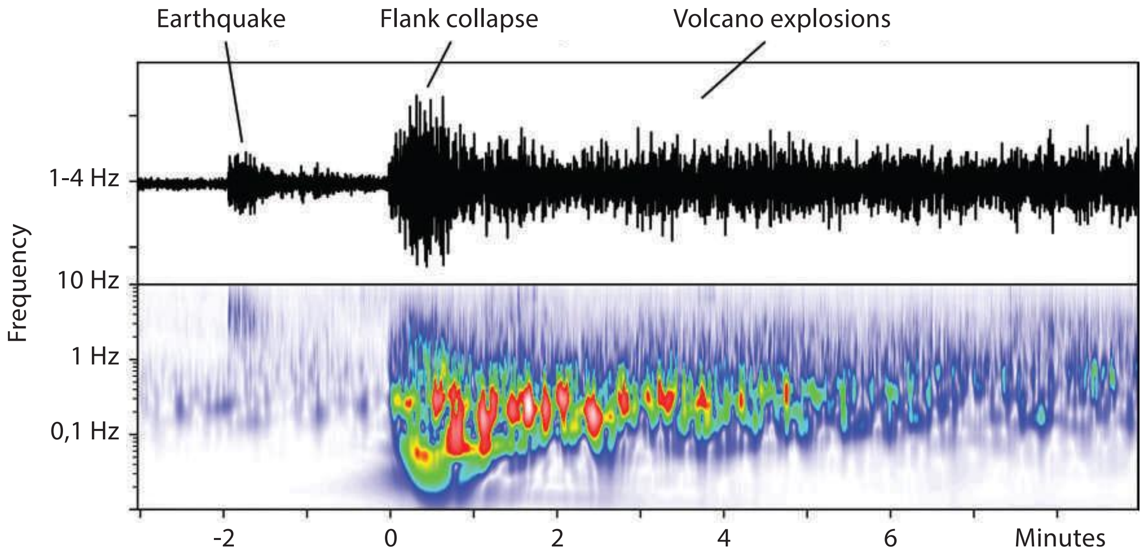


Figure 3.37 Seismic images show a small earthquake only two minutes before the landslide

Anak Krakatau had been rumbling for several years before the major eruption of 22 December 2018 and no other tsunamis from the volcano had been recorded. Thomas Walter of the German Research Centre for Geosciences (GFZ) in Potsdam showed that the volcano did produce clear warning signs before its collapse. His agency was able to come to this conclusion after using multiple sources of data collected from ground instruments, drones and satellites. Satellites, for example, showed the increase in temperature and ground *movement* of the south-western flank and seismic data recorded the *movement* a few minutes before the collapse of the crater (see Figure 3.37).

Managing tectonic hazards

It is not possible to stop earthquakes or volcanic eruptions. However, management of these hazards can minimise the damage they cause and reduce the impact of disaster. Prediction is the most important part of this, as this gives people time to prepare for the event and evacuate if necessary.

A broad range of methods are available to researchers to monitor and predict seismic activity from "satellite observation to ground-based seismic data, from infrasound to drone data, from temperature measurements to chemical analysis of eruption products" according to volcanologist Thomas Walter. The aim of improving the monitoring systems in order to minimise impacts poses a major management challenge.

The methods used in monitoring and predicting volcanic activity are becoming more accurate. Due to their consistent activity and because people choose to live near these hazards, volcanoes such as Soufrière Hills, on the Caribbean island of Montserrat, and Mount Etna in Italy are closely monitored. Residents benefit from early warning signs and are able to prepare for a hazard event (Figure 3.38).

Figure 3.38 Key procedures for monitoring a volcano

Warning signs	Monitoring methods
Hundreds of small earthquakes are caused as the magma rises up through cracks to the surface.	Seismometers are used to detect earthquakes.
Temperatures around the volcano start to rise as the activity starts to increase.	Thermal imaging techniques and satellite images can be used to detect heat around the volcano.
When the volcano is close to erupting, it releases gas: the higher the sulphur content in these gases, the closer it is to erupting.	Samples of gas can be taken and chemical sensors can be used to measure the sulphur levels.
Ground-swelling occurs as the magma moves into the upper layers of the crust.	Laser measures and GPS data indicate rates of swelling.
Electromagnetic energy emitted by volcanoes.	Remote sensing. Using a satellite's sensors to detect the *change* in electromagnetic energy being emitted from the surface of a volcano or from its erupted material.
Gases emitted from volcanoes.	Sulphur dioxide can be measured by remote sensing using NASA's Orbiting Carbon Observatory.
Monitoring the growth rates in forests.	In recent times it has been demonstrated that the prediction of eruptions can be made months ahead by monitoring forest growth. This tool was used during the eruption of Mt Etna during the 2002–2003 eruptions.

ACTIVITIES

1. Research a recent earthquake or volcanic eruption (apart from those mentioned in this chapter) and create an eBook of your findings. In your research you should:

   a. Investigate the characteristics of your chosen geological hazard and its characteristics both natural and human.

   b. Collect some diagrams and images that support your description of the natural and human characteristics.

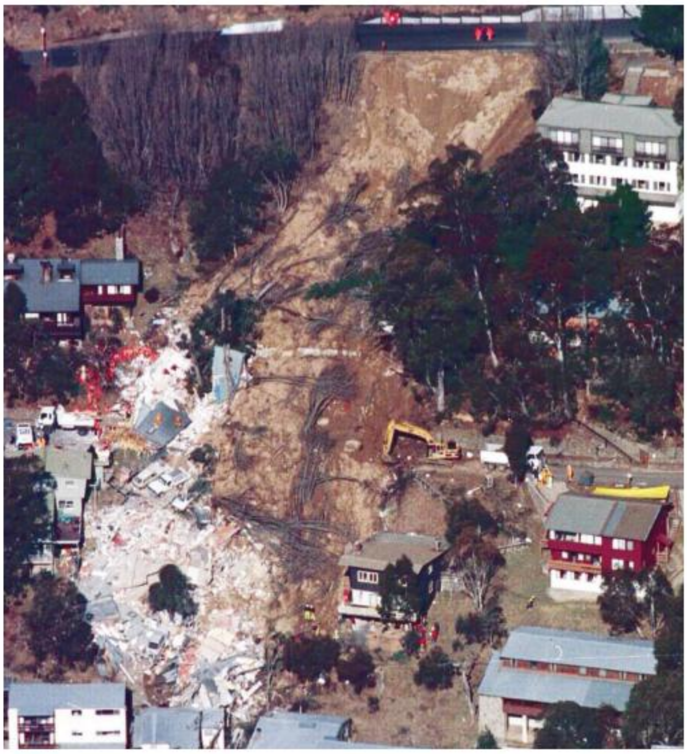
   c. Describe the *changes* that have occurred in the *region* due to the activity.

   d. Describe the preparation and planning required when dealing with a possible geological hazard.

   e. Explain how predicting and planning for an earthquake is different from or similar to that required for a volcanic hazard.

   f. Geospatial technologies are crucial in monitoring geological hazards. These technologies assist in the research and the management of these geological events. Using appropriate case studies, research at least three of these methods and assess their effectiveness.

Geological hazards – landslides, mudslides and avalanches



▲ **Figure 3.39** Thredbo is an alpine resort in the New South Wales Alps, particularly popular in winter, where thousands come to ski and stay in the lodges. On 30 July 1997 a landslide destroyed two occupied chalets, burying 19 people, with just one survivor

Landslides, a form of mass *movement*, are a serious geologic hazard and occur yearly throughout the world (see Figure 3.39). The largest landslide ever recorded was caused by the eruption of Mount St Helens in May 1980. A mixture of melting snow and volcanic materials travelled down the north flank of the mountain, following the North Fork and Toutle River channels (see Figure 3.40). An area of about 62 square kilometres was covered, and the total volume of the deposit was about 2.9 cubic kilometres.

Though snow-covered mountains in winter may be admired for their beauty, the huge amounts of snow that build up on the slopes can be especially hazardous. On a slope, the snow piles up and is supported by a snow-pack. This is what stops it from toppling down. An avalanche is a sudden downhill *movement* of snow. An avalanche occurs when more snow falls on an already large snow-pack and this snow-pack becomes unstable. The pack starts to weaken due to its weight, and with the help of gravity it allows the build-up of snow to be released. Avalanche barriers, as see in Figure 3.41, can be constructed to help reduce this hazard.

▼ **Figure 3.40** Lahar flowing down the north flank of Mount St Helens

ACTIVITIES

1. Identify the types of mass *movement* that exist. Make a list of these and include a definition.
2. Identify the factors that lead to the types of mass *movement* listed in question 1. How predictable are these events?
3. Explain how human activity can contribute to landslides.
4. Investigate how the effects of landslides and the disaster they cause can be lessened or avoided.
5. Find a local example of mass *movement*. It does not have to be a large one. It may be a slumped bank in a local creek, a rock fall in a cutting on the side of a road, or a slight bulge on a hillside which has a distorted fence line.

   Write a brief report on this feature which includes:

   - a sketch map showing its location in relation to other things mentioned in your explanation (e.g. a stream, hard rock, soft soil)
   - a labelled sketch of the landscape feature
   - a paragraph that explains how it may have occurred.

6. Conduct research on a landslide, mudslide or avalanche and create either an AVD, a research report or a photographic essay on the event. In your research include the following:
   a. the characteristics of your chosen geological hazard
   b. diagrams and images that help describe the hazard event
   c. a description of the natural *process* or human activity that contributed to the geological hazard
   d. a description of the *changes* that have occurred in the *region* due to the hazard
   e. a description of the preparation and planning required to minimise any damage
   f. an outline of any responses by government and non-government organisations.
7. There are six main geological hazards mentioned in this chapter. Draw up a table using the headings provided to summarise each of these hazards.

Hazard	Characteristics	Causes	Impacts	Responses
Volcano				
Earthquake				
Tsunami				
Landslide				
Mudslide				
Avalanche				

Figure 3.41 Avalanche barriers protecting ski slopes in Kitzsteinhorn Alps, Austria

4 Hydro-meteorological hazards and disasters

What are hydro-meteorological hazards and disasters?

Hydro-meteorological events involve the weather and climate, and form part of the Earth's natural *processes*. Different hydro-meteorological events can produce extreme heatwaves, floods, droughts, storms, cyclones and bushfires, which can be hazardous to both the natural and human *environments*, and can lead to disasters. Many factors influence the *scale*, frequency, magnitude and impacts of hydro-meteorological hazards including location, physical features of the landscape including the hydrological cycle, climate patterns, climate *change*, ocean currents and management.

▼ **Figure 4.2** Costs of a hydro-meteorological disaster

	Direct	**Indirect**
Tangible	Damage to buildings	Emergency response costs
	Infrastructure	Household costs
	Crops and livestock	Commercial costs
	Natural resources	Loss of production
Intangible	Death	Psychological
	Injury	Inconvenience
	Sense of belonging	Stress

▼ **Figure 4.3** Although hydro-meteorological events pose risks for people, they are an essential *process* in *environments* such as Barmah Forest, NSW and Victoria

▼ **Figure 4.1** The difference between weather and climate

Weather refers to atmospheric conditions over a short time period. Climate is the average weather at a location over a long time period.

Hydro-meteorological hazards affect *regions* all over the world although the *distribution* of specific hazards is determined by local climate and topography. The vulnerability of specific communities is largely based on anthropogenic factors (those caused or produced by people). These are factors originating in human activity such as disaster management, including plans and responses, population density, community preparedness and economics.

Hydro-meteorological events are part of the natural *processes* including cycles vital in maintaining the health of ecosystems that have adapted to *environmental* conditions over time. For example, floods are a vital *process* maintaining the health of river *environments* such as floodplains, wetlands and river channels. River red gum forests like the Barmah Forest rely on the flooding of the Murray River to maintain growth and regeneration (Figure 4.3). In this case, flooding enables the *interconnection* between the floodplain and the river channel. However, hydro-meteorological events often become hazardous when people are involved. Living in areas subject to these *processes* makes them hazardous as they have the potential to cause harm to people and damage infrastructure, potentially leading to social and economic disaster.

Management of hydro-meteorological hazards is a balance between preventing disaster from occurring or minimising the impacts while maintaining the ecological health of the *environment*. In many cases, *changing* the landscape to suit a specific need – such as forest management, coastal development, river regulation and greenhouse gas regulation – impacts on these natural *processes* and can increase the potential hazard. As population density increases globally and more development occurs in low-lying coastal areas, forests and on floodplains, managing hydro-meteorological hazards becomes a more difficult challenge.

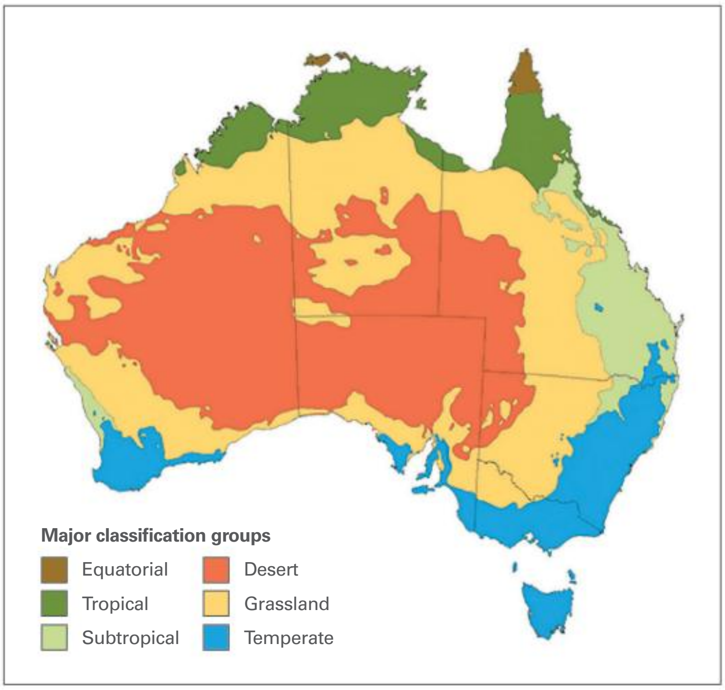
Hydro-meteorological hazards in Australia

Australia's climate varies greatly from equatorial and tropical in the far north, arid in the centre and temperate in the south-east and south-west (Figure 4.4). As a consequence, Australia is vulnerable to a wide range of hydro-meteorological hazards. On average, 13 tropical cyclones form in the Australian *region* each year, often leading to torrential rain that floods towns and farmland. Australia also has a long history of periodic drought which has led to economic hardship and disastrous bushfires. Heatwaves and flash flooding regularly pose risk for infrastructure and the most vulnerable members of society. The *interconnection* between the causes of hydro-meteorological hazards makes them difficult to manage. For example, a lack of seasonal rainfall leading to drought might also increase the dry fuel load for a bushfire or the potential for flash flooding from dry, compacted soils.

▶ ACTIVITIES

1. Using the information in Figure 4.2 and the photos in Figures 4.3 and 4.5, discuss how hydro-meteorological events can impact people and *places* at a range of temporal and spatial *scales*.
2. Describe one way in which the causes of hydro-meteorological hazards are *interconnected*.
3. In groups, create an overlay map of the *distribution* of hydro-meteorological disasters at a national *scale*.
    a. Choose a country such as Australia or the United States and assign each member of the group a hydro-meteorological hazard such as drought, flood, tropical cyclone or bushfire.
    b. Use a search engine and terms such as 'list of floods in the United States' to gather your data.
    c. Decide on a manageable time period such as disasters in the last ten years.
    d. Decide on a common way to represent disasters using appropriate mapping conventions and then map the location of each type of disaster on a separate layer. This can be done by hand or digitally using pins on Google Earth.
    e. Combine your layers to create an overlay map of hydro-meteorological disasters.
4. Use the overlay map created in activity 3 to complete the following:
    a. Describe the *distribution* of each type of hydro-meteorological disaster within your chosen country.
    b. Are there any *spatial associations* between any of the types of hydro-meteorological disasters?
    c. Suggest reasons for your answers to part a or b based on the geographic characteristics of these locations.
5. Using the climate map of Australia in Figure 4.4, explain why it is possible for Australia to simultaneously experience floods in Queensland and bushfires in Victoria.
6. Visit the VicEmergency website or download the app onto your smartphone to explore current incidents and hazards around Victoria.

▼ **Figure 4.4** Australia's varied climate zones means it is susceptible to a range of hydro-meteorological events



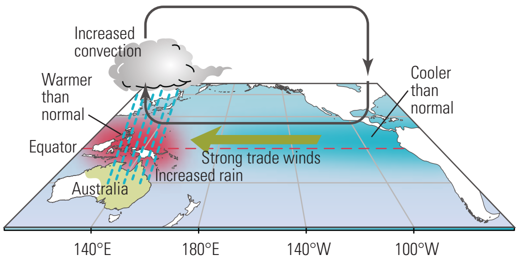
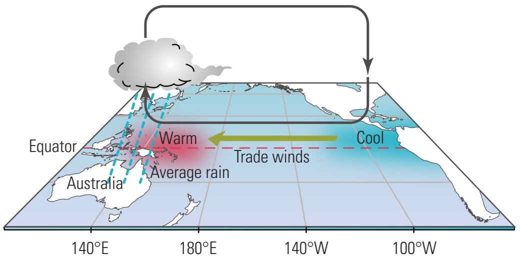
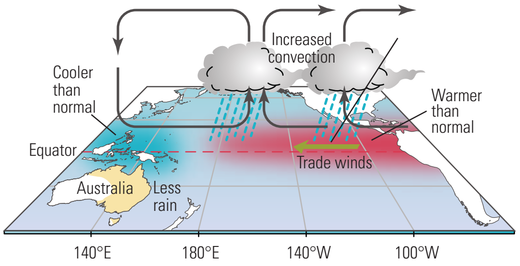
▼ **Figure 4.5** Australia's diverse climate makes it vulnerable to a wide range of hydro-meteorological hazards such as **(a)** tropical cyclones in Queensland and **(b)** bushfires in Victoria

What *processes* cause variations in climate?

Variations in climate and hydro-meteorological *processes* are affected by many factors including latitude, *distance* from the sea, altitude, topography and broad patterns in the oceans and atmosphere. In Australia, South-East Asia, the Pacific Islands and the western *region* of South America, one of the biggest factors affecting variations in climate is the El Niño Southern Oscillation (ENSO). Variations in the Pacific Ocean's temperatures, air pressure and trade winds greatly influence the amount of precipitation, evaporation, cyclone activity and the temperature that these *regions* experience. This in turn influences hydro-meteorological hazards such as heatwaves, droughts and floods.

ENSO fluctuates between three phases: La Niña, neutral and El Niño (Figure 4.6). On average, each phase lasts for about one year but ENSO phases are highly variable and extreme phases last for between three and seven years. The fluctuation between phases can be measured by differences in sea-level air pressure between Darwin and Tahiti. These differences are recorded on a graph called the Southern Oscillation Index (SOI), with values below –7 often indicating El Niño episodes and above +7 typical of La Niña.

▼ **Figure 4.6** ENSO *processes* and their effect in Australia (La Niña, Neutral, El Niño)

Phase	***Process***	**Effect in Australia (opposite in west coast of South America)**	**Diagram**
La Niña **SOI is above +10**	▶ Warm water is pushed west against the east coast of Australia. ▶ Colder water on the west coast of South America. ▶ Stronger trade winds and Walker Circulation.	▶ More evaporation and precipitation. ▶ Increased flood risk and tropical cyclone formation.	
Neutral **SOI is between –10 and +10**	▶ Trade winds blow from east to west in the tropical Pacific *region*. ▶ Warm waters are pushed west. ▶ Walker Circulation is formed.	▶ Occurs more than half the time. ▶ Less extreme weather. ▶ Droughts and floods still possible.	
El Niño **SOI is below –10**	▶ Warm water is pushed towards the west coast of South America. ▶ Walker Circulation breaks down. ▶ Colder ocean temperatures on the east coast of Australia.	▶ Less evaporation and precipitation. ▶ Drought risk in northern and eastern Australia. ▶ More heatwaves and fewer tropical cyclones.	

▶ ACTIVITIES

1. Watch *Understanding ENSO* on the Australian Government Bureau of Meteorology's YouTube channel.

  a. Write down the three phases of ENSO and the conditions Australia experiences during each phase.

  b. On average, how long does an ENSO phase last?

2. Create an animation, draw a series of diagrams or perform a role-play that shows ENSO *processes* and effects in greater detail.

3. Using a blank map of the world, create a map showing the *distribution* of global *regions* that experience different climate conditions under different ENSO phases.

4. Research Australia's climate outlook for the next few months using the Bureau of Meteorology website and use it to explain how state governments, emergency management authorities and local industries might use this information.

5. a. Search for the Southern Oscillation Index monthly history on the Bureau of Meteorology website to gather data about the ENSO status in Australia since 1980.

  b. Using this information and the information in Figure 4.6, try to correlate El Niño and La Niña events with major bushfires, floods, droughts and tropical cyclones in Australia's history.

  c. Using your findings, explain the *interconnection* between ENSO and hydro-meteorological hazards.

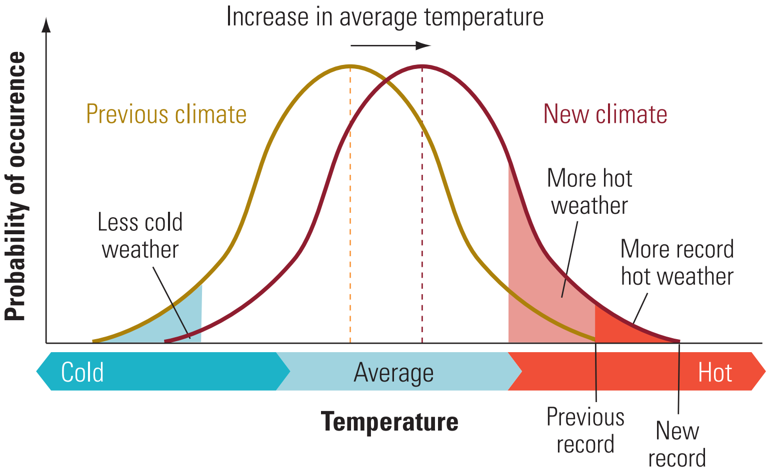
The potential impact of climate *change* on hydro-meteorological hazards

There is strong evidence within the scientific community that human-induced climate *change* is altering, and will continue to alter, hydro-meteorological *processes*. This is likely to cause an increase in the frequency and magnitude of extreme weather events through factors such as an increase in global surface temperature, *changes* to evaporation rates and the amount of moisture in the atmosphere, and sea level rise (see Figure 4.7).

Figure 4.8 summarises the current and future potential impacts that climate *change* will have on various hydro-meteorological hazards. According to the Bureau of Meteorology (BOM), climate *change* has increased the occurrence of extreme bushfire weather and extended the length and intensity of bushfire seasons in many *places* across Australia since the 1950s. Similarly, climate *change* has contributed to more intense and prolonged droughts and an increase in the frequency and magnitude of flood events.

The *distribution* of these impacts is uneven. For example, heavier rainfall has been observed and is expected to increase in eastern parts of North and South America, northern Europe and central Asia. Drying trends have been observed in the Mediterranean, the Sahel in northern Africa, southern Africa and parts of southern Asia. The impacts of these hazards will also be disproportionate. The most vulnerable *regions* will be those housing poorer communities who lack the economic and technological resources to adapt to *changes* and low-lying coastal or island communities.

▼ **Figure 4.7** The relationship between average temperature and extreme temperature



The effects of climate *change* are already being witnessed in many of the hydro-meteorological disasters that have recently occurred around the world. A rise in sea surface temperatures has contributed to an increase in monsoon rainfall and tropical cyclones in South Asia. Intense rainfall during 2020 flooded one-third of Bangladesh, killed 161 people and left 1.5 million people displaced, all while trying to contain the spread of COVID-19. Climate *change* is also affecting ENSO *processes* leading to extended dry periods in Central America. The most recent drought was in its sixth year by 2020. Crop failure in Guatemala, El Salvador, Honduras and Nicaragua has led to food insecurity for 2.5 million people, many of whom have become climate refugees.

▼ **Figure 4.8** The potential impacts of climate *change*

Hazard	Potential impacts of climate *change*
Rising temperatures	More frequent severe heatwaves causing illness and death
Drought	Greater evaporation and less precipitation in many *regions* leading to increase in the intensity and duration of drought conditions and a *change* in the *distribution*
Bushfires	Higher frequency of intense bushfires due to hotter, drier conditions. Extended bushfire seasons.
Storms and tropical cyclones	Increased frequency and magnitude of storms as warm air holds more water vapour. Warmer ocean temperatures will increase the frequency and intensity of tropical cyclones further north and south.
Sea level rise	Projected rise of 0.5–1 metre by the end of the century due to thermal expansion and melting polar ice. Threat of permanent inundation or more frequent flooding due to storm surges in low-lying coastal areas such as Vanuatu in the Pacific Islands.

▶ ACTIVITIES

1. Find up-to-date climate projections from a variety of online sources such as the Intergovernmental Panel on Climate Change (IPCC) and list the *regions* that are likely to be severely affected.
2. Using Figure 4.7, explain how a small increase in the average temperature can have a large impact on the probability of extreme hot weather.
3. Find evidence from the Bureau of Meteorology website that supports or disproves the claim that there has been a significant increase in the number of hot days in Australia over the past decade.
4. Suggest ways in which physical, economic and technological factors may affect the responses of vulnerable countries, including adaption, to the impacts of climate *change* and subsequent hydro-meteorological events.
5. Contrast the direct and indirect impacts that an increased frequency and magnitude of hydro-meteorological events might have on Australia and a country such as Bangladesh or Vanuatu.

Bushfires

Figure 4.9 The difference between wildfires and bushfires

'Wildfire' is the internationally recognised term for describing a fire burning out of control in grass, scrub and forested areas. In Australia, such fires are generally referred to as bushfires.

Bushfires (also known as wildfires) are fires that burn out of control in grassland or forest. They are a major hazard in many parts of the world and are often the cause of major disasters in Australia. When bushfires are driven by strong winds they can spread quickly and unpredictably. Bushfires originate from both human and natural causes (see Figure 4.10) including arson, discarded material such as cigarette butts, burn offs and lightning. While they are an essential and natural *process* within the Australian *environment*, they can also be extremely hazardous to human and natural *environments*. Each year, bushfires impact vast amounts of forest, grassland, farmland and towns and can often lead to the loss of human life.

Figure 4.10 The human and natural causes of bushfires (ignition factors) each fire season based on data from Victoria averaged from 2010 to 2020

Rank	Ignition factor	Percentage
1	Ignition factor undetermined	22.8
2	Suspicious, not during civil disturbance	20.9
3	Lightning	16.4
4	Re-kindled from a previous fire	13.4
5	Vehicle	6.3
6	Inadequate control of open fire	6.2
7	Abandoned, discarded material, including discarded cigarettes/cigars	4.6
8	High wind	3.8
9	Unattended	3.2
10	Part, failure, leak or break	2.4

What is the *interconnection* between drought conditions and bushfires?

Drought is defined as an extended period of time during which less-than-expected rainfall occurs. During drought periods there is not enough water to meet the needs of agriculture, the natural *environment* and the community. Rivers, creeks and water supplies dry up and vegetation dies. The agriculture sector is heavily affected, which impacts on communities and the economy. There is a strong *interconnection* between drought conditions and the *scale*, frequency and magnitude of bushfires. Dry fuel burns more quickly and intensely than damp fuel, and prolonged dry periods will therefore create hazardous bushfire conditions. Furthermore, a lack of rainfall means that large fires will continue to burn for prolonged periods and will be more likely to lead to a disaster.

How are bushfires classified?

Bushfires can be classified by both the type of fire and the *environment* in which they are burning. The three main types of fire are:

- ground fire: underground fire in which peat, coal or tree roots ignite
- surface fire: low- to high-intensity fire burning the surface litter, grass and shrub layers (Figure 4.11 (a))
- crown fire: very high-intensity fire, spreading rapidly through the crown or canopy of trees, especially when fuelled by strong winds (Figure 4.11 (b)).

The two main classifications based on *environment* are:

- grassfires: the most common type of bushfire in Australia, spreading rapidly (up to 25 kilometres per hour) along flat areas covered in grasses or scrubland, with the potential to destroy fences, livestock and buildings
- forest fires: bushfires occurring in forests and woodlands, often in mountainous areas that are less accessible. Steep terrain and dense forest can lead to very rapid and intense fires which are extremely hazardous to homes, infrastructure and human life.

Figure 4.11 Surface fires **(a)** burn fuel at the ground surface whereas crown fires **(b)** spread through tree crowns

What factors affect the intensity and spread of a bushfire?

Bushfire intensity is the rate of energy or heat released at the fire front and is measured in kilowatts per metre (kW/m). A small, planned burn would have an intensity in the order of 500 kW/m whereas a large forest fire on a dry and windy day might reach levels above 100,000 kW/m. There are a number of physical factors that influence the rate of spread and intensity of a fire (see Figure 4.12). These factors are often *interconnected*. For example, hot, dry, windy conditions in a bushland location with steep topography is likely to be vulnerable to a high-magnitude bushfire.

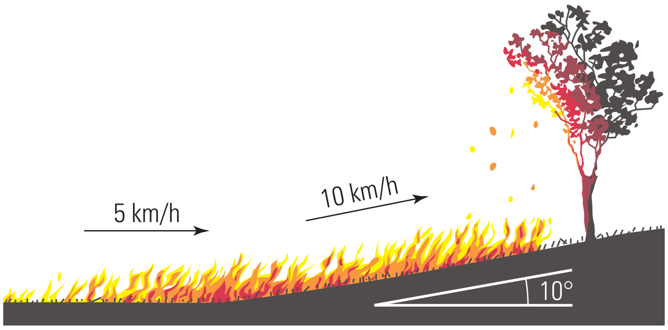
What are the negative impacts of bushfires?

Each year, bushfires cause havoc around the world and, in many cases, lead to disaster. Homes, farms and business are destroyed and infrastructure is ruined, bringing distress, injury and death to people. Ash and smoke may also pollute water supplies or affect air quality which can lead to additional health issues. In 2015, wildfires in Indonesia's tropical forests killed 19 people directly but led to an estimated additional 100,000 deaths due to respiratory tract infections. There is also an ongoing economic cost in rebuilding. Each year, bushfires cost Australia over $300 million.

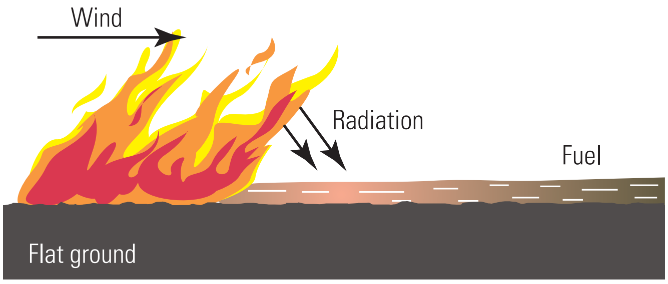
▼ **Figure 4.12** Factors affecting bushfire behaviour

Factor	Effect on bushfire behaviour
Climate	Particular *regions* are more fire-prone due to the amount of rainfall and average temperatures (e.g. south-eastern Australia, the Mediterranean).
Temperature	Hot, dry weather will dry fuel and encourage fire spread especially during prolonged spells (e.g. the weather leading up to the 2009 Black Saturday fires).
Topography	Fires burn faster up steep, forested slopes as flames can reach more unburnt fuel and radiant heat pre-heats higher fuel (see Figure 4.13).
Wind	Dry winds can feed a fire, increase its speed, dry fuel, and spread and carry embers which cause spot fires (see Figure 4.14).
Fuel load	Large amounts of dry, flammable fuel such as grasses, leaf litter and scrub increase the magnitude of the fire.

▼ **Figure 4.13** For every 10 degrees increase in slope, a fire will double its speed



▼ **Figure 4.14** High winds tilt flames forward, drying and preheating unburnt fuel



Responses to bushfires

Many of the physical factors that cause and affect bushfire behaviour, such as climate and topography, cannot be changed. Bushfire management therefore includes responses such as reducing fire risk and magnitude through fuel reduction (see page 64), extinguishing fires and using warning systems and survival plans. Extinguishing fires involves cutting oxygen supply to small-*scale* fires using soil or chemical foam, using water to reduce the temperature, back-burning fuel to stop the combustion *process* and removing fuel using machinery or controlled burns. Community preparedness is also a major factor in determining bushfire vulnerability. This involves managing vegetation on private properties to reduce fuel load, building houses with fire-resistant materials and features such as rooftop sprinkler systems and keeping informed via warnings issued by emergency broadcasters and social media.

▼ **Figure 4.15** The ten largest wildfires that have occurred in the 21st Century based on the area burnt

Location	Year	Area burnt ('000) ha	Fatalities
Russia	2003	20,000	0
Australia	2019–20	18,000	34
Russia	2019	4300	0
Canada	2014	3400	0
Australia	2002–03	2100	7
United States	2020	1700	26
Bolivia	2010	1500	0
Australia	2011–12	1400	0
Australia	2006–07	1300	5
Canada	2017	1200	0

ACTIVITIES

1. Using the data in Figure 4.10, state whether more fires in Victoria are caused by natural *processes* or human activities.
2. Refer back to Figure 4.2 and use it to classify the direct and indirect impacts of bushfires.
3. Visit the Country Fire Authority (CFA) website and read through the Fire Ready Kit. List five of the recommendations for improving bushfire safety and rank these in order of importance.
4. Watch the VICE documentary *How to Fight Forest Fires* on YouTube. Discuss what these firefighters are doing to reduce the vulnerability of their local area.
5. Explain how several of the factors that affect bushfire behaviour in Figure 4.12 are *interconnected*.
6. Figure 4.15 contains a list of the ten largest wildfires in the 21st Century based on the size of the area burnt.
   a. Undertake research online to find a list of the ten wildfires that had the most fatalities or that had the greatest economic cost.
   b. Compare this list with Figure 4.15 and discuss whether or not there is a correlation between the size of a wildfire and the number of fatalities or the economic cost.

Bushfires in Australia

Some *regions* of Australia are known worldwide for being extremely fire-prone. Each year, rural towns and urban–forest fringe areas are threatened by bushfires. The timing of the bushfire season is based on the climate of the *region* as depicted in Figure 4.16. Hazard management and investment in mitigation from state and local governments ensure that only a small percentage of bushfires develop into disasters. A *changing* climate and increasing population density in high-risk areas are likely to increase the fire hazard in the future.

What are the *environmental* impacts of bushfires in Australia?

Fire is a fundamental part of Australia's natural and Indigenous history. For millions of years, forests have evolved from wetter rainforest to drier eucalypt forest, scrubland and grassland. Flora and fauna have adapted to these unique arid conditions and require bushfire to replenish their growth and revitalise forest ecosystems. Many Australian trees and shrubs rely on fire for their seeds to germinate and for nutrients to be released into the soil. Therefore, although bushfires lead to costly destruction of infrastructure and danger to human life, they are a positive and essential component of many Australian ecosystems.

▲ **Figure 4.16** Australia's diverse climate and contrasting weather means that bushfire seasons occur at different times of the year in different *regions*

How have human activities and management altered bushfire *processes*?

Fire has the potential to become hazardous to the natural *environment* and more hazardous to the human *environment* if the natural fire regime is altered. The fire regime of an area relates to the fire intensity, frequency and the season in which it occurs. For tens of thousands of years, Indigenous Australians have cared for country by igniting regular low-intensity fires to reduce fuel loads, attract game animals and improve access through the bush; and this regime is still practised in central and northern Australia. By altering the landscape and stopping fires from burning to reduce their dangerous impacts, especially since the 1940s, people have modified the fire regime. Experts are arguing that this is leading to an increased fuel build-up, so that instead of regular, lower magnitude fires, Australia now experiences less frequent but more severe bushfires (Figure 4.17). These more intense bushfires can cause permanent damage to local ecosystems that are not adapted to their increased magnitude, especially as forests have been reduced in size and become more fragmented thereby decreasing regeneration.

How can vulnerability to bushfires be managed?

Bushfire management in Australia focuses on fuel reduction, forest management, warning systems, and fighting fires once they begin. Bushfire management requires a complex balance as preventing forest fires will protect communities but can lead to a build-up of fuel over time, potentially increasing the magnitude of future bushfire events.

Prior to each bushfire season, fire authorities such as Victoria's Department of Environmental, Land, Water and Planning (DELWP) conduct hazard reduction operations. The aim is to reduce the fuel load so that any future fires will generate less heat, travel more slowly and will be less likely to develop into a crown fire. An efficient method of reducing fuel over a large area

▼ **Figure 4.17** A selection of the most destructive bushfires in Australia's history based on deaths, houses destroyed and area burnt

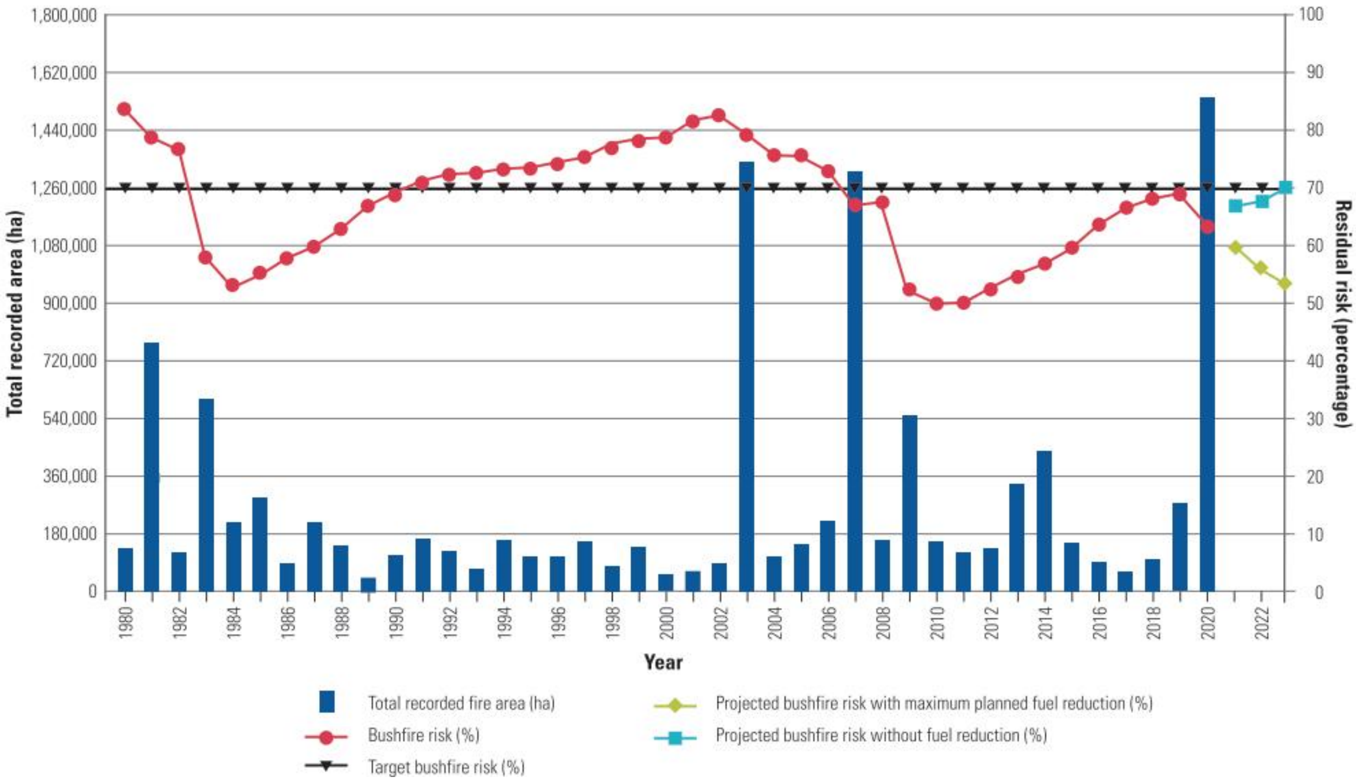
Fire	Location	Destruction		
		Deaths	**Houses destroyed**	**Hectares burnt**
2019–20 Black Summer	All states and territories	33	3500	19,000,000
2016	Western Australia	2	181	69,000
2013	New South Wales	2	208	118,000
2009 Black Saturday	Victoria	173	2000	411,239
2006	Victoria	3	57	1,000,000
2003	Canberra	4	500	164,000
2001–02	New South Wales	2	121	300,000
1993–94	New South Wales, Queensland	4	225	800,000
1983 Ash Wednesday	Victoria	76	1900	210,000
1967 Black Tuesday	Tasmania	62	1300	260,000
1939 Black Friday	Victoria	71	650	2,000,000
1926 Black Sunday	Victoria	60	–	400,000

is through planned burning. On days when conditions are suitable, low-intensity, controlled fires are lit with the intention of removing accumulated forest litter, plant debris and understorey plants. While this will not completely remove the threat of fires, it is intended to reduce the likelihood of very intense fires. The Victorian state government uses modelling to determine the bushfire risk following planned burning or a bushfire event (see Figure 4.18). Projected risks are based on worst-case weather scenarios, taking into account the area burnt and amount of fuel load remaining.

Managing fire hazard through planned burning is a contentious issue:

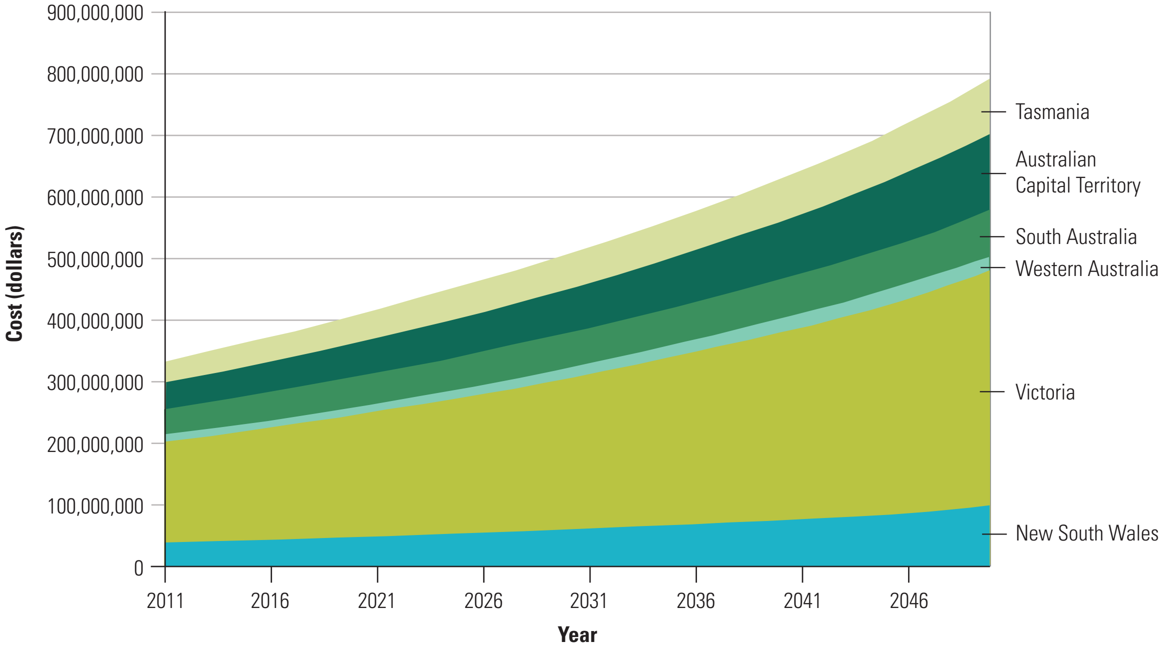
- the Victorian state government supports planned burning as one of the most effective ways of reducing bushfire risk by reducing the amount fuel in the landscape
- some conservationists argue that the regular use of low-intensity fires to reduce fuel will result in a loss of biodiversity, as certain species will be favoured over others
- other conservationists welcome the controlled fire as a way of maintaining natural fire regimes
- recent data has shown that planned burning may have little effect in reducing larger bushfires
- there is a small percentage of planned burns that have accidentally led to larger bushfires.

▼ **Figure 4.18** Victoria's bushfire risk profile from 1980 to 2020 and the forecast risk through to 2023. Data from *Fuel Management Report 2019–20,* Forest Fire Management Victoria (FFMVic). Search Forest Fire Management Victoria, bushfire risk to life and property, for an interactive version of this graph



Despite attempts to reduce vulnerability, the expected total economic cost of bushfires in Australia is rising. This is largely due to an increase in population and infrastructure density especially in urban–forest fringe *regions*. Climate *change* is also expected to increase the frequency and ferocity of large bushfire events such as megafires. A cost-benefit analysis of bushfire mitigation undertaken in 2014 showed that the economic cost of bushfires in Australia is expected to rise from an annual average of approximately $337 million in 2011 to $800 million in 2050 (see Figure 4.19). This average takes into account infrequent disasters such as the Black Saturday fires in 2009 which cost an estimated $4.4 billion. However, it did not take into account the massive *scale* of the Black Summer bushfires, 2019–20. Fire seasons of this magnitude are likely to raise the annual average cost considerably. When intangible costs such as mental health and other social impacts are taken into account, along with *environmental* costs such as loss of biodiversity, bushfires could become Australia's costliest disasters.

▼ **Figure 4.19** The projected total economic cost of bushfires in Australia (Deloitte Access Economics, 2014)



▶ ACTIVITIES

1. Refer to Figure 4.17.
   a. Identify the *regions* of Australia that were affected the most by bushfires from 1926 to 2020.
   b. Which Australian *regions* have experienced the most severe bushfires?
   c. Suggest reasons why this might be the case.

2. In groups, choose a *region* of Australia and research its climate, geographic characteristics, bushfire season and bushfire history.

3. Research an adaptation that a particular Australian tree or plant species has to allow it to survive or regenerate after a fire event. Annotate a sketch or photo to show this adaptation.

4. a. In what way has the Australian bushfire regime *changed*?
   b. What impact has this had on bushfire hazards?
   c. Do you think some bushfires should be left to burn naturally? What information would influence your decision?

5. Refer to Figure 4.18.
   a. Is there any association between the size of the area burnt each year and the bushfire risk in the following years?
   b. Based on this model, how are fuel reduction burns expected to influence projected bushfire risk?
   c. What information would be required in order to develop an informed opinion on whether or not planned burning should continue?
   d. Visit the Planned Burns Victoria website to explore the interactive map for where planned burns are currently occurring.

6. Watch *Extreme Fire Danger: Megafires* on the ABC Education website and list the reasons why experts are advising that megafire frequency and fire danger may increase in the future.

7. Choose one of the fires from Figure 4.17 and prepare a case study that includes the location, cause, areas affected, weather conditions, vulnerability of the location, damage and cost.

8. What do you think is the primary factor leading to the projected increase in the economic cost of bushfires shown in Figure 4.19?

9. Using information from the Country Fire Authority (CFA) website, make a fire preparation plan for a block of land, house or town located in a fire-prone *region*. With the use of a diagram or map, illustrate and explain the measures that you would take to prepare this site prior to the bushfire season.

CASE STUDY Black Summer bushfires, 2019–20

> 'Recent projections of fire weather suggest that fire seasons will start earlier, end slightly later, and generally be more intense. This effect increases over time, but should be directly observable by 2020.'
>
> Ross Garnaut, *The Garnaut Climate Change Review*, 2008

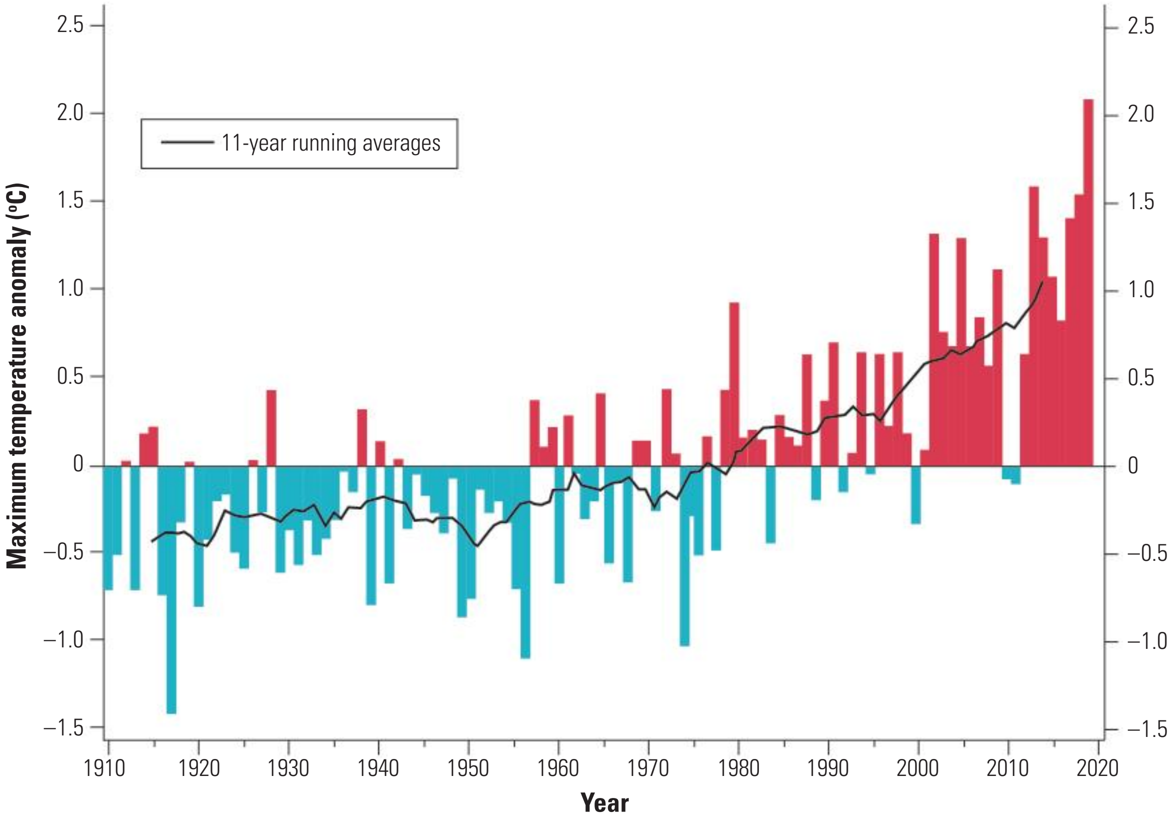
The 2019–20 bushfire season, known as Black Summer, was one of the most disastrous in Australia's history. It has been described as unprecedented based on the spatial *scale* of its destruction and the intensity of many of the fires that it contained. The Gospers Mountain fire was the largest ever recorded in Australia, alone burning over 500,000 hectares. In total, hundreds of fires burnt an estimated 19 million hectares across all states and territories over 240 consecutive days, devastating both human and natural *environments*.

What factors led to the Black Summer disaster?

A major factor contributing to Black Summer was drought conditions leading up to the bushfire season. Much of southern and eastern Australia had experienced several years of drought and the landscape was extraordinarily dry. 2019 was the driest and hottest year in Australia since records began with an annual mean temperature of 1.52°C above the long-term average (see Figure 4.21). These conditions meant that the fuel load was particularly flammable and that fires were more likely to ignite and spread. Furthermore, features of the landscape that would ordinarily create natural fire breaks such as moist gullies and swamps were also dry, allowing the *scale* of the fires to increase. According to the Commonwealth Scientific and Industrial Research Organisation (CSIRO), long-term weather modelling shows that climate *change* has exacerbated weather systems to create these dangerous and unprecedented conditions. It is leading to a lengthening of Australia's fire season and an increase in the number of fire-danger days – but it is still difficult to determine if any particular fire is due directly to climate *change* given our very long history of bushfires.

▼ **Figure 4.20** Over 80 per cent of the Greater Blue Mountains *region* burned causing severe *environmental* impacts

▼ **Figure 4.21** Variation in Australia's maximum temperature anomaly from 1910 to 2019 (Based on a 30-year climatology (1961–1990))



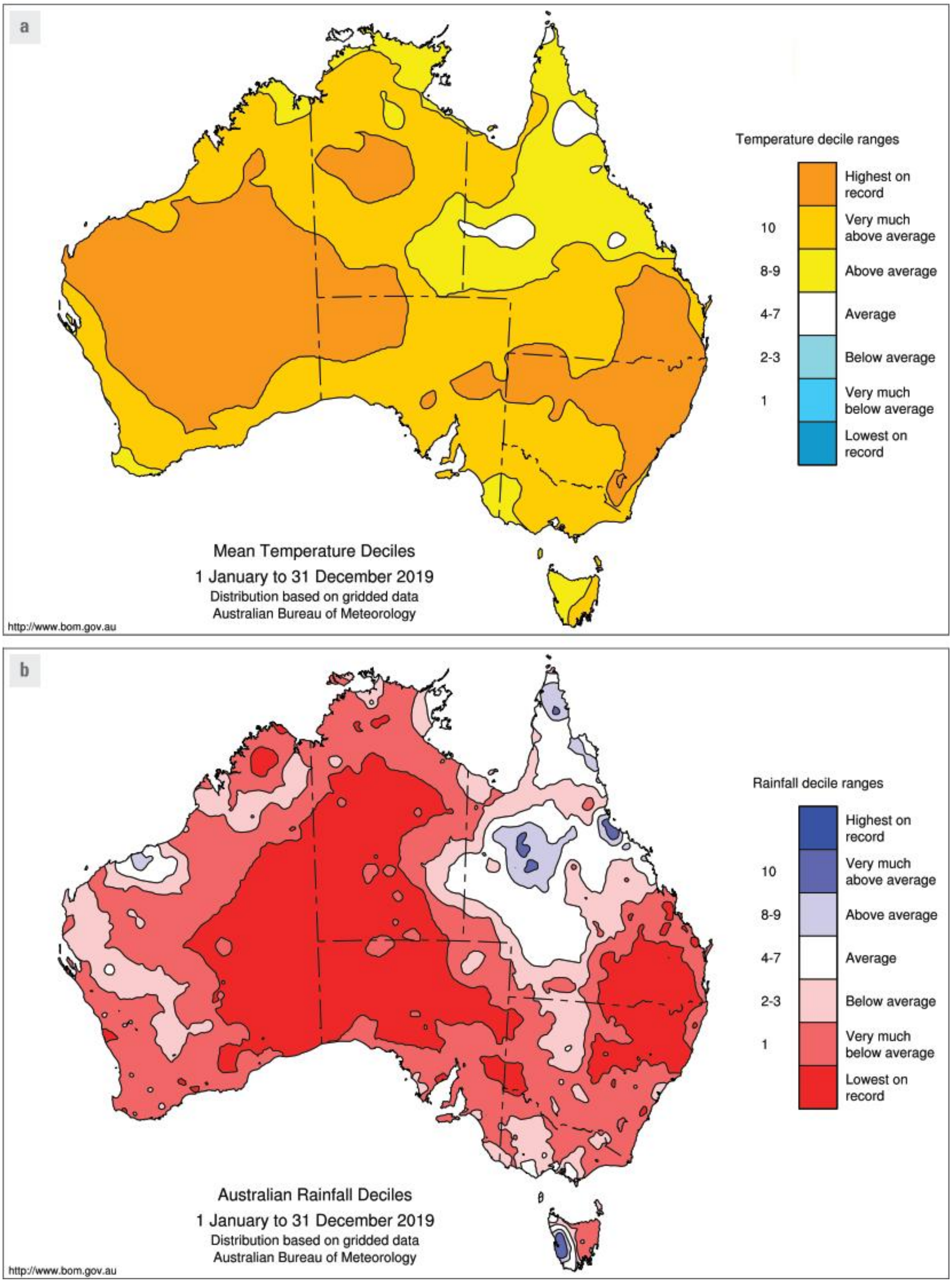
Of all the Black Summer bushfires that burned between June 2019 and May 2020, only a very small percentage were started deliberately by people. Just 1 per cent of the area burnt in NSW has been attributed to arson and the percentage is even lower in other states. Most of the fires, especially the larger ones, were instead started by dry lightning storms. This includes lightning from pyrocumulonimbus clouds, formed in smoke plumes from intense bushfires.

What were the impacts of Black Summer?

The impacts of Black Summer on Australia's human *environments* are severe (Figure 4.23). Thirty-three people died from the fires including nine firefighters, three of whom were from the United States. For several weeks there was poor air quality in many Australian cities, and this resulted in the deaths of 445 people. Although over 3000 houses were lost across Australia, the larger fires had minimal impact on major population centres. There was, however, significant damage to the agricultural industry with 80,000 livestock killed.

Combined, direct damages have been estimated at $5 billion. However, the actual cost is likely to be much higher due to indirect consequences. These include mental health issues, increased unemployment and significant long-term damage to a range of industries. For example, Australia's domestic and international

▼ **Figure 4.22** The *distribution* of Australia's **(a)** mean temperature and **(b)** rainfall in 2019 compared to long-term historical averages



▼ **Figure 4.23** The impacts of the Black Summer fires by *region*

State	Burned area (ha)	Number of fires	Houses lost	Lives lost
NT	6,800,000	NA	5	0
NSW	5,595,739	10,520	2475	25
QLD	2,500,000	NA	48	0
WA	2,200,000	NA	1	0
VIC	1,505,004	3500	396	5
SA	286,845	1324	186	3
ACT	60,000	NA	0	0
TAS	36,000	NA	2	0
Total	**18,983,588**	**15,344**	**3113**	**33**

NA – data is not available

tourism industry suffered significant losses during the season and the widespread global media coverage of the disaster is likely to affect Australia's image as a tourist destination into the future. Some economists have estimated that the overall cost of Black Summer could reach as high as $100 billion which would make it Australia's costliest disaster to date.

Although the human impacts were significant, the *environmental* impacts made Black Summer an unprecedented disaster. Twenty-one per cent of Australia's temperate broadleaf forest biome burnt. This is more than ten times greater than what has burnt in previous fire seasons. More than 80 per cent of the Greater Blue Mountains *region* burned which is important due to its World Heritage listing for its biodiversity and significant number of threatened endemic species.

While the total number of animals killed by the fires is difficult to measure, it has been conservatively estimated at one billion mammals, birds and reptiles. It is estimated that hundreds of billions of insects were also lost. Ecologists fear that some endangered species, such as Kangaroo Island's micro-trapdoor spider, will become extinct as a result. While typical fires burn part of a habitat, leaving suitable habitat for surviving animals to recolonise, the enormous *scale* and intensity of Black Summer meant that entire habitats were destroyed. Many animals that survived the initial fires later died from starvation and a lack of shelter and protection from feral predators such as foxes and cats that moved to affected areas to hunt.

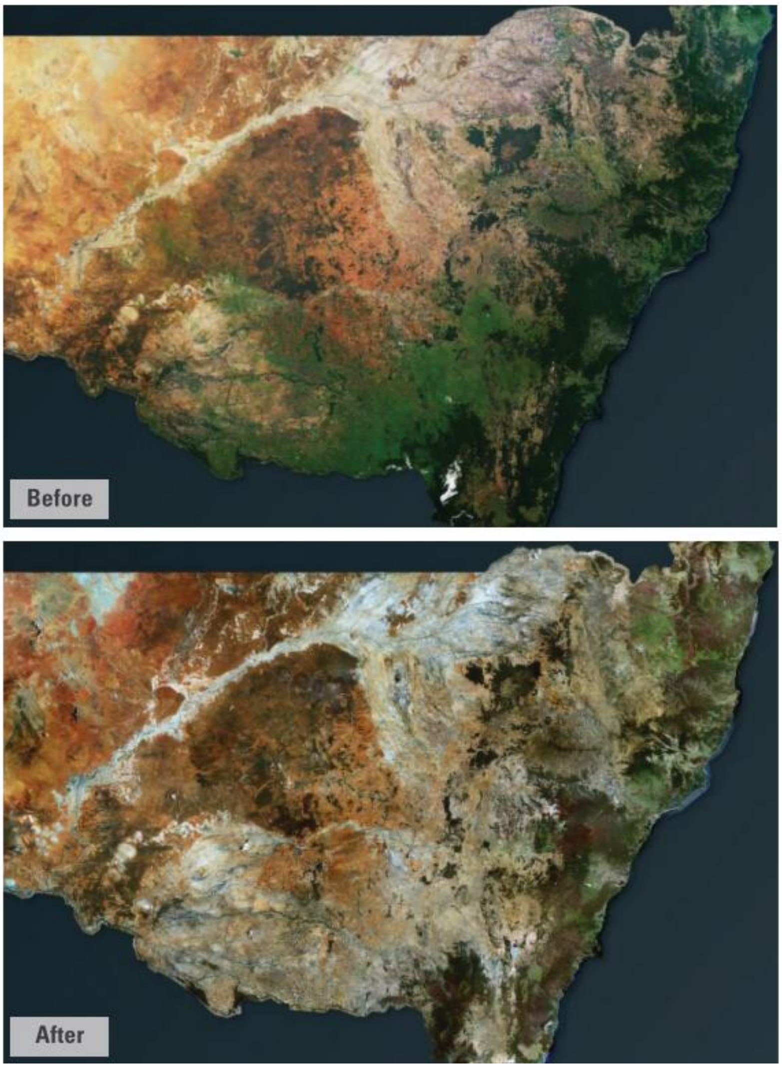
An additional consequence of the Black Summer fires was carbon emissions. The Australian Climate Council have estimated that between 650 million and 1.2 billion tonnes of carbon dioxide were released into the atmosphere during the fires. This is greater than Australia's total annual emissions in 2018 which were 535 million tonnes. While much of the carbon will be reabsorbed by forest regrowth, this will take decades, and meanwhile there will be less carbon uptake because of forest destruction. Furthermore, forests that regenerate will be filled with trees of a similar age and species, making them particularly vulnerable to future fires, and providing less structural and species diversity to attract a wider range of other plants and animals.

How did Australia respond to Black Summer?

Before the fires – prescribed burns

Following the 2009 Black Saturday Royal Commission, the amount of prescribed burning to reduce fuel loads has increased in south-eastern Australia. The number of burns that can be completed is limited by the availability of personnel and the decreasing windows of safe weather. The warm and dry conditions prior to the 2019/20 fire season reduced the number

▼ **Figure 4.24** Satellite imagery reveals *changes* to the landscape in New South Wales after fires burnt 5.5 million hectares



of safe burns that could take place. Despite this, 139,000 hectares of hazard reduction burns occurred in New South Wales in the two years prior to Black Summer which exceeded targets. Unfortunately, bushfire authorities have stated that high-intensity fires due to extreme weather conditions, as experienced in many *places* during Black Summer, have the ability to burn through *regions* that have recently undergone hazard reduction burns, reducing their effectiveness.

During the fires – Australia's largest deployment of firefighting personnel

Battling the Black Summer fires required the coordination of Australia's largest ever interstate and international deployment of fire personnel. Seven thousand firefighters assisted from across Australia and from countries such as the United States, Canada, Indonesia, New Zealand and Singapore with many countries also lending aircraft. Volunteer firefighters called out for more than ten days were provided with financial compensation. Six thousand five hundred Australian Defence Force personnel were also used and on 4 January 2020 the Australian Government announced a compulsory call out of 3000 Australian Defence Force Reserve Brigade members for the first time in Australia's history. Jobs included clearing roads, repairing fencing, creating fire breaks, purifying water, supplying meals and temporary accommodation for emergency service workers and evacuees and delivering water, fuel and fodder.

After the fires – Royal Commission into National Natural Disaster Arrangements

On 20 February 2020, Prime Minister Scott Morrison announced the establishment of the Royal Commission into National Natural Disaster Arrangements. This was met with some resistance based on the cost, the lengthy *process* and claims that the 2009 Victorian Bushfires Royal Commission following Black Saturday achieved little in preventing or managing future disasters. The commission has focused on several ways that Australia can improve its preparation and response to natural disasters including:

- the national coordination and collaboration between various levels of government across Australia
- opportunities for improvements in national mitigation and preparedness such as emergency planning, evacuations, land management and Indigenous fire management
- the provision of data through national information systems including an improvement in air quality information and associated public health advice
- improvements in national response arrangements such as the Bushfire Warnings System
- opportunities to improve national recovery arrangements with a focus on mental health, funding allocation and *environmental* conservation.

The findings of the Royal Commission acknowledge that that bushfire behaviour in Australia has become more extreme and less predictable and that catastrophic fire conditions may become more common. Current predictive models are becoming less accurate and management techniques are becoming less effective. This raises the question of how to best manage bushfire hazards in the future in the context of a *changing* climate to ensure the protection of local communities, infrastructure and forest ecosystems.

Salahuddin Ahmad

Spatial Analyst, Department of Environment, Land, Water and Planning (DELWP)


CAREER PROFILE

As a spatial analyst my work involves monitoring, evaluating and researching for the Fire and Emergency division of DELWP, Victorian State Government. I believe Geography is the 'mother of all sciences', essential in fostering analytical skills and gaining knowledge in understanding all aspects of the Earth and its processes. I develop tools and models to assist emergency managers in making decisions, and create cartographic, thematic and analytical maps using spatial datasets. My work with fire management involves analysing fire danger (based on topography, land cover and climate), tracking existing fires and comparing this with the location of communities. This data is used to create maps of bushfire-prone areas. The division I work in at the DELWP was responsible for developing the FIREMOD tool which predicts state-wide fire behaviour for seven-day periods, a highly recognised tool in Victoria's emergency management. Colleagues in my team include cartographers, statisticians, and interpreters of aerial photographs and satellite images.

ACTIVITIES

1. Refer back to Figure 4.17. Compare the Black Summer fires to other major bushfires in Australia's history. Based on this information, discuss whether or not you think the description of Black Summer bushfires as unprecedented is justified.
2. a. Referring to Figure 4.22, describe the degree of *spatial association* between above average temperature and below average rainfall across Australia in 2019.
   b. Discuss the significance of this *spatial association* in contributing to the Black Summer bushfires.
3. Research pyrocumulonimbus clouds and explain how this *process* contributes to bushfire disasters using a series of steps or diagrams.
4. Using a table, summarise the impacts of Black Summer and categorise them as social, economic or *environmental*.
5. Explain how climate *change* can be considered both a cause and an impact of the Black Summer bushfires.
6. Review the findings of the Royal Commission into National Natural Disaster Arrangements on the royal commission's website. Discuss whether or not you think the findings will be useful and whether this justifies its cost.
7. In addition to prescribed burns, there have been suggestions that traditional burns undertaken by Indigenous Australians could help to manage vulnerable landscapes more *sustainably*. Research the *process* and benefits associated with traditional burning regimes and discuss whether you think this response is a viable option for the future management of Australia's forests.
8. Choose one of the major bushfires that occurred during Black Summer and prepare a case study covering its origin, spatial extent, time sequence, impacts, the success of its management and its likelihood of recovery. Suggestions include Kangaroo Island, Gospers Mountain, Busbys Flat and Green Valley.

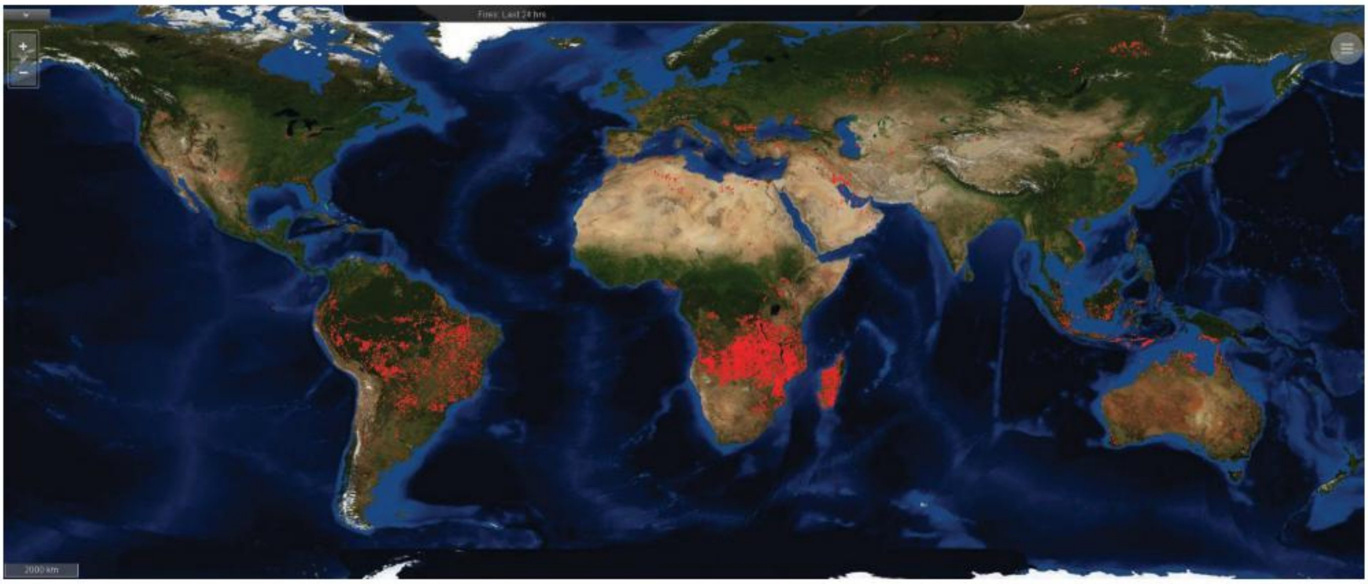
The use of geospatial technology in bushfire management

Using geospatial technology, authorities have been able to improve their management of bushfires with improved predictions, monitoring and warning systems. This has led to increased efficiency and effectiveness in managing bushfire hazards, ultimately improving the safety of firefighters and the public.

Moderate Resolution Imaging Spectroradiometer (MODIS)

Moderate Resolution Imaging Spectroradiometer (MODIS) is a sensor aboard NASA's (National Aeronautics and Space Administration) Terra and Aqua satellites which orbit the Earth each day. They collect a range of data including a measure of areas burnt by fires based on the presence or lack of vegetation and the location of current fires based on the infrared energy that they release. The locations of fires are represented as hotspots in a Geographic Information System (GIS) called Fire Information for Resource Management System (FIRMS) as shown in Figure 4.25. Data is analysed over several time periods from daily to monthly to monitor the spread of fires in different world *regions* and to predict future fires.

MODIS uses thermal imaging to map the location of fires and it therefore does not distinguish between different types of fires. This means controlled burns, oil and gas rigs and even volcanoes are mapped alongside wildfires. The resolution of the data collected is in one-kilometre pixels. This means that fires that cover over 1000 m^2 are usually detected but smaller fires, especially those that are less than 100 m^2,



▲ **Figure 4.25** Global fire data collected by satellites is *distributed* using a GIS called FIRMS (fires shown in red) are not detected unless conditions are perfect. Cloud cover, heavy smoke and thick tree canopies can obstruct the satellite's view, leading to errors in fire detection. For these reasons, data is also collected on the ground by fire managers which is added to the FIRMS GIS using handheld devices.

Digital Earth Australia Hotspots

Digital Earth Australia (DEA) Hotspots (formerly Sentinel Hotspots) is an Australian bushfire monitoring system developed through a partnership between the CSIRO, Department of Defence and Geoscience Australia. It is an internet-based satellite tracking system launched in 2003 and allows fire authorities, emergency personnel and the public to see where fires have started and where they are headed across Australia. Data comes from various sources, including thermal imagery from NASA's MODIS sensors, and is updated several times each day using a GIS. The system has an accuracy of 1.5 kilometres which makes it useful for monitoring fires in remote locations and calculating their *distance* from infrastructure and towns. Digital Earth Australia Hotspots was used during the Black Summer fires to regularly monitor the location and *movement* of fires to help assess potential impacts and distribute resources.

Using geospatial technology to manage Californian wildfires

California's hot, dry and windy climate makes it vulnerable to severe wildfires. The 2020 wildfire season was one of the most disastrous in California's history. By October 2020, over 1.6 million hectares had been burnt, which is over 4 per cent of the state's area, 9000 structures had been destroyed and 31 people had lost their lives.

To battle these blazes, firefighters use traditional techniques, such as constructing fire breaks, together with geospatial technology. GIS is used to provide real-time information about the spread of fires to help target their management. ESRI's portal, Wildfire Public Information Map (Figure 4.26), provides a live feed of fire behaviour in the United States. Data is gathered using remote sensing, such as satellite data from MODIS. This information is accessible online to fire managers and the general public.

GIS is useful in managing hazards such as wildfires because information from a variety of sources can be combined on the same mapping portal using data layers. For example, the location and spread of fires can be overlayed with topography, current and forecasted weather, population *distribution*, the location of vulnerable infrastructure, natural features and the location of emergency shelters. GIS is also used to forecast the spread of smoke and monitor air quality and it can be used to manage updates and issue warnings to local residents. Together this information can be used to analyse vulnerability to assist with preparation, decision making and resource allocation during a disaster. It can also assist with damage assessments following a disaster by efficiently recording the location and status of damaged structures in order assist with repairs and rebuilding.

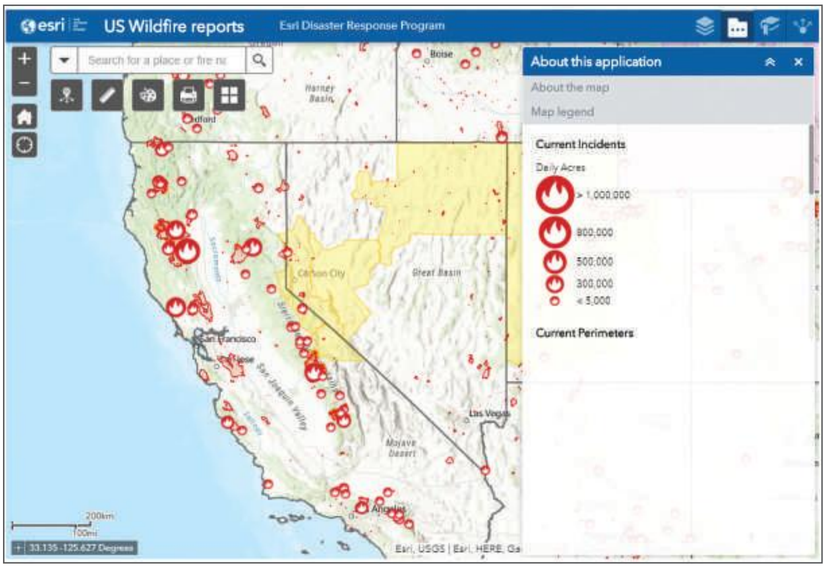


Figure 4.26
ESRI's Wildfire Public Information Map is a GIS portal providing live feed of fire behaviour in the United States

▶ ACTIVITIES

1. Search for FIRMS Active Fire Data to locate a database of recent fire data by *region*. Download a KML file for a *region* of your choice. Open the file in Google Earth and describe the landscape and land use surrounding one of the bushfires. How will the geographic characteristics of the land contribute to its spread and the potential for disaster?
2. Visit the Digital Earth Australia Hotspots website and explore the interactive map and its layers. Describe the current *distribution* of fires in Australia. Use the topography, land cover and Nexis Population layer to identify which *regions* are vulnerable.
3. Download the Victorian government's VicEmergency app onto a tablet or mobile device and use it to obtain information about recent fire warnings and incidents. Describe how this geospatial technology would be useful to residents in fire-prone rural areas.
4. Search for ESRI Wildland Fire Management to learn more about the use of GIS in identifying wildfire risk and managing responses in the United States. Explain how this technology is used to respond to bushfire hazards.
5. Using information from any of the examples provided above, evaluate the effectiveness of geospatial technology in identifying, assessing and managing bushfire hazards.

Storms and floods

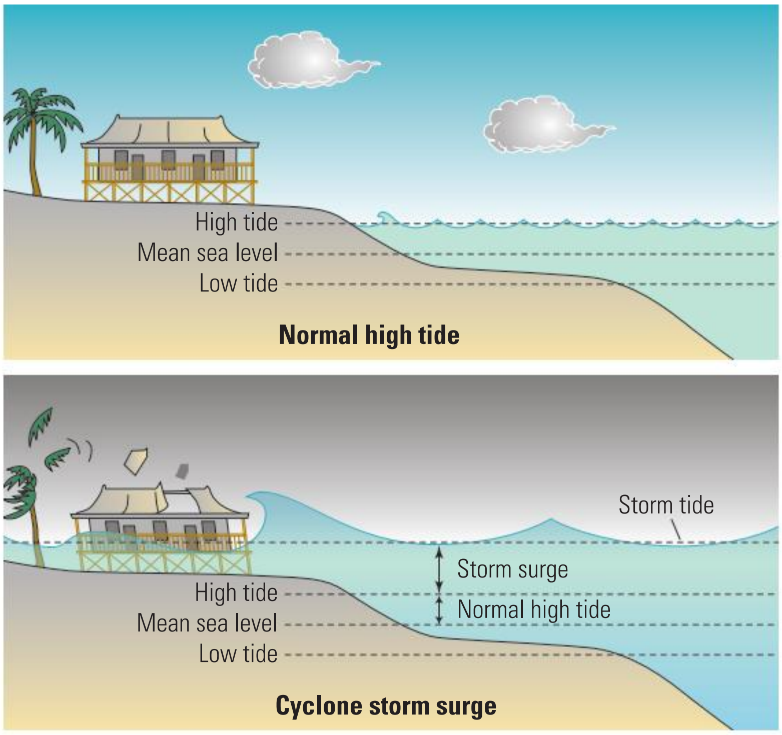
When rain falls, water infiltrates the soil, evaporates, or runs off the land into creeks, rivers and urban drainage networks. During severe or prolonged storms, monsoon seasons and tropical cyclones, rainfall quantities can be very large over a short time period. As the soil becomes saturated and unable to absorb more water, run-off increases. As run-off becomes too great for creeks, rivers and urban systems to contain, excess water overflows onto the surrounding land. When this water temporarily flows over land that is normally dry it is called a flood.

In coastal areas, storm surges or tsunamis may cause severe flooding as sea water inundates low-lying areas (see Figure 4.27). Less common causes of flood include dam failure, landslides blocking river flow, or geological events such as earthquakes or volcanic activity.

What are the impacts of floods on people?

Floods are hazardous to many human *environments* and have the potential to be disastrous (see Figure 4.28). They affect both rural and urban areas at a range of *scales*. Short-term impacts include inundation of homes, damage to infrastructure such as bridges, roads and railway lines, destruction of agriculture, and injury and death. In the long term there are social impacts, larger-*scale* costs to the economy during rebuilding and potential damage to ecosystems if the natural landscape is modified.

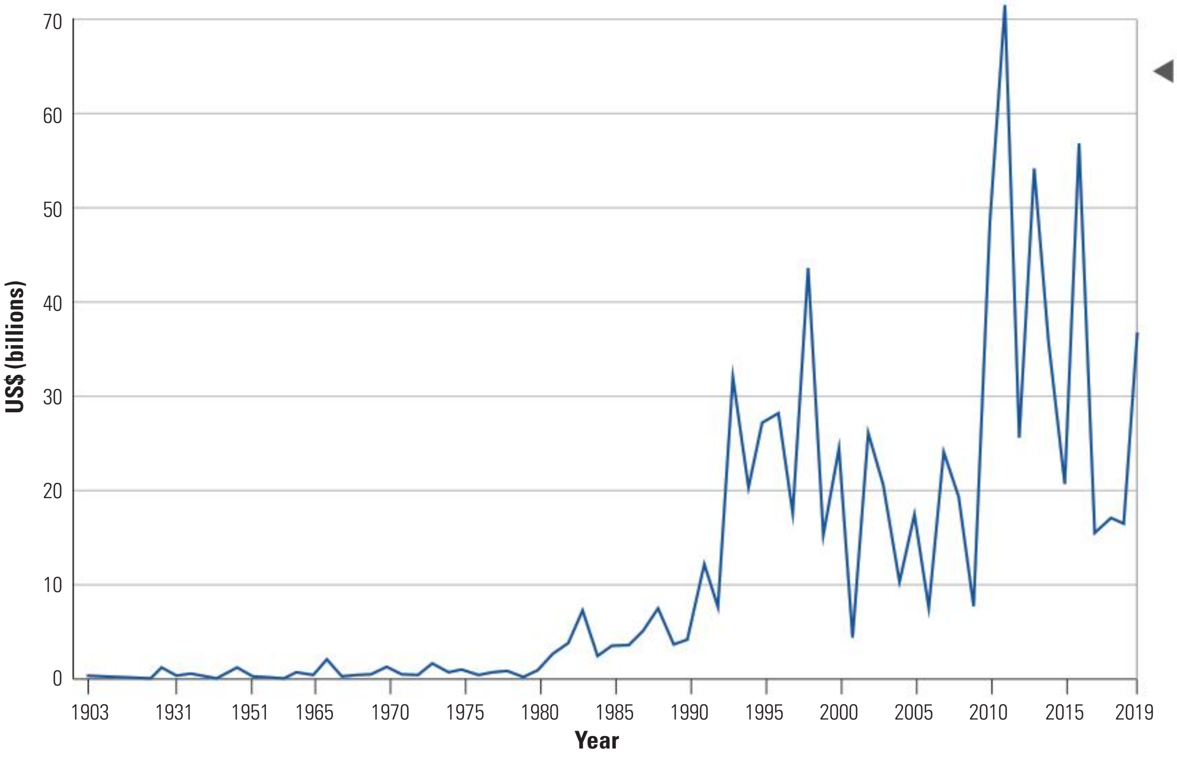
As population density increases globally and more communities develop on floodplains and in low-lying coastal areas, floods are becoming more hazardous to communities. Climate scientists predict sea levels will rise, tropical cyclones will become more widespread and the frequency and magnitude of severe storms will increase. Low-lying island nations such as Kiribati and Fiji (Figure 4.29) are likely to become increasingly flood-prone.



▲ **Figure 4.27** Storm surge inundating low-lying coastal areas

What are the impacts of flood on *environments*?

Although flooding is hazardous to the human *environment*, it is an essential part of many ecosystems. It enables nutrients to cycle in river systems, groundwater aquifers to recharge and dormant seeds to germinate across vast inland areas. Flora and fauna in Australia are adapted to wet and dry cycles, and floods are required to replenish areas that have suffered drought. For example, Kati Thanda–Lake Eyre in the central Australian desert is a dry salty lake bed covering around one-sixth of Australia.



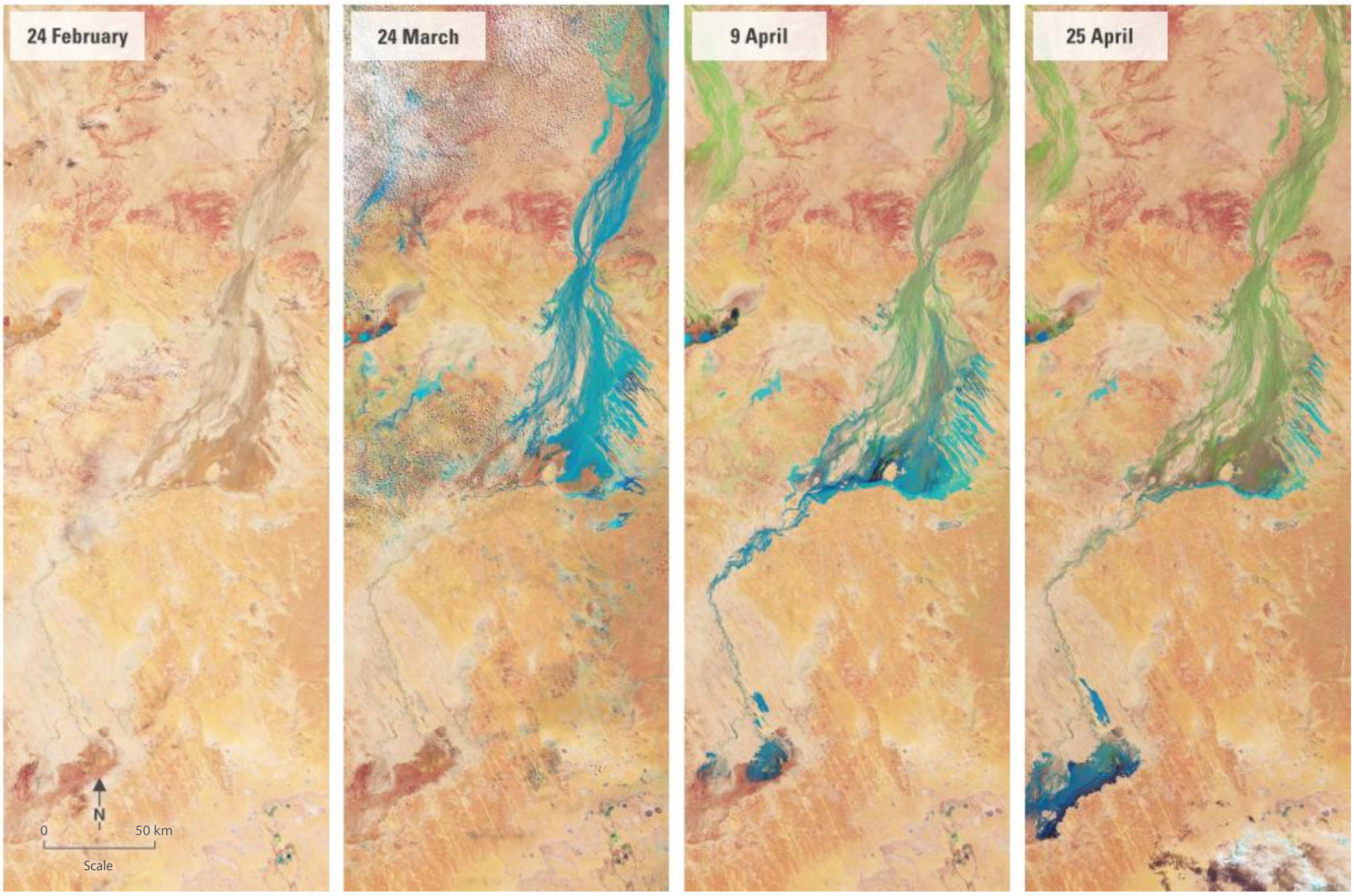
◀ **Figure 4.28** The global economic impact of flood from 1903 to 2019

▲ **Figure 4.29** Low-lying coastal communities, such as those in Fiji, are particularly vulnerable to flooding

On average it experiences a 1.5 metre flood every three years, a four metre flood every ten years and fills three times each century. The basin partially flooded in 2018 (Figure 4.30) and filled in 2019 when floodwaters travelled more than 1000 kilometres to turn a barren landscape into a thriving oasis. Dormant seeds germinated and migratory birds flocked to the area for breeding.

As riverine floodwaters recede, fine silt is deposited onto floodplains. Farmers take advantage of this fertile soil for growing crops and pasture even though these areas are vulnerable to future flooding. However, floods in agricultural and urban areas can degrade water quality. Receding floodwaters carry fertilisers, pesticides and other pollutants into river systems causing long-term and potentially irreversible damage to ecosystems.

▼ **Figure 4.30** Satellite imagery from NASA's Landsat satellite show floodwaters in Kati Thanda–Lake Eyre temporarily allowing vegetation to thrive during the 2018 floods



How are floods classified based on their *scale*, frequency and magnitude?

There are a variety of different flood types that can be characterised by their cause and effects (Figure 4.31).

What factors affect the risk level and impacts of flooding on people, *places* and *environments*?

Although heavy rain is the main driving force behind flood events, there are many factors that interact to cause flooding or compound risks (see Figure 4.32). These *environmental* factors, along with human activities such as land use, will determine the magnitude and frequency of floods that occur in different *regions* and the level of destruction that follows.

The predictability, seasonality, duration and speed of floods greatly determine the potential for disaster as they can limit the ability for communities to respond to flood events. Economic factors are also extremely important as they influence the ability to construct flood prevention infrastructure, implement warning systems, educate the public, and recover and rebuild following a disaster. This leads to an uneven and disproportionate *distribution* of flood risk as poorer communities especially in developing countries are more likely to be affected (see Figure 4.33). There is often a strong *spatial association* between cheap housing and flood-prone land so that flooding affects those who can't afford to live elsewhere.

Bangladesh is one of the most flood-prone *regions* in the world (see Chapter 2, page 26). It is located on the vast alluvial delta of the Ganges, Meghna and Brahmaputra rivers with most of its coastal land mass less than ten metres above sea level. In addition to these physical characteristics, monsoon rains, an extremely high population density and relative poverty make Bangladesh particularly vulnerable. In contrast, flood-prone areas in Australia have a relatively low population density, which leads to fewer deaths but a large economic cost due to extensive damage to or destruction of infrastructure.

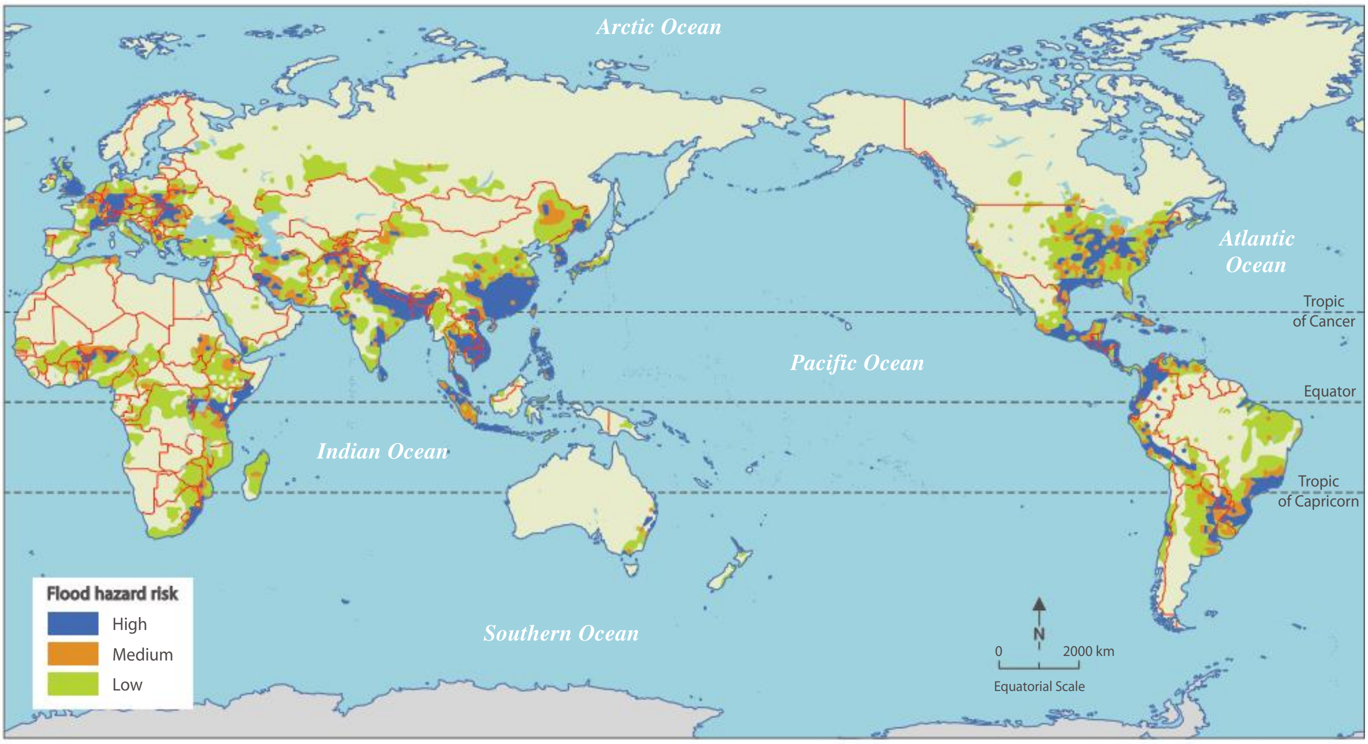
▼ **Figure 4.31** Four different flood classifications

Flood type	Characteristics
Slow-onset floods	▶ last several weeks or months, covering vast areas on the floodplains of flat, inland, slow-moving river systems ▶ are natural, seasonal events caused by heavy rainfall during wet or monsoon seasons ▶ cause damage to towns, roads, rail, bridges, livestock and crops ▶ allow residents ample warning to prepare
Rapid-onset floods	▶ last for one or two days, occurring quickly ▶ caused by sudden, large amounts of rainfall which rivers cannot contain ▶ incur risk to property and life, with faster-flowing water leaving less time to prepare ▶ are common in mountainous areas where rivers have a steeper gradient and rainfall is high and locations prone to severe storms
Coastal floods	▶ caused by strong winds from tropical cyclones, and storms and tsunamis ▶ sea water inundates low-lying coastal land in storm surges ▶ effects are compounded during unusually high tides
Flash floods	▶ usually affect isolated locations on a small *scale* such as some suburbs of Melbourne ▶ caused by short, intense rainfall events often due to severe thunderstorms ▶ can affect all areas, especially urban areas where drainage systems cannot cope with increased quantity of run-off ▶ pose greatest threat to life and property due to lack of sufficient warning and difficulty in predicting

▼ **Figure 4.32** Factors that influence the impact of flooding

Factor	Impact of flooding
Location	Communities living on floodplains, low-lying coastal areas or cyclone-prone areas are exposed to greater risk.
Urbanisation	Impervious materials in urban areas such as roads and roofs increase run-off during rainfall events.
Vegetation	Vegetation slows and reduces the amount of floodwater by allowing more water to penetrate the soil.
Soil type	Coarse sand or gravel will absorb more water than fine clay particles, especially when saturated.
Topography	Mountains channel rainfall into river channels while flat floodplains enable floodwaters to travel and spread over large *distances*.
Income	Communities with high incomes and a strong economy are able to construct flood prevention infrastructure and recover with greater ease.
Recent weather	Soil that is already saturated from previous rainfall will create more run-off.

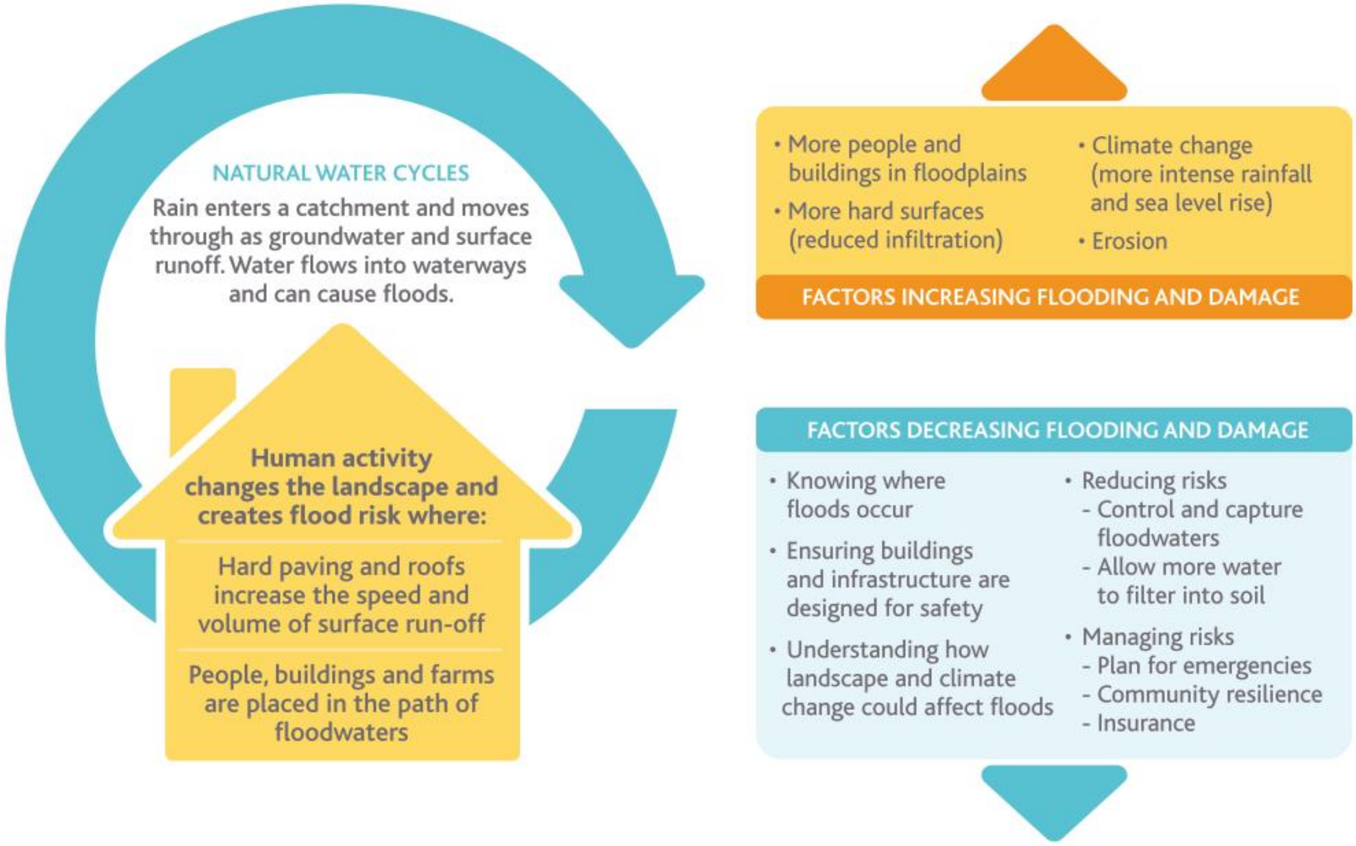
Figure 4.33 The global *distribution* of flood hazards



ACTIVITIES

1. Using Figure 4.27 and your own research, describe what a storm surge is, their cause and the types of *places* in which they are most likely to occur.
2. a. Using Figure 4.28, describe how the global economic impact of flooding has *changed* from 1903 to 2019. In your answer, refer to specific years and their corresponding costs.
   b. Suggest a factor that might account for the yearly variation over this period.
3. a. Using Figure 4.33, describe the global *distribution* of floods.
   b. Suggest reasons why some *regions* are more vulnerable than others based on their location.
   c. How do factors other than location affect the level of flood risk in different *places*?
4. Undertake research to create a table listing a national or international example of each of the types of floods classified in Figure 4.31. Research the geographic characteristics of the *places* where these floods occurred to try to determine why it was vulnerable.
5. Explain why slow-onset floods might be less dangerous than flash floods but might cause more damage.
6. Discuss how two or more of the factors listed in Figure 4.32 are *interconnected* and how this can increase a *place's* vulnerability to flooding.
7. In pairs or small groups, prepare two brief case studies of contrasting flood events in Australia and the Pacific Island *region*. Include in each case study the location and its geographic characteristics, causes, weather conditions, vulnerability of the location, damage, cost and recovery.
8. Research and explain why an erratic flood regime and subsequent 'boom and bust' conditions are essential in supporting the abundance of unique plants and animals in the Kati Thanda–Lake Eyre basin.
9. Type 'Brisbane flood awareness map' into a search engine and launch the interactive map.
   a. Name and describe three locations that have a high, medium and low likelihood of flooding.
   b. Suggest possible reasons why some *regions* of Brisbane are more at risk than others.
   c. Discuss how geospatial technologies such as interactive GIS maps can be used to assess and manage flood hazards.
10. Investigate the July 2021 European flash floods that inundated parts of Germany and Belgium. Why is there so much concern in the press coverage that this may be another example of 'extreme weather'?

Figure 4.34 Flood management can reduce the likelihood and extent of flood damage. Image provided courtesy of Melbourne Water



Human responses to flood hazards and disasters

Flood management (see Figure 4.34) focussing on reducing the threat or potential impact of floods in flood-prone areas involves constructing flood prevention infrastructure such as levees, dams and drainage systems. These function in the following ways:

- dams built in the upper reaches of a river system control the flow of water downstream
- levees act as a barrier around low-lying towns or along rivers so that they do not break their banks
- drainage basins (see Figure 4.45) and flood breaks collect run-off so that it does not enter river systems
- river channels are modified by widening, deepening, straightening or concreting, allowing flow velocity to increase, thus reducing flooding upstream (see Figure 4.37)
- flood warnings issued by authorities and community awareness enable residents and governments to take protective action.

The likelihood of a flood occurring can be measured by the Annual Exceedance Probability (AEP) and the Average Recurrence Interval (ARI) (Figure 4.35). The AEP refers to the likelihood of a flood of a particular magnitude occurring (e.g. 20 per cent chance) and the ARI refers to the average number of years between floods of this magnitude (e.g. 1-in-5-year flood). Flood mitigation techniques often reduce the risk from a 1-in-20-year flood but might not be designed to cope with extreme events such as a 1-in-100-year flood.

Figure 4.35 A comparison between Annual Recurrence Interval and Annual Exceedance Probability

Average Recurrence Interval (ARI)	Annual Exceedance Probability (AEP)
1 in 1000	0.1%
1 in 500	0.2%
1 in 100	1%
1 in 50	2%
1 in 20	5%
1 in 10	10%
1 in 5	20%
1 in 2	50%
1 in 1	100%

Tokyo, Japan, is located on an alluvial floodplain with 1.5 million residents living below sea level and eight major rivers flowing through the Tokyo Basin. To reduce the potential impacts of floods during 'guerrilla storms', the Tokyo Government has built the Metropolitan Outer Area Underground Discharge Channel. This is the largest stormwater drain in the world and is built 22 metres beneath the city. It cost $3 billion and took thirteen years to complete.

In countries or *regions* that do not have the resources to construct this infrastructure, more rudimentary measures are taken such as building houses on stilts (Figure 4.36). Sandbagging is often used to construct temporary levees when unpredicted floodwaters approach.

While flood prevention techniques may reduce the risk of flooding, they may indirectly cause additional hazards. Modifying the flow of rivers by straightening or concreting channels, as shown in Figure 4.37, may reduce flooding or erosion in a localised area; but it may also increase the chance of flooding downstream as the velocity of flow increases. It also alters the natural flow of the river which may impact the natural balance of the ecosystem. Levees protect areas to a certain point but, once levees break, they can create a sudden rush of water which will intensify damage. In rare occurrences, dams may fail causing disastrous floods in valleys downstream. In 2018, heavy monsoon rains led to the collapse of a series of dams in Laos. Floodwaters flowing down the Mekong River system caused flooding in Cambodian villages 250 kilometres downstream.

▶ **Figure 4.36**
High-density housing on stilts in Sumatra, Indonesia

▶ **Figure 4.37**
Channel modification along Dandenong Creek, Dandenong

▶ ACTIVITIES

1. If it is known that building on floodplains or in low-lying coastal areas increases the risk of flooding, then why do you think people choose to build in these areas? What are the benefits and do they outweigh the risks?
2. Using a topographic map, assess the flood risk of a local area by considering the topography, climate, vegetation cover, soil type and development.
3. Watch the Catalyst documentary *Tokyo Flood Prevention* on the ABC website, exploring the construction of Tokyo's underground discharge channel.
    a. Why is Tokyo particularly vulnerable to floods?
    b. What are 'guerrilla storms'?
    c. What magnitude of floods was the infrastructure designed to cope with and has it made the city completely flood-proof?
    d. What is the main factor preventing other cities from constructing similar infrastructure?
4. Compare the flood mitigation techniques in Sumatra (see Figure 4.36) and Tokyo. Discuss the extent to which economic, technological and geographic factors influence the ability of a community to deal with flood hazards. Rank these factors in order of importance.
5. Research an example of dam failure, such as the 2018 disaster in Laos, including its causes and impacts. Using this information, discuss how issues and challenges can arise from this response to flood hazards.
6. Choose a flood management technique to research in more detail such as the use of levees or drainage basins. Find out how it works and provide an example of a location where this technique has been successful in reducing the flood risk.
7. Discuss how the effects of climate *change* or increased population density in flood-prone *regions* affect the *sustainability* of vulnerable communities.
8. Suggest reasons why a government might introduce measures to protect a community from a 1-in-20-year flood but not a 1-in-100-year flood.

CASE STUDY

China's summer of floods, 2020

> 'I have always been concerned about the people in flood-stricken areas. The Chinese nation has fought natural disasters for thousands of years… We will continue to fight.'
>
> President Xi Jinping

In the summer of 2020, southern China experienced one of the worst flood seasons in its history. More than 70 million people across China were directly or indirectly affected when torrential rains led to flooding and landslides in cities and villages across 28 provinces. *Regions* affected include Guangxi, Guizhou, Sichuan, Hubei and Chongqing within the middle and lower reaches of the Yangtze River's 180-million-hectare basin. A total of 443 rivers flooded with 33 reaching their highest level ever recorded. An estimated four million people were evacuated, 1.5 million were left homeless and 271 died or were reported as missing. Five million hectares of farmland were also damaged. The Ministry of Emergency Management estimated the direct economic costs to be in excess of US$29 billion.

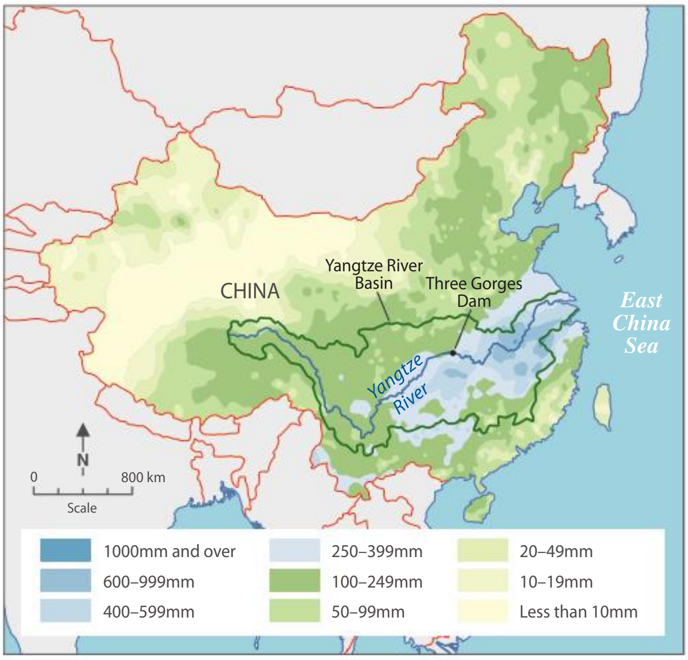
What factors led to this disaster?

Natural *processes*

The main factor leading to this flood event was torrential rainfall. Twenty-seven of China's 31 provinces experienced incessant downpours in June and July. High rainfall occurs during this period each year, referred to as the East Asian rainy season (see Figure 4.38). As warm moist air from the Pacific Ocean meets the cooler continental air mass, a weather front is formed. As the moist air cools, water within it condenses, forming rain. As the front moves back and forth due to the varying strength of cool and warm air masses, it causes large-*scale* precipitation until the warm air mass from the subtropical ridge is strong enough to push it further north. This *process* affects China, Taiwan, Korea and Japan each year except in years of drought. Figure 4.39 shows rainfall data for the 2020 season which was of above average intensity due to a stronger subtropical high pressure system over the western North Pacific Ocean.

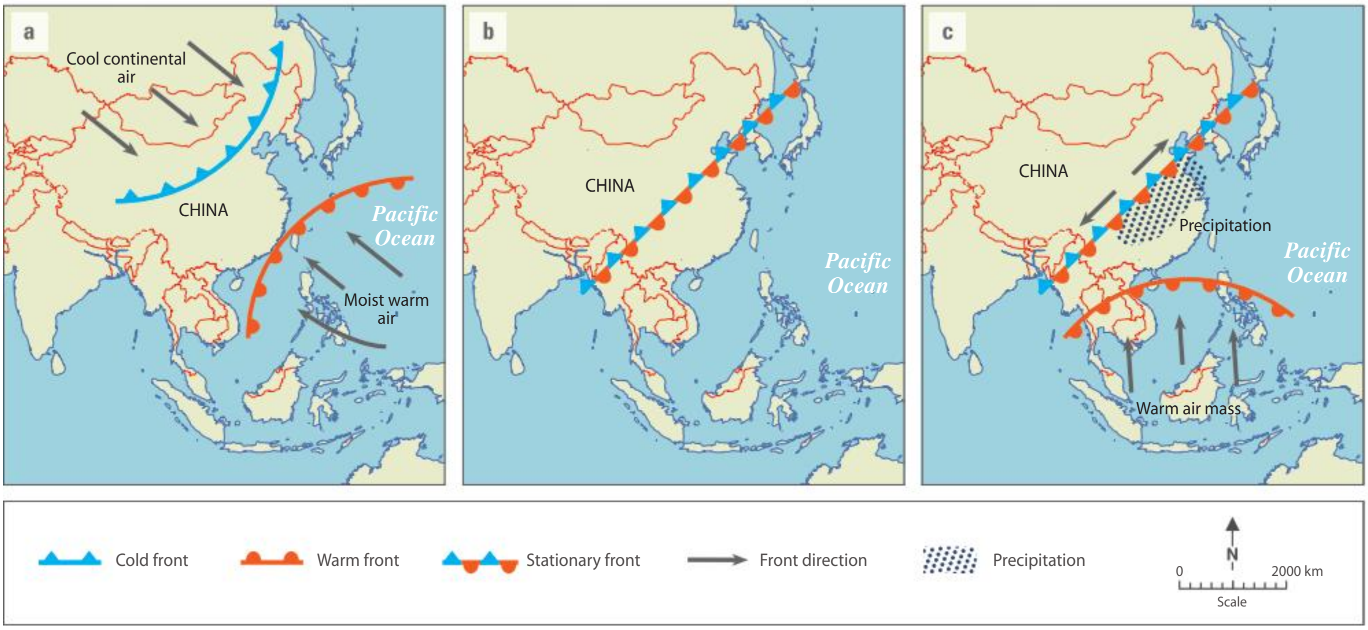
Climate *change*

While the East Asian rainy season is a natural *process*, many experts claim that climate *change* is increasing the frequency and magnitude of extreme weather events. Data already shows that the average intensity, quantity and duration of large-*scale* rainfall events is increasing, with the 2020 period among the highest since the 1960s. According to China's National



▲ **Figure 4.39** The *distribution* of rainfall within the Yangtze River Basin between 22 June and 21 July 2020

▼ **Figure 4.38** The East Asian rainy season occurs when **(a)** warm most air from the Pacific Ocean meets cooler continental air, **(b)** causing a weather front to form which **(c)** moves back and forth causing heavy rainfall until a warm air mass pushes it further north



Climate Centre, the number of days of heavy rain has increased by 3.9 per cent each decade over the last 60 years. Studies have shown that a projected rise of 2°C is likely to further increase the frequency of disastrous floods in the Yangtze River Basin. According to the Intergovernmental Panel on Climate Change (IPCC), a rise of 4°C by the end of the century could lead to an increase in China's average annual flood impact from affecting nine million people at a cost of US$30 billion to affecting 40 million people at an annual cost of US$130 billion.

Land management

Rapid population growth and economic expansion in China since the middle of the 20th Century has been an underlying factor leading to China's increased flood vulnerability. Land within the Yangtze River Basin that once contained lakes and wetlands has been drained and cleared so that it can accommodate urban and agricultural development. These *changes* have reduced the natural *environment's* ability to store floodwater.

China's sponge cities – an urban response to flood hazards

In 2015, China launched its Sponge City program which mandates that urban areas must contain artificial wetlands, raingardens and other porous landscape features to absorb and slowly release excess rainwater (Figure 4.40). It is hoped that this will reverse some of the impacts of *unsustainable* urban development by artificially replicating the *processes* of natural wetlands that were once found within these *environments*. Although these features may have helped reduce the impacts of the 2020 floods in urban centres, the concept has not yet been applied to rural areas which left smaller cities and villages at risk.

How effective was the Three Gorges Dam in managing the 2020 floods?

In response to devastating flooding in 1998, China undertook a massive infrastructure project to construct dams and other flood control measures along its major waterways. As a result, China now has over 98,000 dams, more than any other country. The Three Gorges Dam is the largest of many in the Yangtze River Basin. The dam reduces the speed and extent of rises in water levels in the middle and lower reaches of the Yangtze River.

The inflow of water to the Three Gorges Dam in 2020 was the largest since its construction. As shown in Figure 4.41, the dam was designed to store a water level of 175 metres. The dam almost reached this capacity on 22 August when the water level reached 167.85 metres. In order to prevent the breach of the dam, which would have had devastating consequences, several of the dam's sluice gates were opened and floodwaters were released downstream throughout this period (Figure 4.43). The. The success of this strategy is contested. While many claim that the released water increased downstream flooding in cities such a Yichang, others claim that the dam managed to slow the release of floodwaters and prevented an even greater disaster. Conflict has arisen between rural and urban residents as dams are often used to prevent disasters in major cities by diverting floodwaters to farmland, forcing the evacuation of rural residents and the destruction of agricultural infrastructure. Had the Three Gorges Dam failed, a sudden and uncontrolled release of water would have caused catastrophic flooding downstream, threatening the lives of 480 million residents and having a devastating impact on China's economy.

▲ **Figure 4.40** Sponge cities, such as the district of Yuelai in north-eastern Chongqing, are designed to soak up heavy rainfall and release it slowly into local waterways

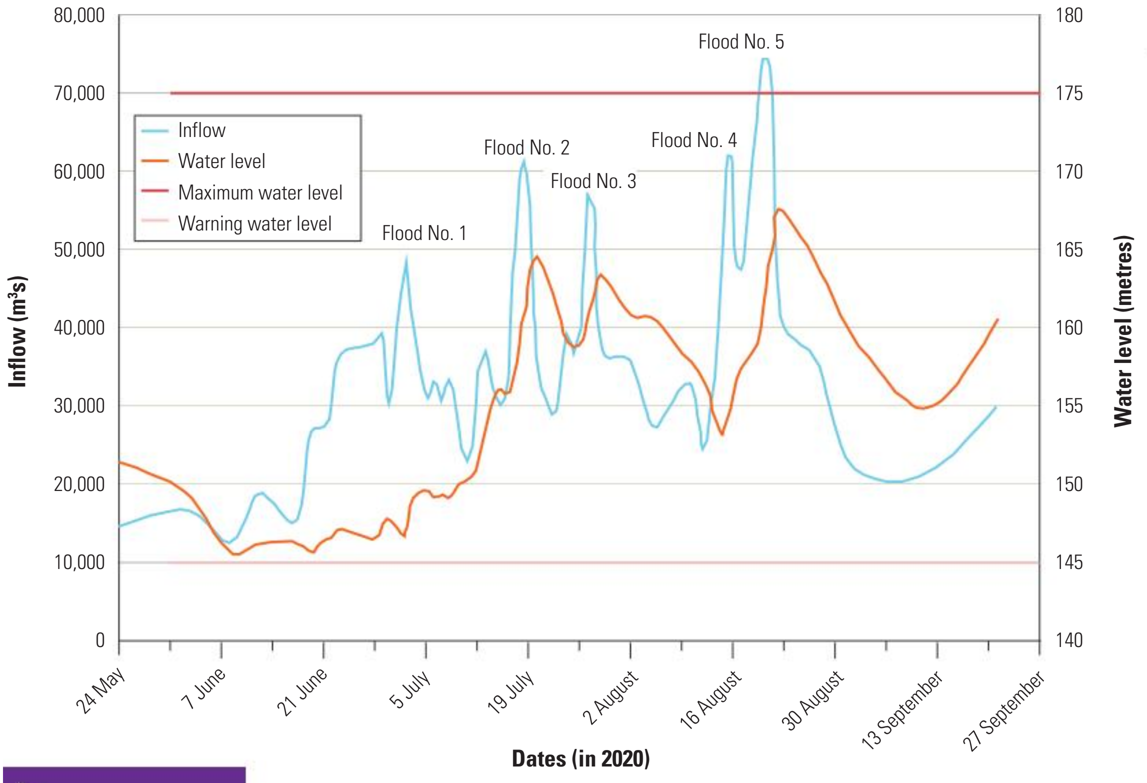


Figure 4.41 The Three Gorges Dam reached dangerous levels several times during the 2020 floods, forcing managers to release water downstream to prevent a breach

ACTIVITIES

1. Classify the type of flooding that occurred in China in 2020 using the information in Figure 4.31. Justify your choice.
2. a. In a table, summarise the factors that contributed to the 2020 flood and classify them as economic, social, political, *environmental* or cultural.
   b. Choose three of these factors and rank them in order of importance. Discuss the reasons for your ranking.
3. a. Using Figure 4.39, describe the *distribution* of rainfall within the Yangtze River basin between 22 June and 21 July 2020.
   b. Using this information, explain why the Three Gorges Dam played an important role in managing the flood disaster.
4. a. Referring to Figure 4.41, suggest the dates in which significant amounts of water was released from the Three Gorges Dam.
   b. State why these releases were needed.
   c. Discuss whether or not this was an appropriate response to the flood event.
5. Floods in China are not a unique occurrence with three of the largest flood disasters in the world occurring in China since 1950. Research one of China's previous floods and compare it with the 2020 floods in terms of its causes, the magnitude of the flood and *scale* of the impacts, the preparedness of affected communities and the responses to the disaster.
6. 'The combination of climate *change* and *unsustainable* urban development is likely to lead to an increase in hydro-meteorological hazards in the future.' Discuss the extent to which you agree with this statement making reference to specific examples.

Figure 4.42 Floodwaters released from dams were diverted to farmland, protecting local cities but destroying rural villages and agricultural infrastructure

Figure 4.43 Authorities were forced to release floodwater from the Three Gorges Dam at a rate of up to 48,000 cubic metres per second in order to prevent a dam breach and a further catastrophe

Local flood risk in Melbourne

> 'Ideally society would like to be free of the risk of flooding, but this is neither practically nor economically feasible.'
>
> (SCARM [Standing Committee on Agriculture and Resource Management] 2000, *Floodplain Management in Australia: Best Practice Principles and Guidelines)*

Melbourne's geographic location and design means that over 100,000 of its properties are at risk of being flooded. It is estimated that the cost of flooding in the Port Phillip and Westernport *regions* is approximately $245 million each year. This flooding occurs as rivers, creeks or the city's drainage systems overflow during heavy rain events and storms (Figure 4.44). Due to the inability of water to infiltrate the hard surfaces of urban areas, excess rainfall flows along natural pathways (which in some cases were once watercourses) that have been drastically modified to suit the urban *environment*. An example of this is Elizabeth Street in Melbourne's CBD, which is built on the site of a small creek which now flows as a drain beneath the original creek bed, emptying into the Yarra River. Upgrades to Elizabeth Street were finalised in 2020 and it is hoped that the new design will help to mitigate future flood risk.

Local responses to flood risks in Victoria

The design and infrastructure of suburbs largely determines their vulnerability to floods. Prior to the 1970s, developers of Melbourne's suburbs did not always take flood risk into account. When developing new suburbs, flood risk is analysed and used to plan appropriate infrastructure. This includes underground drainage systems designed to cope with 1-in-5-year storms. During more severe storms (1-in-100-year storms), drainage becomes full and run-off is designed to flow along roads and channels which direct water to rivers and creeks. Large, open spaces known as retarding basins also act to slow down flow and increase infiltration. Retarding basins such as Jubilee Park in Ringwood (see Figure 4.45) are multi-function resources used as sports fields and parkland when not inundated.

Water authorities such as Melbourne Water have worked to reduce flood risks by upgrading infrastructure. Flood modelling is used to assess flood risk and identify the extent of flooding in different storm scenarios. Vulnerable areas are identified and prioritised for infrastructure upgrades, taking social, safety and economic factors into account. Not all drainage infrastructure can be replaced due to excessive cost, social impacts, disruption to other infrastructure and time. Sea level rise, river gauges and rainfall are monitored so that management can adapt to local conditions.

In order to reduce the impacts of floods, the Department of Environment, Land, Water and Planning (DELWP) have developed FloodZoom. This web-based tool provides flood information before, during and after floods. A range of spatial data including flood forecasts, flood mapping, real-time river height gauges and property data, has been consolidated into a GIS tool to provide agencies with improved knowledge of likely flood impacts. This helps Emergency Services and local Catchment Management Authorities to make informed decisions about flood risk information and prepare communities by predicting and monitoring floods and producing accurate warnings. FloodZoom won the internationally acclaimed 2015 Spatial Achievement in GIS Award for its innovative platform.

Figure 4.44 Massive storms on 6 March 2010 caused widespread flooding in central Melbourne

Figure 4.45 Retarding basin at Jubilee Park, Ringwood

ACTIVITIES

1. Watch some YouTube videos of flash flooding in Elizabeth Street, Melbourne, in 2010. Why does regular flooding occur in this area?
2. Research historical flood data and the flood emergency management plan for your local area using information provided by your local council. Is your local area at risk of flooding and what is being done by your council to ensure your safety?
3. a. What is a retarding basin?
   b. How would a retarding basin such as the one in Figure 4.45 reduce the flood risk in an urban area?
   c. Find a retarding basin near your school and describe the land uses and additional benefits it provides for the local community.
4. Visit the Melbourne Water website and select the 'Building and works' tab followed by 'Browse our works and projects'. Click on the 'Topic' filter and select 'Flood mitigation' and 'Flooding' from the drop-down menu to reveal a list of current flood management projects. Choose one of these projects and write a paragraph summarising how it intends to manage the local flood risk.
5. Using the Victorian State Emergency Services (SES) website, list ways that communities can prepare themselves to reduce their vulnerability to flooding.
6. Watch the FloodZoom video on the DELWP YouTube channel. Explain how DELWP are using geospatial technology to manage flood risk in Victoria.

Balancing natural *processes* and human activities in responding to hydro-meteorological hazards

Due to the complexities of hydro-meteorological *processes* and their *interconnection* with the human *environment*, managing hazards in order to prevent disaster while maintaining natural *processes* is a very difficult task. Choose one of the topics in Figure 4.46 and research it further in order to write an opinion piece or conduct a class debate. Some research questions have been provided to get you started. Ensure your initial research is broad to develop your opinion before focusing on your contention. Remember to collect data and statistics as evidence to strengthen your arguments.

▼ **Figure 4.46** Topics to debate

TOPIC 1:

Current management of Victoria's forests is creating an unnatural *environment* in which the threat of bushfires is enhanced.

- In what ways are bushfires an essential forest *process*, fundamental in maintaining biodiversity?
- How does the current fire regime compare to pre-human and Indigenous records?
- What impact does the reduction of fires due to human intervention have on the build-up of fuel load and the potential for larger-intensity fires? Does this affect the vulnerability of local communities and native species?
- Does the protection of forests from logging and development influence the fire regime?
- What is the plight of Leadbeater's possum and other endangered species? Is logging or bushfire the greatest threat to these species?
- Should forests be protected from bushfires to preserve this resource for future generations?
- Should people live near fire-prone forests and do they have a choice?
- Are current forest management practices *sustainable*?

TOPIC 2:

Climate *change* is the biggest factor influencing future vulnerability to hydro-meteorological hazards.

- What are the projected impacts of climate *change* on specific hydro-meteorological hazards around the world?
- How will the frequency and magnitude of disasters be altered?
- How will the ability to manage disasters *change*?
- What might the economic impacts be?
- In what ways might technological factors reduce the impacts of climate *change*?
- To what extent will other factors such as population density and poverty also influence vulnerability?
- What barriers exist for countries wanting to take action on climate *change*?
- How might climate *change* threaten the *sustainability* of some communities due to hydro-meteorological disasters?

TOPIC 3:

The construction of dams should continue as they are essential in reducing inland flood hazards.

- What are dams and why are they constructed?
- Is dam construction increasing or slowing around the world?
- How do dams vary in *scale* across river systems and between countries?
- What are the positive *environmental*, economic and social impacts of dams?
- What are the negative *environmental*, economic and social impacts of dams?
- Where and when have dams helped to prevent flooding disasters?
- Are there any examples of when dams have contributed to flooding disasters through the release of floodwater either intentionally or by dam failure?
- Does the design of a dam influence its ability to be effective?
- Are there alternative management solutions to reducing the vulnerability of flood risks? Are they applicable to all *environments*?
- Do the benefits of dams outweigh the disadvantages and risks?

TOPIC 4:

Australians cannot afford to live in areas that are vulnerable to hydro-meteorological events.

- Which hydro-meteorological hazards have the biggest potential to harm communities and where are these most prevalent?
- Why do people choose to live in areas that are at risk of disasters?
- What are the costs of hydro-meteorological disasters to the economy and Australian lifestyle?
- Are all hydro-meteorological hazards manageable? What is the cost of managing them and will we ever be completely safe?
- Are there examples of disaster management in other countries that Australia could adopt?
- What effect are people having on the natural *environment* by living and managing areas prone to these disasters?
- Are attempts to prevent hydro-meteorological hazards making some communities more vulnerable?
- How is climate *change* likely to alter the situation?
- Is our current population *distribution sustainable?*

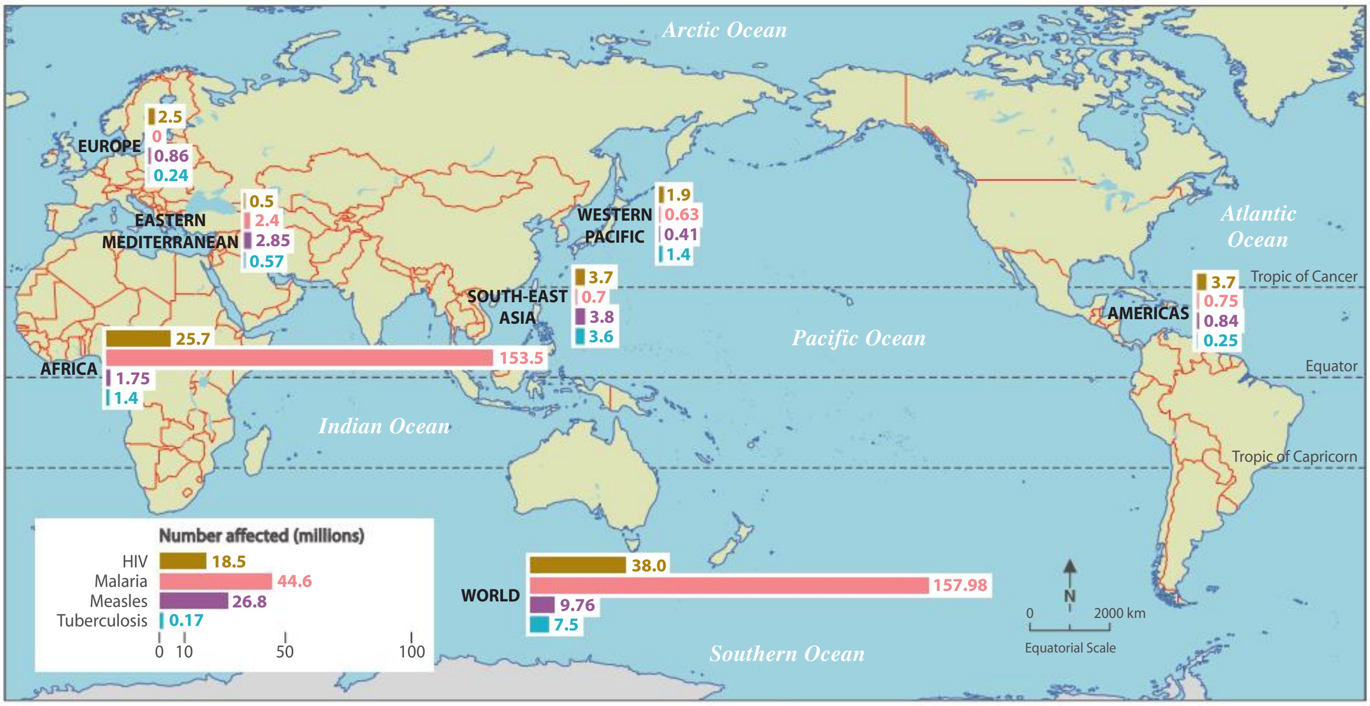
5

Biological hazards and disasters

Biological hazards involving the spread of micro-organisms, plants, insects and animal pests have been a source of concern for people throughout history. For example, skeletal remains uncovered in archaeological sites show that the ancient Egyptian pharaohs were victims of diseases such as smallpox, and incidences of locust plagues were documented during biblical times. Various epidemics have spread across wide *regions* and populations, with far-reaching impacts (see Figure 5.1). While people have been able to successfully manage some biological hazards, others remain a continual problem (as shown in Figure 5.2). In addition, new hazards continually emerge, like that shown in Figure 5.3 and the global pandemic of COVID-19 (page 92), particularly with growing *interconnections* across our world.

▼ **Figure 5.1** Some major diseases over time

Name	When	Where	Cause	Impact
Influenza	From c2,500BC; many epidemics since 1100s, 14 pandemics documented since 1500s	From Asia and Europe through Americas and Africa, to global *distribution*	Virus spread from direct contact or airborne droplets after coughing or sneezing	Fever, respiratory distress and may cause pneumonia; total mortality in history at least many tens of millions; 1918 pandemic alone infected 500 million people and killed at least 50 million
Cholera	First modern description 1563; 1817 spread led to major epidemic 1830s	From Ganges River delta, India, to Europe, Canada, US	Bacteria spread by water contaminated by human waste	Diarrhoea, dehydration, death. Continued issue in poorer countries today where a lack of hygiene exists with over 129,000 cases reported in 2013
Smallpox	Major spread 1500s–1600s with *movement* of Europeans; 1700s major outbreak	From Europe, Africa, Asia and into the Americas. Now eradicated	Virus spread by contact with an infected person	Killed over half the native populations in the Americas (no immunity). Some tribes entirely wiped out. Vaccinations 1800s onwards. It was eradicated 1979 at a cost of $313 million
Plague (Black Death)	Major outbreak 1340s; again in early 1700s. Last major outbreak 1855	Central Asia into southern and western Europe and northern Africa	Bacteria spread by fleas carried by rats	Approximately 1/3 Europe's population killed (between 75 and 200 million). Sporadic outbreaks occur in Africa, Asia and South America in rural areas
HIV/AIDS	Identified 1981. Rapid spread during 1980s and 1990s	Originated in Africa and spread to the Americas and beyond. Now concentrated in Sub-Saharan Africa but *distributed* worldwide	Virus spread by sharing bodily fluids	According to World Health Organization (WHO), 39 million have died so far and 35 million people are living with the virus. Many 'AIDS orphans', especially in Sub-Saharan Africa
Tuberculosis (consumption)	Identified BC. Major spread 1700s; resurgence 1990s	From Europe to North America and then worldwide	Bacteria spread in the air via coughing, sneezing	Vaccine developed 1926 but drug resistance; 1/3 of world's population carries TB bacteria and 10% of these likely to get the disease
Ebola	First in1976; 26 outbreaks since; major ones 2014–2016 and 2018–2020	Focused in 10 countries in West Africa e.g. Guinea, Sierra Leone, Liberia	Virus spread via direct contact through the skin or bodily fluids	Over 50% fatality rate; in 2014–2016, over 28,000 cases and 11,000 deaths. Health workers disproportionally affected. Decline in agricultural production



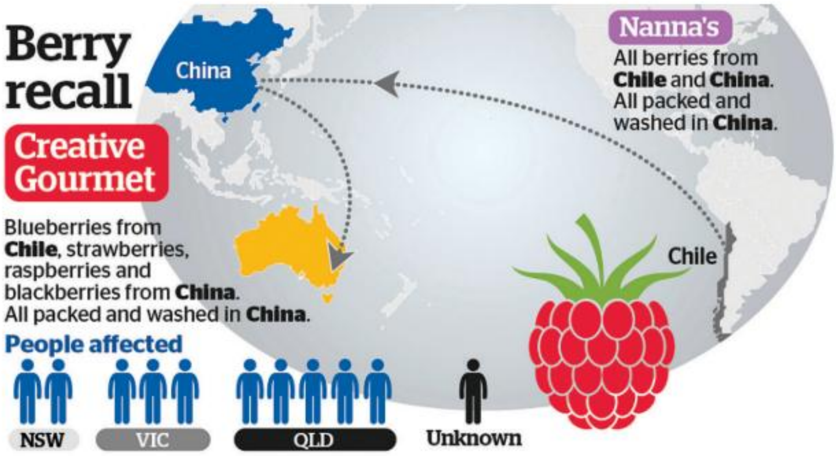
▲ **Figure 5.2** Global *distribution* of some current major diseases

Early epidemiological studies

Epidemiology is the study of patterns and causes of health-related states or events in specified populations. One of the first people to examine the *distribution* of disease was Dr John Snow. In the 1850s, at least ten years before germ theory was developed, the neighbourhood of Soho, London, faced a cholera epidemic. At that time, people were unaware of the cause of this disease generally believing it was due to miasma or 'bad air'. Snow mapped the *distribution* of cholera cases and found a *spatial association* between those affected and use of a particular water pump that had become contaminated with human waste (see Figure 5.4). The city authorities consequently removed the pump handle, which resulted in a rapid decline in cholera cases (although it would be some time before they admitted that this was the cause of the disease).

ACTIVITIES

1. Refer to Figure 5.1. List the similarities and differences in location, *process* and impact of any two of the diseases listed.
2. Refer to Figure 5.2.
   a. Which disease causes the greatest number of infections?
   b. Which *regions* appear to be most and least susceptible to these diseases?
   c. Suggest possible factors to account for your answer above.
3. Refer to Figure 5.4. Describe the *distribution* of cholera cases relative to the central water pump.



▲ **Figure 5.3** Contaminated berries posed a hazard by spreading hepatitis in February 2014

▲ **Figure 5.4** Dr John Snow's map showing the *spatial association* between water pumps and the *distribution* of cholera in the Soho *region* London, redrawn using modern geospatial technologies

Malaria

Overview

Malaria is a disease caused by the *Plasmodium* parasite which is transmitted to humans via the bite of the female *Anopheles* mosquito. This parasite enters the bloodstream and causes symptoms such as fever, chills, headache, nausea, muscle pain, fatigue, vomiting and possibly death. These symptoms usually occur ten days to four weeks after infection but can recur up to a year afterwards, and some forms of malaria can cause relapses over many years.

▲ **Figure 5.5** The *Anopheles* mosquito – the major vector for spreading malaria

Over 40 per cent of the world's population is at risk of malaria. According to the World Health Organization (WHO) 3.4 billion people are at risk of the disease. Although the disease is preventable and treatable, in 2018 there were an estimated 228 million cases resulting in 405,000 deaths, 93 per cent of which occurred in the *region* of Africa.

As Figure 5.6 shows, the incidence of malaria is *spatially associated* with tropical *regions* as the hot wet climate provides an ideal breeding ground for the *Anopheles* mosquito. At a smaller *scale*, low-lying wetlands often harbour mosquitoes. In addition to natural *environmental* factors, human activities such as provision of irrigation channels have enhanced these breeding *environments* by providing pools of still water for mosquito larvae to grow. Where these *environments* are *interconnected* with the economic factor of poverty, a high incidence of malaria occurs such as in Sub-Saharan Africa where ten countries account for over half of the global cases.

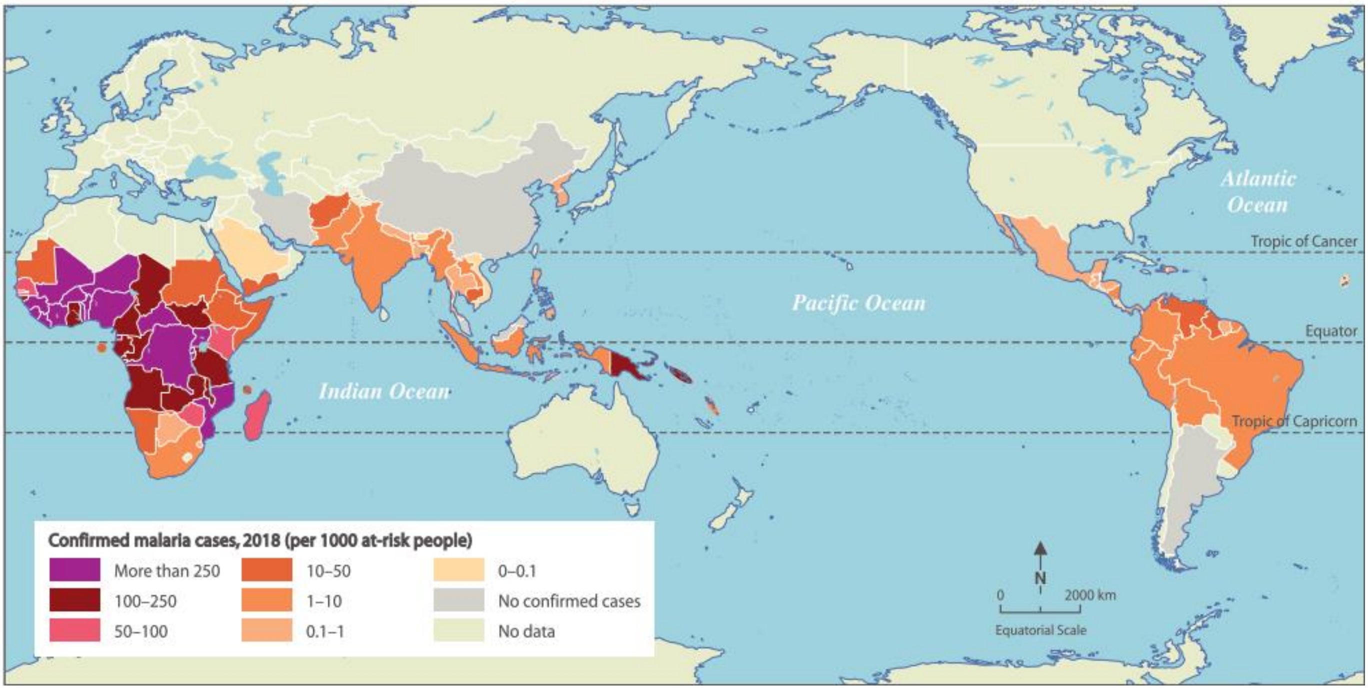
Social factors also contribute to malaria *distribution*. Population *movement* is *interconnected* to the spread of malaria. For example, the migration of people from endemic to non-endemic *regions* occurred in Brazil (with the expansion of settlements in Amazonia since the 1960s) and *movement* of refugees from Burma into Thailand (1984 onwards) have helped spread malaria as recently arrived migrants act as new hosts for the malaria parasite.

The *distribution* of malaria is likely to *change* in future due to the *process* of climate *change* and future *environmental* factors. The predicted increase in temperatures and rainfall in some *regions* (as indicated in Chapter 2) will enable the *Anopheles* mosquito to inhabit a wider range of *regions* (see Figure 5.8). The potential impact of this hazard may therefore increase.

What are the impacts of malaria?

- Economically, malaria contributes to the issue of poverty. 58 per cent of malaria cases occur in the poorest 20 per cent of the world's population. This creates a challenge as these people are more likely to have low education levels and lack knowledge of preventative measures, and are also less able to afford treatment if it is available.
- Malaria poses a high economic burden on countries. The African Leaders Malaria Alliance estimates that in the African continent as much as 40 per cent of health care spending in endemic countries goes on malaria, straining the already limited health care systems. Any overall progress in improving living conditions may therefore be challenged.
- Malaria causes the issue of reduced economic productivity. Sick people and those looking after ill family members cannot work so food production and income suffers, thus continuing the poverty cycle – an enormous challenge to overcome. At a national *scale* the economy is also affected by reduced export earnings.
- In terms of social impacts, sick children cannot attend school: up to 50 per cent of preventable absenteeism is estimated to be caused by malaria. This issue limits students' life opportunities, again perpetuating the poverty cycle.

▼ **Figure 5.6** The global *distribution* of malaria



- Another significant social impact is on infants and pregnant women. They are the most vulnerable demographic as they have lower immunity. In 2018, WHO estimated 67 per cent of malarial deaths occurred in children aged under five years of age. Recurrent bouts of malaria also stunt a child's growth and development, and pregnant women who have malaria are more susceptible to delivery complications.

What can be done to manage the malaria hazard?

Although there are many ways of tackling malaria, vector control is the main public health intervention used to prevent the spread of malaria, as it is usually most cost effective. Use of long-lasting insecticide-treated nets (LLITNs) is one of the main ways to protect vulnerable people by covering them at night when most bites occur (see Figure 5.9). Another method, indoor residual spraying (IRS), involves spraying the walls of houses. This kills mosquitoes for four months or more depending on the insecticide used (see Figure 5.10).

Figure 5.7 Rural villages such as this one in Uganda are highly susceptible to malaria due to their tropical climate and limited access to preventive methods

Figure 5.8 Possible *change* in *distribution* of malaria due to climate *change*

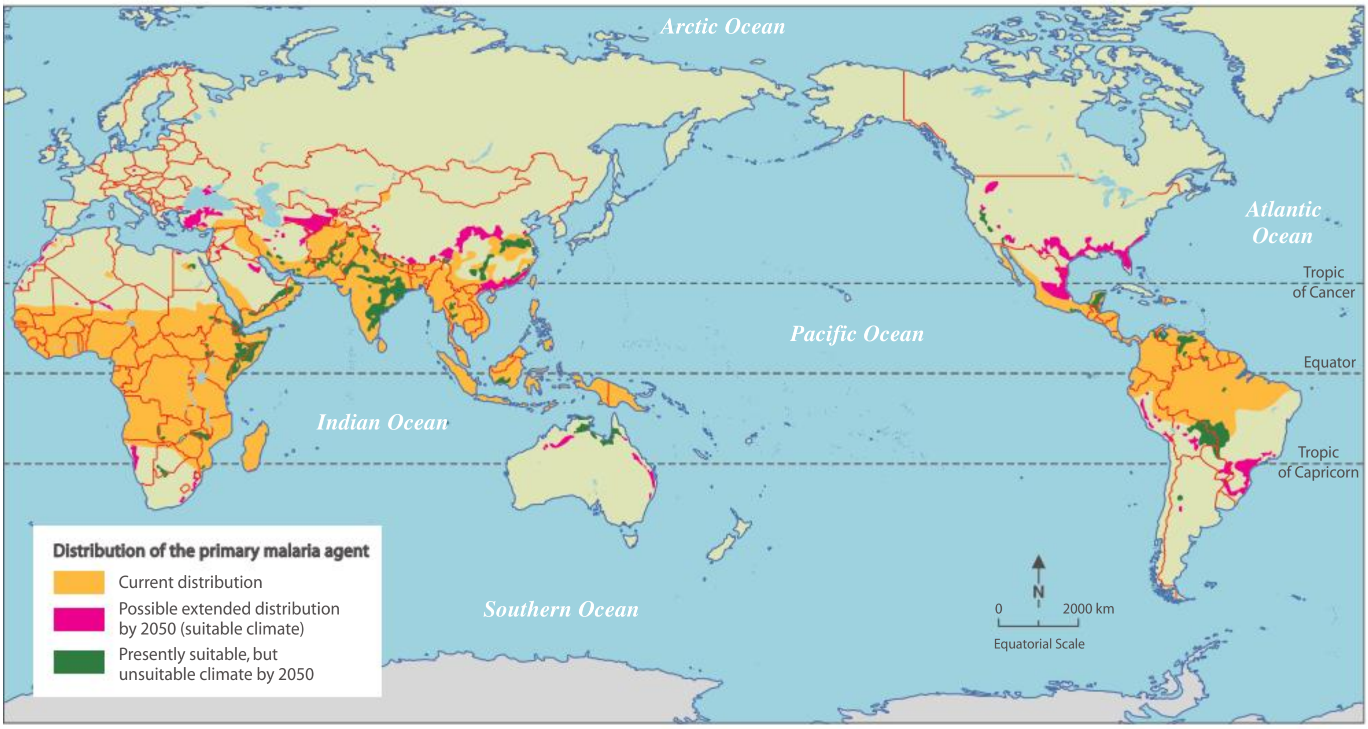


Figure 5.9 Use of insecticide-treated nets (ITNs) can greatly reduce the incidence of malaria

Figure 5.10 Indoor residual spraying (IRS) is a highly effective method of malaria prevention, protecting homes for four to ten months

Sprays can also be used to kill larvae in breeding sites, but there is a trade-off between malaria control and the use of persistent toxic chemical sprays that may also cause illness to people or harm other species.

Malaria in pregnant women can be reduced by administering an anti-malarial drug during pregnancy. Drugs such as chloroquine exist which can prevent malaria but these must be taken on an ongoing basis. Once symptoms occur, prompt treatment for the disease, with mass drug administration, can cure a patient and prevent death. This also reduces malaria transmission to other people. Whilst a general vaccine against malaria does not currently exist, progress has been made with seasonal vaccinations for children (as outlined in the next section).

▶ ACTIVITIES

1. Using Figure 5.6, describe the global *distribution* of malaria cases.
2. Using an atlas or the Esri GIS for Schools unit on malaria, compare the *distribution* of malaria with a temperature and rainfall map. What *environments* and climatic conditions appear to have a *spatial association* with malaria?
3. Investigate some of the human activities that could possibly affect the current *distribution* of malaria. You could use a website such as Gapminder to examine the *interconnection* between indicators such as income and malaria.
4. Describe the likely *change* over time in malaria *distribution* using Figure 5.8. Include quantification and specific country names.
5. Which issue caused by malaria do you consider to be the most serious? Justify your response.
6. Draw a visual representation to show the direct and indirect impacts of malaria within a community, clearly distinguishing between the economic and social issues caused by the disease.

A global-*scale* response: RBM Partnership to End Malaria

The objectives of reducing the disease burden and eliminating malaria are *interconnected* to many of the Sustainable Development Goals (SDGs) as malaria control and elimination will contribute to *sustainable* development. Malaria is specifically the focus of SDG 3: 'Ensure healthy lives and promote well-being for all at all ages' and its Target 3.3: 'By 2030, end the epidemics of AIDS, tuberculosis, malaria and neglected tropical diseases and combat hepatitis, waterborne diseases and other communicable diseases.'

At a global *scale* a key program working towards this target RBM Partnership to End Malaria (formerly known as Roll Back Malaria) involves over 500 organisations including WHO, UNICEF (United Nations Children's Fund), UNDP (United Nations Development Programme) and the World Bank. Its vision is 'a world free of the burden of malaria' via the implementation of its Action and Investment to defeat Malaria 2016–2030 (AIM) program and WHO's Global Technical Strategy for Malaria 2016–2030.

It has a three-step series of goals and targets for 2016–2039 (see Figure 5.11). In 2018, a total of US$2.7 billion was provided for malaria control and elimination a reduction from US$3.2 billion in 2017. Funding levels are well below the estimated US$5 billion that is required to achieve global malaria control and elimination, a significant economic challenge. Nearly three quarters of this funding went to countries in the African *region*.

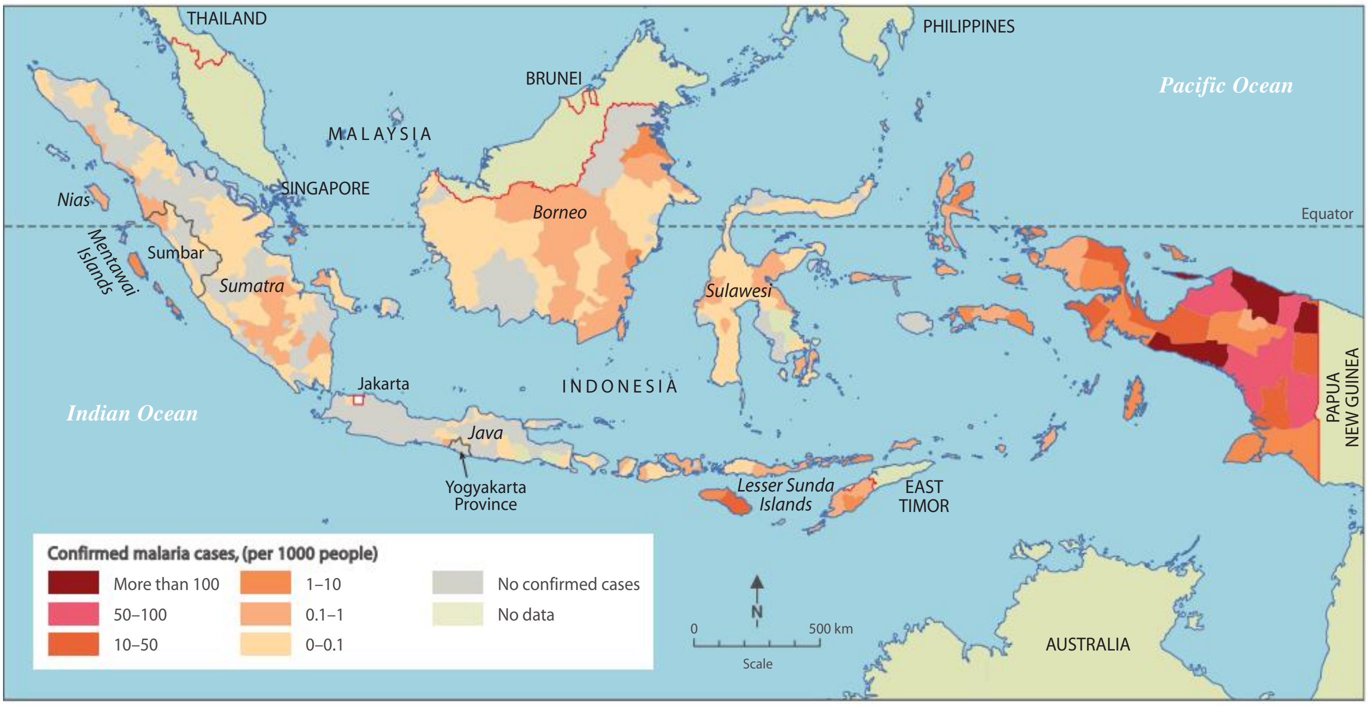
WHO estimates that on a global *scale* since the year 2000 nearly seven million deaths and over one billion new infections were averted due to these programs. This was mainly due to provision of insecticide-treated nets (ITNs) with a total of 578 million *distributed* globally between 2016 and 2018. In Sub-Saharan Africa, 50 per cent of the population at risk had access to a mosquito net in their household in 2018, compared to 29 per cent in 2010.

Use of indoor residual spraying has been less successful, with only 2 per cent of the global population at risk protected. Insecticide resistance to the most common sprays has proved a challenge, especially in countries along the Mekong River (Cambodia, Laos, Myanmar, Thailand and Vietnam). Preventative drug treatment levels for pregnant women and children aged under five have increased but still remain low: in 2018 only 31 per cent of pregnant women (up from 19 per cent in 2016) received the recommended three doses and 12 million children who could have benefited from this treatment were not covered. In the Sahel *region* of Africa, most childhood malarial disease and deaths occur during the rainy season, which is generally short (3–4 months). Providing monthly vaccines of anti-malarial medicine at this time – known as seasonal malaria chemoprevention – was implemented in the countries of Ghana, Kenya and Malawi by WHO in 2018. This has been shown to be 75 per cent protective against malaria in children under five years of age. This method

▼ **Figure 5.11** RBM Partnership to End Malaria goals and targets

By 2020	By 2025	By 2030
▶ Malaria mortality rates and incidence are reduced by at least 40% compared with 2015. ▶ Malaria does not re-emerge in countries that were malaria-free in 2015. ▶ Malaria is eliminated in a further 10 countries compared to 2015.	▶ Malaria mortality rates and incidence are reduced by at least 75% compared with 2015. ▶ Malaria does not re-emerge in countries that were malaria-free in 2015. ▶ Malaria is eliminated in a further 10 countries compared to 2015.	▶ Reduce malaria incidence and mortality rates globally by at least 90% compared with 2015 levels. ▶ Malaria is eliminated in a further 35 countries compared to 2015. ▶ Prevent re-establishment of malaria in all countries that are malaria free. ▶ End the epidemics of AIDS, tuberculosis, malaria and neglected tropical diseases and combat hepatitis, waterborne diseases and other communicable diseases.

▼ **Figure 5.12** The *distribution* of malaria in Indonesia



is considered economically cost-effective and socially acceptable as it is safe and can be administered by community-health workers. Consequently, it has been expanded to other countries in this *region*.

National-*scale* case study: malaria in Indonesia

The population of Indonesia – an archipelago located in South-East Asia – was over 274 million in 2020. Indonesia is one of nine malaria-endemic countries in this *region*, accounting for 21 per cent of cases. Although the country has made huge progress towards achieving its goal of malaria elimination by 2030, an estimated 25 per cent of the population remains at risk from this hazard (see Figure 5.12). The country has a long history of attempting to manage malaria. Formal efforts to eradicate malaria first began in 1959 as part of the Global Malaria Eradication Program with the spraying of DDT to kill mosquitoes, particularly in Java and Bali. However, insecticide resistance developed and this, together with political and financial challenges, hampered this program. *Environmental* and health concerns about the use of DDT led to this program ceasing in 1968.

The launch of the Roll Back Malaria program triggered the implementation of Indonesia's 'Crush Malaria' policy in 2000. With funding from WHO, UNICEF and Global Fund, the first phase focused on malaria control by testing communities to identify specific locations affected then mapping these to ensure effective treatment was being provided. Since 2004 more than 27 million insecticide-treated nets have been *distributed*. Malaria cases have dropped an estimated 700,000 in the last decade but the challenge of covering some 6000 inhabited islands remains, particularly in the more isolated, less developed eastern *regions* of the country (as shown in Figure 5.12). In addition, *movement* of migrant workers has led to an increased incidence of malaria in parts of Yogyakarta Province after five years with low rates of occurrence.

Today Indonesia's malaria program is *interconnected* to the country's general health system rather than being a stand-alone program. For example, screening of pregnant women and providing them with malaria prevention strategies takes place at antenatal care visits. Geospatial technology has played a crucial role in improving Indonesia's progress towards its malaria elimination goal. A mobile phone based malaria reporting system, Malaria Case Rapid Reporting, was developed in 2018 to speed up reporting and management of cases from isolated islands such as South Halmahera. Data collection, mapping and reports previously were done by hand and delivered by boat once per month due to lack of reliable electricity supply and internet connection. The new mobile phone system reduced data collection time by 19 days, enabling a much more effective treatment response to the disease. Patient data and medicine stock can also be visualised.

In 2020 progress in reducing malaria incidence had been challenged by the COVID-19 pandemic. Malarial testing had been reduced (in the first three months of 2020 this was less than half of that of the 2019 rate) so case numbers are likely to be under reported. House-to-house visits by community health workers and the *distribution* of nets have also been reduced. However, Indonesia remains confident that its 2020–2024 Malaria National Strategic Plan can continue to work towards total malaria elimination by 2030.

A local-*scale* response to malaria in the Mentawai Islands of Indonesia: SurfAid International

SurfAid is a non-profit organisation whose aim is to improve the health, wellbeing and self-reliance of people living in villages near surfing locations in some of the remote Indonesian islands. Founded in 2000 by a group of concerned surfers, SurfAid focused initially on the Mentawai Islands, 150 kilometres off the West Sumatran coast (see Figure 5.12, part of the province of West Sumatra). In 2013 it expanded its work to Nias Island (125 kilometres off the North Sumatran coast), and in 2014 to the islands of Sumbawa and Sumba in eastern Indonesia. (Since then it has also established programs in the Solomon Islands and Maja Sun in Mexico.) In these locations many people suffer from a high prevalence of treatable and preventable diseases, including malaria, and nutrition is generally poor.

SurfAid operated the Malaria Free Mentawai Program (2013–17). Its goal was to reduce the incidence of malaria and associated deaths by the establishment of malaria clinics in communities and by increasing the knowledge and skills of the local people to manage this disease. Groups of community health volunteers worked together with the local health department to deliver health messages on nutrition, hygiene and sanitation to their neighbours, focusing on at-risk households. Prior to intervention, in the worst affected villages, one-quarter of children died from preventable and treatable diseases, including malaria, before reaching the age of 12 years. Throughout the Mentawais, 50 per cent of all families lost at least one child. In 2006, up to 50 per cent of people were found to be carrying the *Plasmodium* parasite.

▲ **Figure 5.13** SurfAid's anti-malaria program at Mapoupou village. Children under nine years of age are tested for malaria

SurfAid delivered over 60,000 insecticide-treated nets to some 300 villages during that program. Initially net *distribution* was not totally successful due to the social factor of lack of education on how to use the nets; some locals used the nets for fishing. In addition, economically, for some families in poverty, the priority of feeding their family came before the perceived risk of the malaria hazard. So, from 2008 onwards a more holistic approach to development was taken: the community was educated using local, trained health workers thus empowering local communities as well as increasing the effectiveness of tackling malaria and other diseases (see Figure 5.13). Parasite testing now shows a 1–2 per cent prevalence rate in children under nine years. SurfAid focuses now on delivering Mother and Child Health Programs including clean water and sanitation, basic healthcare, improved nutrition and economic development projects. In the past ten years, these programs have reached 178,686 people and have significantly reduced infant and maternal mortality rates.

▶ ACTIVITIES

1. Create a table to show the advantages and disadvantages of each form of malaria control or treatment.
2. Refer to the United Nations Sustainable Development Goals (SDGs) website. Select at least three of these goals and explain the *interconnection* between reducing the incidence of malaria and the achievement of that goal.
3. Evaluate the likely effectiveness of the RBM Partnership to End Malaria to meet its short term and long term targets.
4. Describe the *distribution* of malaria in Indonesia, contrasting the eastern and western *regions* of the country.
5. How effective has the Indonesian response to malaria been? Justify your answer using appropriate statistics.
6. Evaluate SurfAid's response to malaria using criteria (such as economic, social, political, *environmental* impacts) and include strengths and weaknesses of each. Additional information can be sourced from the SurfAid website.
7. Bill Gates stated in March 2013: "The malaria vaccine in humanist terms is the biggest need. But it gets virtually no funding. But if you are working on male baldness or other things you get an order of magnitude more research funding because of the voice in the marketplace than something like malaria." Watch his TED Talk *Mosquitos, malaria and education*, and discuss this statement as a class.

National-*scale* case study: malaria in Madagascar

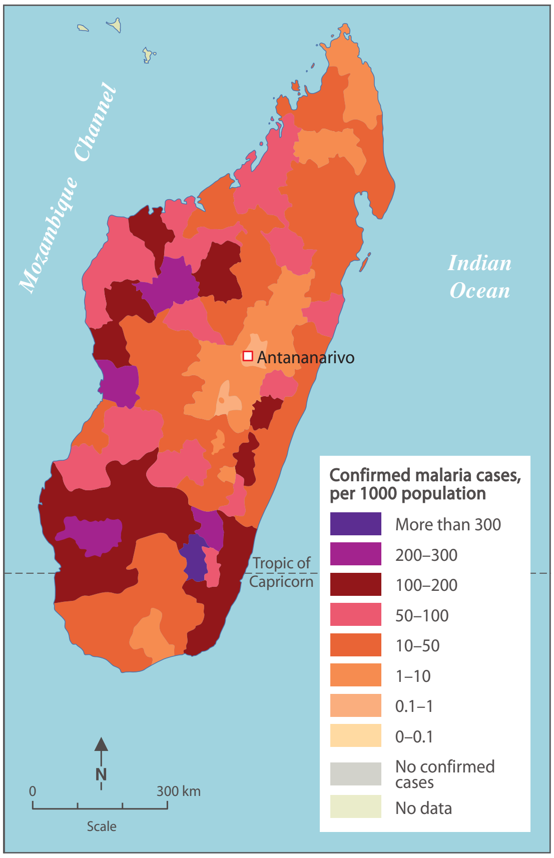
Madagascar is an island nation located off the east coast of Africa. Economic and social factors contribute substantially to malarial risk. It is one of the poorest nations in the world: in 2019 it ranked 162 out of 189 countries on the United Nations Human Development Index (HDI). The gross national income per capita is US$1404, while 70.7 per cent of the population live below the poverty line. Approximately 28 per cent of the country's 27.9 million people are illiterate. *Environmental* factors also increase risk of malaria. With a hot, rainy season from November to April, the entire country is considered at risk: 30 per cent of the population live in high-transmission areas with the remaining 70 per cent living in areas with low rates of transmission which are prone to epidemics. Children under the age of five are the most impacted group: UNICEF estimates a child mortality rate for Malagasy children of 50.6 per 1000 and the average life expectancy was 67.3 years in 2020.

As shown in Figure 5.14, the *distribution* of malaria cases varies across the country. The warmer coastal *regions* have greatest transmission although residents have developed high immunity due to this higher infection level. With *changing* temperature and rainfall patterns, transmission has spread to the Central Highlands, a *region* which has not traditionally experienced malaria. Epidemics here have resulted in high mortality as the population has very low immunity: in the late 1980s an outbreak killed over 30,000 people. Despite recent improvements in prevention and treatment, epidemics still occur such as in the first half of 2012 when the weather was warmer and wetter.

A major national-*scale* response to malaria in Madagascar has been via the US President's Malaria Initiative (PMI). The PMI was launched in 2005 as a five-year US$1.2 billion commitment from the US government to reduce the impact of malaria and poverty in Africa. Madagascar became a PMI focus country in 2008 and since then a total of over US$312 million has been provided. The goal of PMI is to reduce by 70 per cent malaria-related deaths of the most vulnerable members of the community – pregnant women and children under the age of five. To achieve this, they use four methods: insecticide-treated nets, indoor residual spraying, preventative treatment for pregnant women, and diagnosis and treatment. In 2020, over 350,000 homes were sprayed and 80 per cent of households had at least one insecticide-treated net. Although over one million nets were procured for that year, the PMI estimated the need for an additional million nets. As shown in Figure 5.15, transmission rates have been variable. Political instability resulted in some disruption to programs from 2009–2015.

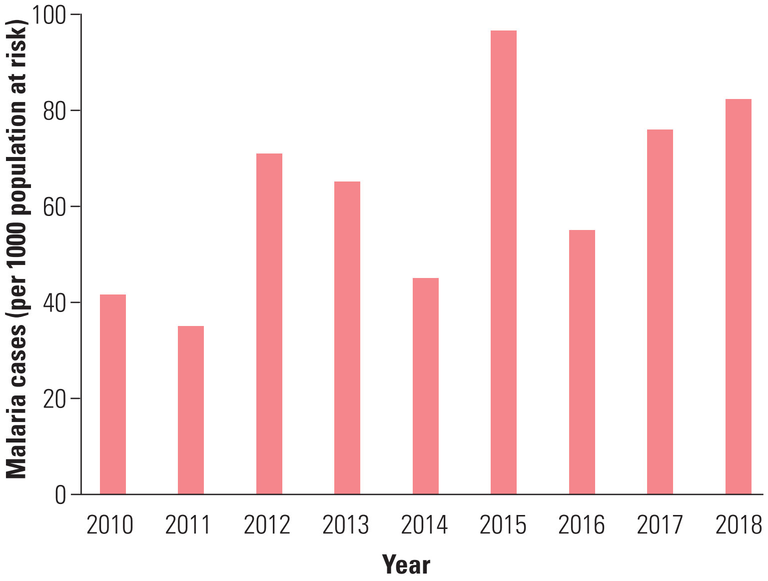
One of the major drugs used to treat malaria is made from a plant called *Artemisia annua*, a plant that grows in Madagascar. It is used to create artemisinin-based combination therapies (ACTs) which WHO considers are the most effective antimalarial medicines available today. In 2005, the United Nations Development Programme (UNDP) provided funding via its Growing Sustainable Business Program for a joint project with a Malagasy company Bionexx and local farmers to grow and produce this plant for sale. Since then, over 3000 tonnes, sufficient for 50 million treatments, has been produced each year. This far exceeds the four million treatments required annually in Madagascar. Additional benefits of this project have been the creation of 450 jobs, and the opportunity for 10,000 farmers to earn higher incomes (US$300 per season) in addition to growing their own food crops. In 2020, 513,440 ACT treatments were *distributed* in Madagascar.

Geospatial technology is used by PMI and partners to help manage malaria in Madagascar. A sentinel surveillance system is used which collects data from 34 sites throughout the country. Data such as fever cases and testing results is recorded using mobile health technology. Satellite weather data *interconnected* to *changes* in malaria prevalence such as information on temperature and rainfall are linked to this system. Added GIS map layers include net *distribution* and *location* of indoor residual spraying. These tools enable early warning of potential outbreaks and detection of the disease and assist in rapid control actions to reduce deaths (see Figure 5.16).



◀ **Figure 5.14** The *distribution* of confirmed malaria cases in Madagascar

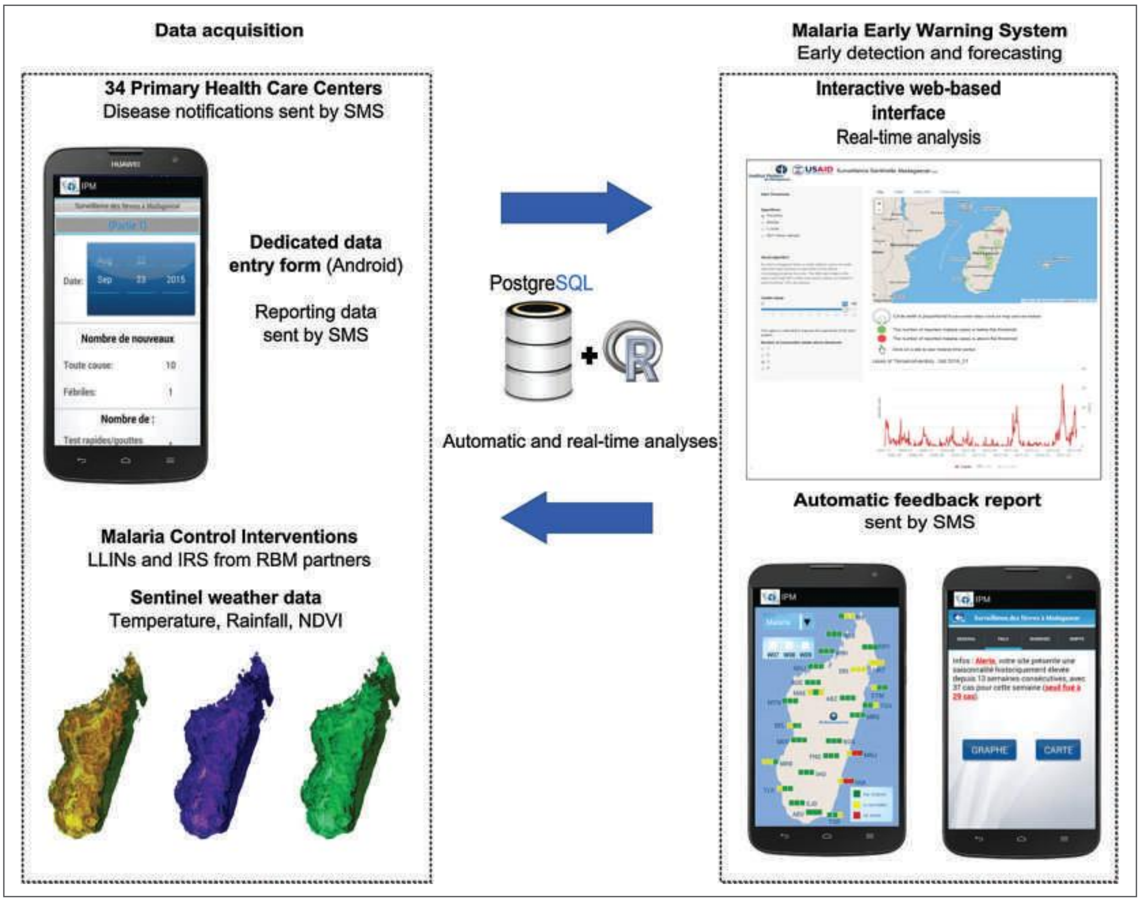
▼ **Figure 5.15** *Change* in malaria cases over time



▶ ACTIVITIES

1. In what way can malaria be considered both a cause and a result of poverty?
2. 'Community involvement is essential in combating malaria.' Discuss this statement.
3. Analyse the likely effectiveness of geospatial technology in reducing malaria hazards in a specific country.
4. Use a website such as the BBC to investigate the progress being made towards the development of a malaria vaccine. What impact would this have on the future *distribution* of this disease?
5. Explore the website The Malaria Atlas Project. This Perth based company aims: "to generate new and innovative methods to map malaria, to produce a comprehensive range of maps and estimates that will support effective planning of malaria control at national and international *scales*." Analyse how they undertake this work.

▶ **Figure 5.16** The *process* of malaria monitoring using geospatial technology in Madagascar



COVID-19 – a modern pandemic

Overview

COVID-19 is the infectious disease caused by the coronavirus, SARS-CoV-2. Coronaviruses are a group of viruses that usually cause mild illnesses such as a common cold. However certain types, such as COVID-19, can infect the lower airway causing serious illnesses such as pneumonia. The name *corona* is due to the shape of the virus when viewed under a microscope as it looks like a crown (or corona) with spikes (see Figure 5.17). Prior to the COVID-19 outbreak, there had been two major coronavirus outbreaks in the last 20 or so years: Severe Acute Respiratory Syndrome (SARS) in 2002 and Middle East Respiratory Syndrome (MERS) in 2012. These however, were more localised epidemics in terms of *scale* and impact and were not classified as pandemics – the latter being defined by WHO as: "an epidemic occurring worldwide, or over a very wide area, crossing international boundaries and usually affecting a large number of people". COVID-19 was officially classified by WHO as a pandemic in March 2020.

WHO first learned of this new virus originating in Wuhan, People's Republic of China on 31 December 2019 (Figure 5.18) via a media statement from the Wuhan Municipal Health Commission on their website about cases of 'viral pneumonia'. It is likely that this virus first passed to humans via an animal, possibly a bat, and then via a seafood and poultry market

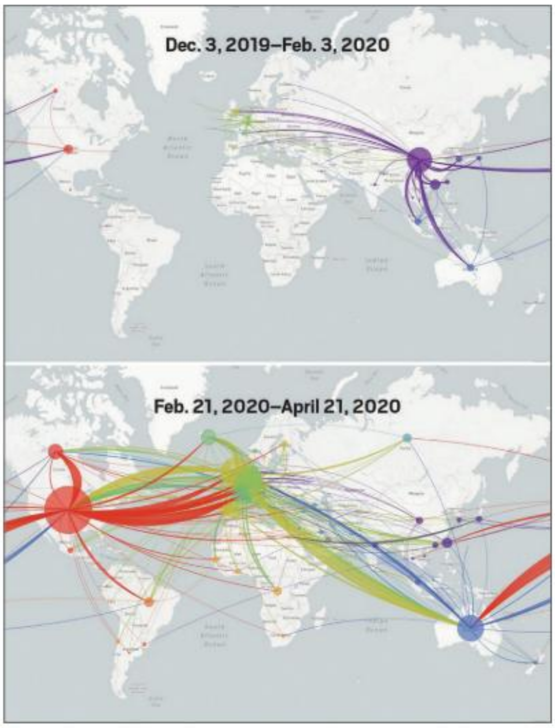
▲ **Figure 5.17** Representation of the coronavirus

▲ **Figure 5.18** The location of Wuhan, the centre of the COVID-19 outbreak. Wuhan, the capital of Hubei Province, has a population of 7.9 million in Wuhan – an estimated 75 per cent of new or re-emerging diseases in humans have animal origins. It is believed that the virus is primarily spread through contact with an infected person and from droplets from an infected person's cough or sneeze. Airborne transmission may occur especially in indoor, crowded and poorly ventilated settings. Touching objects or surfaces (like doorknobs or tables) which have droplets on them from an infected person, and then touching your mouth or face, can also cause the virus to spread.

Initial analyses of COVID-19 showed that an infected person can potentially spread the virus to two or three other people, but later variants may have higher contagion rates, like the Delta strain in 2021. In our globalised world, the disease spread quickly. Air travel in particular facilitated the *process* of *movement* of the virus. As shown in Figure 5.19, by early February, approximately 14 countries reported cases; since then it has spread to nearly every country. As Figure 5.20 shows, the pace of the pandemic continued to increase in 2020. It took around three months to reach the first 10 million cases, 38 days to go from 5 million to 10 million cases but only 17 days to go from 30 million to 35 million cases.

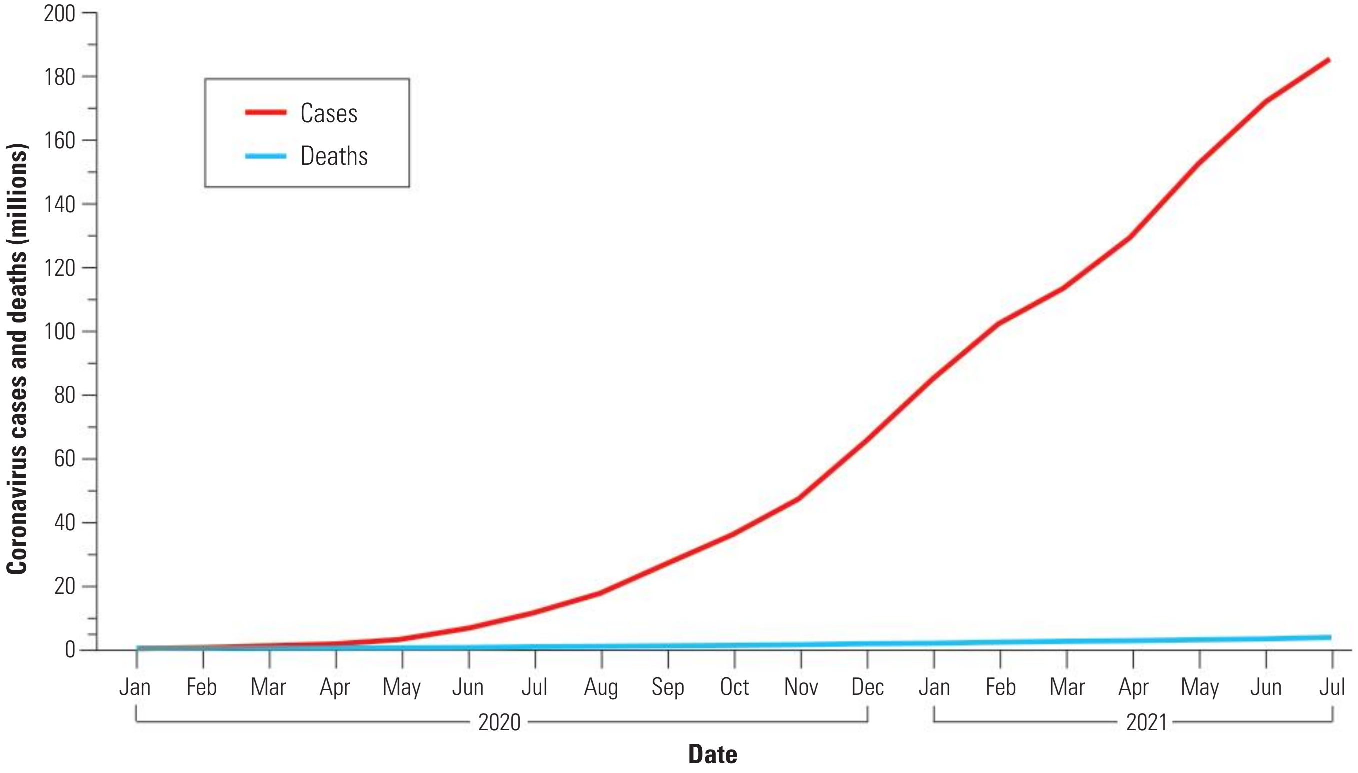
By July 2021, over 188.9 million people globally had been infected by this virus, with a peak of over 895,000 daily cases in mid-April 2021. Over 4 million people have died (a peak of over 18,000 per day in January 2021) and approximately 173 million have recovered.

▼ **Figure 5.19** *Movement* and *change* in *distribution* of COVID-19 December 2019–April 2020



Most people who are infected will develop symptoms within 14 days of infection although up to half of those infected may be asymptomatic – that is they can pass on the disease prior to showing symptoms. Symptoms of the disease include fever, dry cough and fatigue and possible nausea, dizziness and headaches. In severe cases shortness of breath, confusion, persistent pain or increased pressure in the chest also occur. WHO data to date suggests that 80 per cent of infections are mild, 15 per cent are severe infections requiring oxygen and 5 per cent are critical infections, requiring ventilation. The estimated average mortality rate is 3–4 per cent, but some groups are more vulnerable. Possible long term health impacts include damage to lungs, heart and brain. At the time of writing, there is no cure but vaccine production and vaccination is gaining momentum across the world.

▼ **Figure 5.20** *Change* in global case numbers for COVID-19 over time (data is from 22 January 2020 to 8 July 2021)



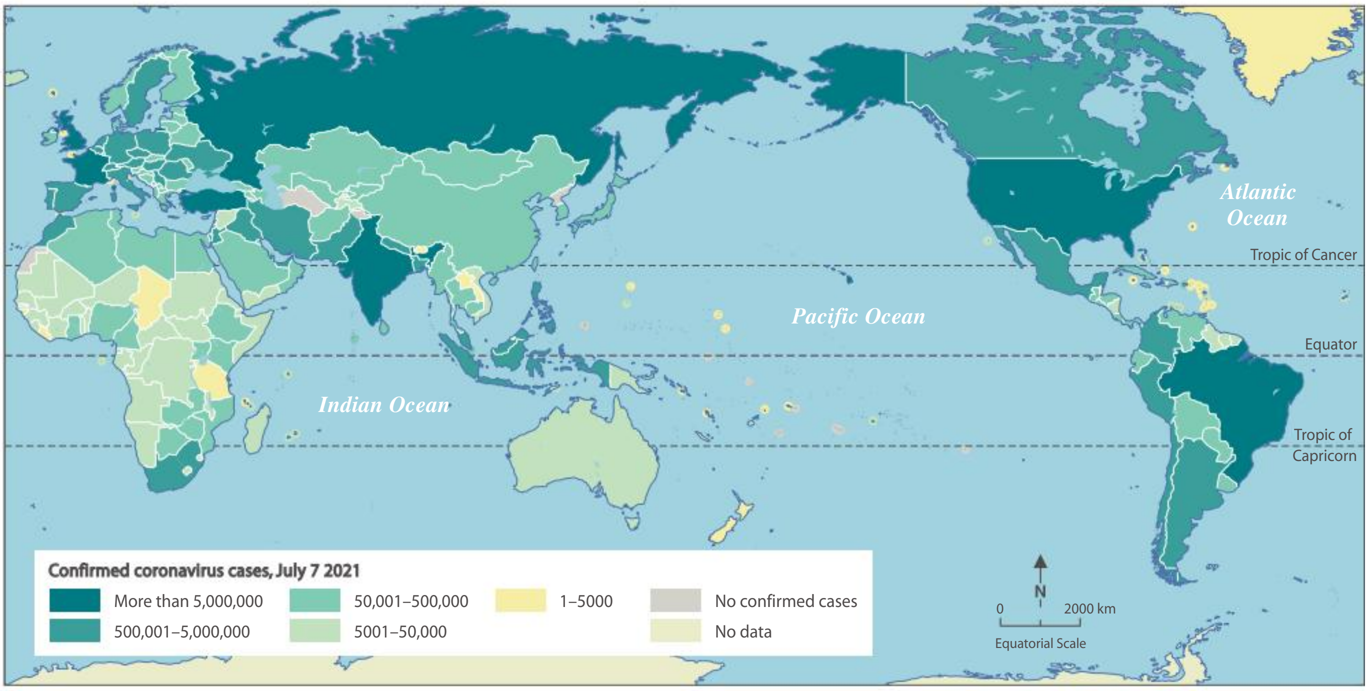
What factors affect the global *distribution* and risk of COVID-19?

Figures 5.21 and 5.22 show the global *distribution* of COVID-19 cases and deaths as of July 2021. Case *distribution* is concentrated in the *regions* of the Americas with around 74.4 million cases, followed by Europe (57.6 million) and South-East Asia (36.5 million). USA has the highest incidence with over 33.6 million confirmed cases, followed by India with 31 million and Brazil with 19 million. In terms of deaths, there is a similar *regional* pattern: the Americas (1.9 million), Europe (1.2 million) and South-East Asia (522,000). Countries with the highest number of deaths are USA, Brazil and India with figures of approximately 603,000, 537,400 and 412,500 respectively. Ten countries account for 72 per cent of deaths worldwide: in addition to the top three previously mentioned, these are Mexico, Peru, United Kingdom, Italy, France, Spain and Iran. A Yale University epidemiologist estimates that at least 40 per cent of the world's population of 7.6 billion are likely to eventually become infected, resulting in millions of deaths.

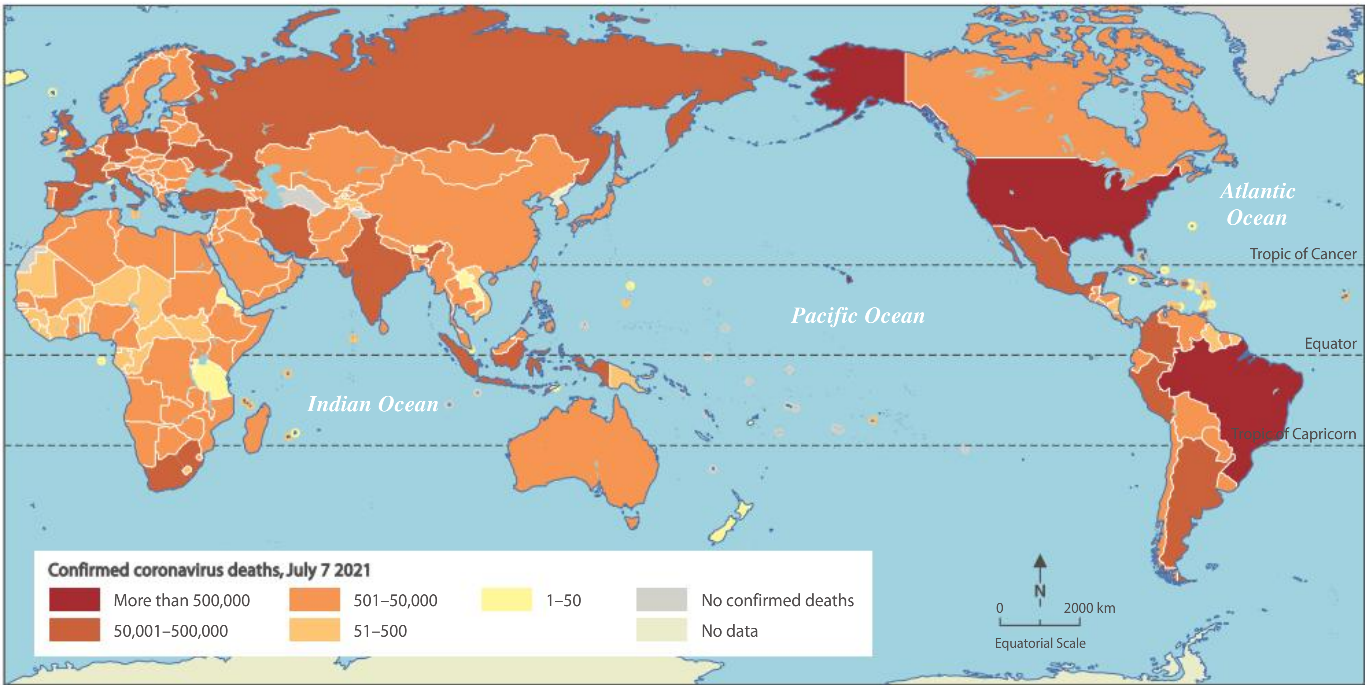
There are a number of factors contributing to this *distribution*.

- Social factors – Population structure and dynamics play a significant role. Countries with large populations such as India and USA, the second and third largest global populations, have high case numbers. China, the world's largest population is an obvious exception here with fewer cases despite being the source of the outbreak (refer to the role of government response later in this chapter). Population density also plays a role: where people are living in close proximity

▼ **Figure 5.21** Global *distribution* of COVID-19 cases



▼ **Figure 5.22** Global *distribution* of COVID-19 deaths



to each other, the virus is more easily spread. This was evident in dormitories of up to 300,000 migrant workers in Singapore. Foreign workers from countries such as India and Bangladesh, who mainly work in construction and manufacturing, must be provided with accommodation by their employer. Prior to COVID-19 it was normal for up to 20 men to share a room. The crowded conditions resulted in migrant workers hosting 90 per cent of this country's cases. Globally, according to the United Nations, at least 90 per cent of COVID-19 cases have been in urban areas.

Age structure of population affects both the rates of infection and fatality. The risk of death from COVID-19 has been calculated to increase by 13 per cent for every year of age: a 65 year old is 100 times more likely to die than a 25 year old. The aged population is unevenly *distributed* around the world with the *region* of Europe having over 20 per cent over 65 years, compared to only 3 per cent in Sub-Saharan Africa. Minority groups may be more vulnerable, particularly if they face the additional challenges of communication barriers and/or economic disadvantage.

- *Environmental* factors – From the evidence so far, the COVID-19 virus can be transmitted in a range of climates, from hot to cold. The usual influenza viruses do commonly have peak transmission in winter as people spend more time together indoors and such viruses are more stable in cold, dry conditions with low levels of ultraviolet light. Studies to date are inconclusive as to whether the incidence of COVID-19 will be reduced in warmer weather. It is likely that the *interconnection* between people's activities and the seasons plays a much more important role. As mentioned in Chapter 6 there is a possible *interconnection* between air pollution and the *distribution* of COVID-19 and resulting deaths.
- Economic factors – Historically, poor countries have been hardest hit by pandemics. Developing countries are less likely to have a health care system which can cope with yet another burden of disease and a large proportion of the population may already have reduced immunity due to their limited ability to access medical treatment for other illnesses such as malnutrition and malaria. Health care spending per capita reflects economic challenges: WHO estimates Sub-Saharan Africa spent only US$83 per head in 2017, India US$69 compared with US$3261 in the European Union countries and US$10,246 in the USA. Poorer countries are unlikely to afford the drugs used to treat patients which can reduce deaths by 20–30 per cent.

  Economic factors also affect the amount of testing undertaken for the virus: limited testing means that cases will be underestimated and the data less reliable. According to criteria published by WHO in May 2020, a positive rate of less than 5 per cent is one indicator that the epidemic is under control in a country. Mexico had a positive rate of 29.5 per cent in October with Nepal at 23.9 per cent compared with Australia's rate of under 1 per cent.

  Economic factors are *interconnected* with social and *environmental* factors. The poor living in slum areas of cities such as Sao Paulo in Brazil or Mumbai in India are not only in close proximity to others and unable to socially distance but face challenges of accessing running water for hand washing and are more likely to be under pressure to keep working to support their families. They are also likely to be less well educated, therefore hindering communication about appropriate action in response to the hazard.
- Political factors – Past experience with viruses has assisted with the level of government preparedness to this pandemic. Singapore's experience with SARS proved valuable in responding quickly; similarly countries such as Guinea which had relatively recently dealt with Ebola, were better prepared in terms of communication providing a level of public trust and confidence in those governments. Government responses to COVID-19 obviously varied in approach and effectiveness, therefore impacting the disease *distribution*. Some of these are explored later in this chapter.

ACTIVITIES

1. Undertake research on the SARS and MERS outbreaks. Compare the *scale* and *distribution* of these to COVID-19. Suggest what factors may have been responsible for these differences.
2. Use the John Hopkins University Coronavirus Resource Centre website to view an extensive range of data on COVID-19.
   a. Provide updated statistics for cases and deaths for each *region* and the most affected countries.
   b. Compare and contrast the most recent data to that provided in the text.
3. Evaluate the relative importance of factors contributing to the *distribution* of COVID-19 cases and deaths (you may find it useful to refer to the Our World in Data website where they graph a number of data *interconnections* to assist you with this response).

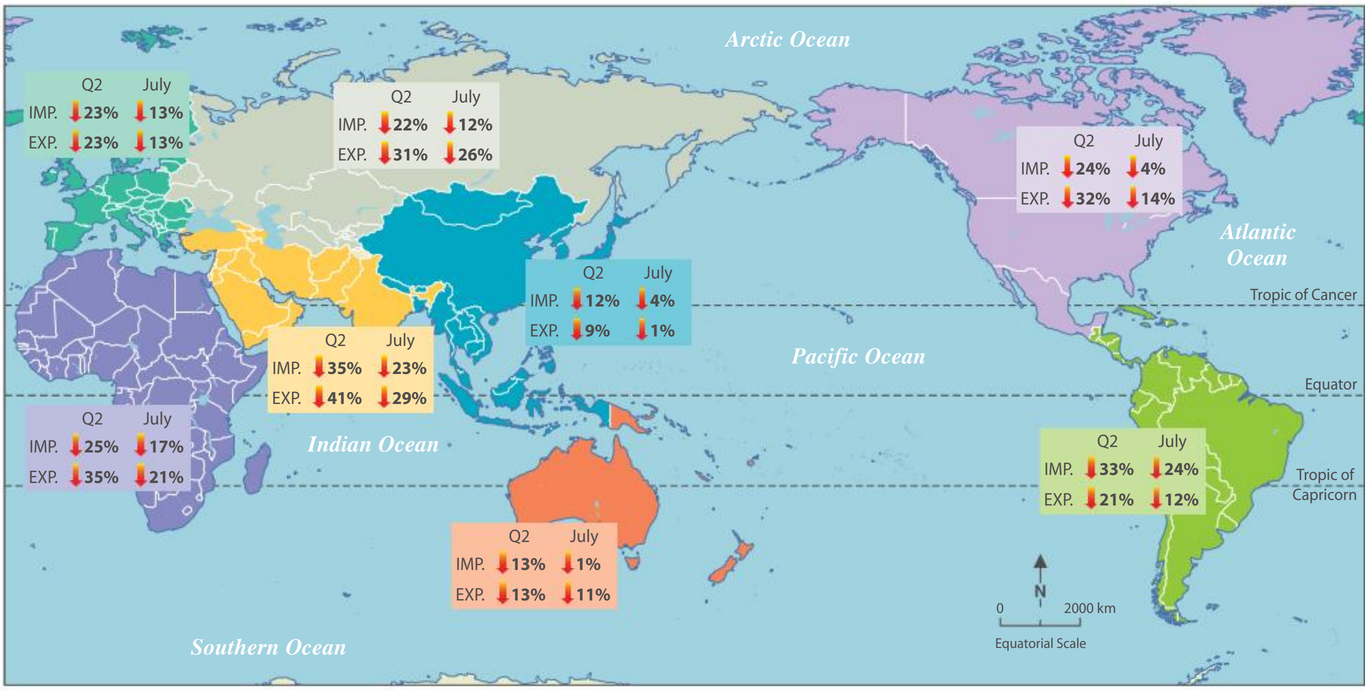
What are the impacts of COVID-19?

Below is a summary of some of the major impacts of this virus.

Economic impacts

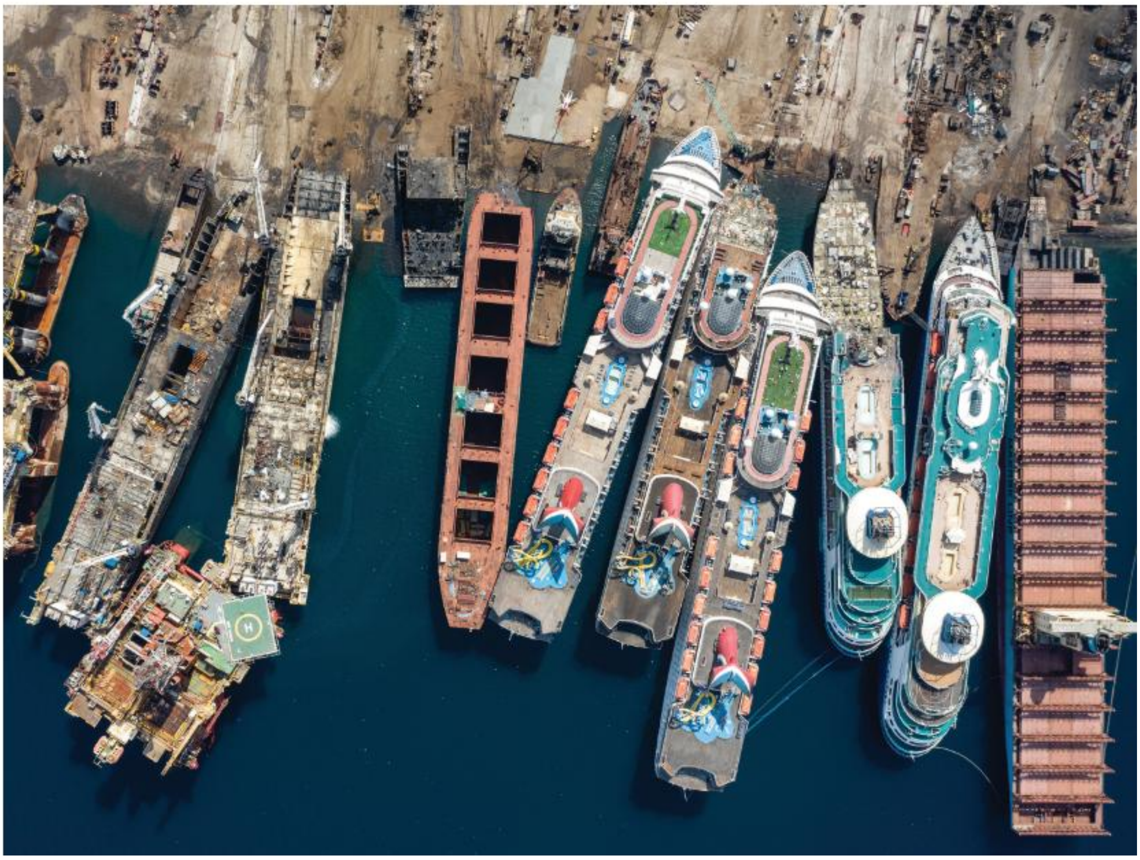
- Decrease in global trade estimated to be 7–9 per cent 2019–2020 but significant *regional* variation (see Figure 5.23). Trade in COVID-19 medical supplies has grown by an average of over 50 per cent since April 2020, mainly to the benefit of wealthier nations.
- The tourism industry particularly hard hit: in the second quarter of 2020 international travellers' expenditure declined 81 per cent and transport expenditure was reduced by 31 per cent. The cruise industry has been particularly impacted, up to 2500 jobs are lost per day globally and liners have been scrapped for recycled parts and metal (see Figure 5.24).
- Fall in GDP of most countries with reduced production and consumer spending: data for the second quarter of 2020 shows figures range from a 30 per cent decline in Peru to less than 1 per cent in Taiwan (see Figure 5.25).

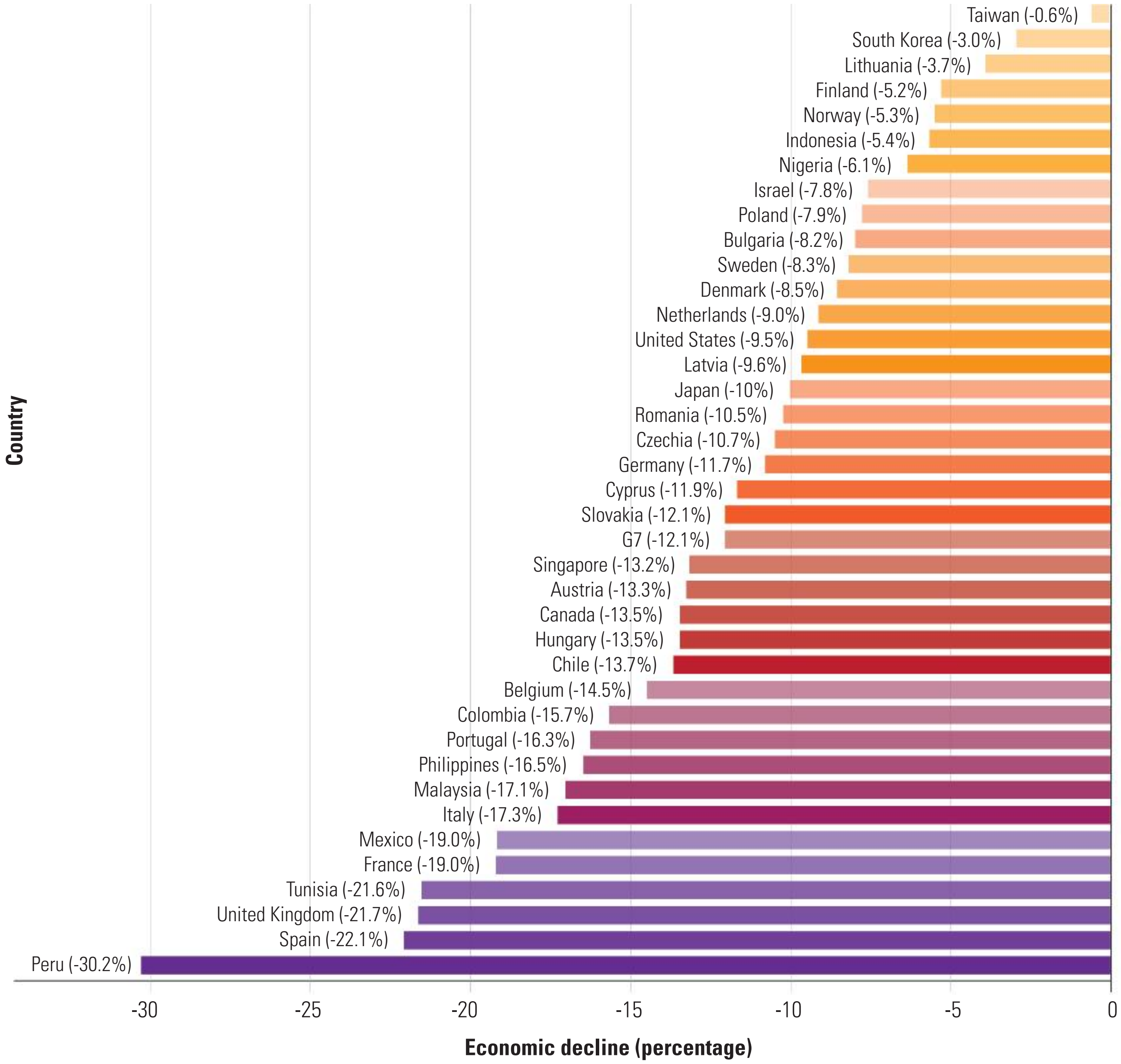
Figure 5.23 *Change* in global trade due to COVID-19 2020



- Increased unemployment: in developing countries, many jobs have been lost in the informal sector, making it difficult to quantify, for example, 27 per cent in Nigeria and 16.5 per cent in Peru. Developed economies include USA around 8 per cent and the European Union 7.4 per cent. In Australia, unemployment peaked around 7 per cent; over 50 per cent of jobs were lost in the accommodation, food, arts and recreation industries and are considered unlikely to recover before the end of 2025.
- Reduced flow of remittances by one fifth from migrant workers back to their home country.
- Increased inequality: estimated numbers of extreme poor (those under $1.90 per day) expected to rise globally by 70–100 million.
- Increased demand for some products: items such as toilet paper and hand sanitiser were the subject of panic buying in Australia in February and June 2020. In response, supermarkets imposed limits and companies such as manufacturer Kimberly Clarke increased production; some manufacturers such as Four Pillars Gin moved to produce hand sanitiser instead. Demand for computer and subscription services, groceries and items such as board games also increased.

Figure 5.24 A decline in global tourism due to COVID-19 has led to the retirement of cruise ships on the Turkish coast





▲ **Figure 5.25** Decline in GDP for selected countries April–June 2020

- More people moved to online shopping: in USA an estimated 31.8 per cent increase on 2019, with e-commerce now accounting for over 16 per cent of sales.
- The number of employees permanently working remotely globally is estimated to rise from 16.4 per cent to 34.4 per cent in 2021. A recent Australian survey found 85 per cent of respondents would prefer to work remotely two to three days a week in the future.

Social/cultural impacts

- Reduced international migration: Australia is expecting negative migration for 2020 for the first time since 1946 compared with net forecast 271,000. Many workers are returning to their countries of origin e.g. 1.3 million returned to India from other countries. The expected decline in Australian house prices from lower migration did not happen as domestic demand increased significantly thereby making houses less affordable.
- Internal *movement* of people in developing countries back from urban to rural areas; over 10 million people estimated to have relocated in India due to virus fears and lack of employment.
- Disruption to education: only six of 39 African countries had schools open in August 2020; many developed countries had online schooling systems operating, including Australia. Some Victorian students had more than two terms of learning remotely. Disadvantaged households were likely to be disproportionately affected.
- Impact on aged population: those over 70 years are most vulnerable. Over 20,000 deaths of elderly in UK; 788 out of 905 deaths in Australia were those in aged care facilities, mainly in Victoria. However, deaths from influenza reduced from 837 older Australians in 2019 to 28 in the first six months of 2020.
- Vaccination rates for children disrupted: estimated to be set back 20 years with a likely rise in other diseases such as measles.
- UN World Food Program estimates an additional 130 million people in 2021 will suffer malnutrition due to reduced incomes.
- Cancellation of major festivals such as Rio de Janiero's Carnival: major impact on working class communities as well as loss of tourism revenue of an estimated A$1billion.

- Rise in mental health issues: due to fear of infection, uncertainty, loneliness and financial worries. Before COVID-19, Lifeline was receiving about 2500 calls a day across Australia. By August 2020 there were about 3000 calls a day, about one-third of which came from Victoria.

Environmental impacts

- Global greenhouse gas emissions declined 8.8 per cent in the first six months of 2020; emissions from transport decreased by 40 per cent as more people worked from home and did not travel. Road passenger numbers fell 57 per cent below pre-COVID-19 levels in China.
- Possible future *changes* in the built *environment* of city structures: with more people working from home, there may be less demand for the traditional central business district model, and increased decentralisation to provincial towns is occurring.

Political impacts

- Increase in government debt to finance responses: the IMF estimated this was US$66 trillion globally at the end of 2020 with the gross public debt to GDP ratio of advanced economies rising from 105 per cent to 132 per cent by 2021. The USA deficit is set for 15 per cent of GDP, Australia's 10 per cent. Of course, poorer countries have fewer options to finance increased debt despite low interest rates; the poorest countries in the world are spending only an extra US$4 per person.
- Reports of leaders exploiting the pandemic to gain power or to control the flow of information. For example, postponing elections in Bolivia; the Hungarian prime minister now ruling by decree; banning of print newspapers in Jordan, Oman and Yemen; and manipulation of health response and restrictions by some military governments to suppress opposition.

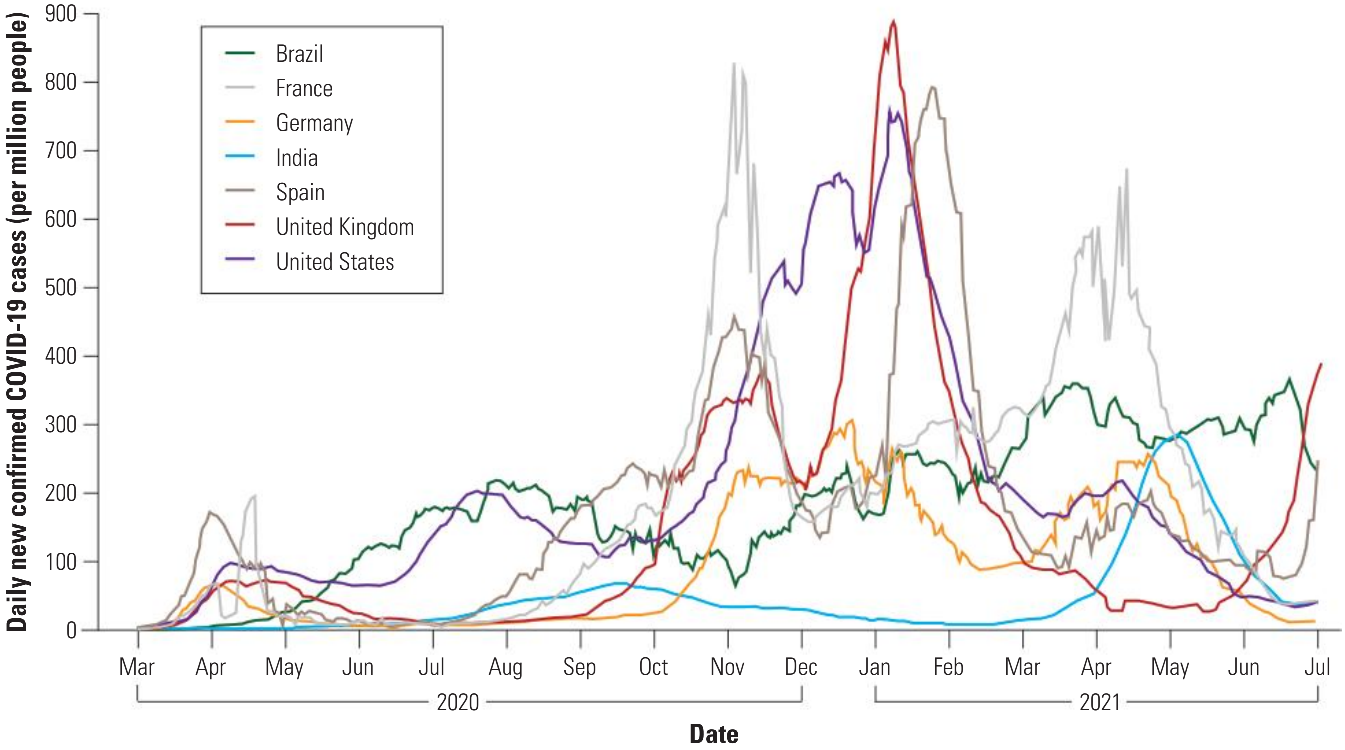
What can be done to manage the COVID-19 hazard?

Countries worldwide are aiming to "flatten the curve" of the coronavirus pandemic. Flattening the curve involves reducing the number of new COVID-19 cases each day so that healthcare systems are less likely to be overwhelmed. Figure 5.26 shows this curve for selected countries; it is evident that some have been more successful than others in reducing new cases overall, with others evidently experiencing a 'second wave' or a resurgence of viral cases as indicated by multiple peaks and troughs.

General advice on minimising risk of infection from COVID-19 has focussed on social distancing – maintaining at least one metre *distance* between people – and wearing of masks to reduce risk of infection from coughing, sneezing or speaking. People are encouraged to avoid spaces that are closed, crowded or involve close contact. In addition, good hygiene practices such as regularly and thoroughly cleaning hands and disinfecting surfaces especially those which are regularly touched, such as door handles, have been emphasised.

Contact tracing is also considered a crucial part of responding to this disease to help slow its spread. In communities using contact tracing, clinics and hospitals send the names of people who have recently been diagnosed with COVID-19 to their local health department. The health department asks each infected person about people with whom they have recently had close contact then quickly alerts those people that they may have been exposed to the COVID-19 virus. Officials do not share the name of the person who may have exposed them to keep the *process* anonymous and confidential. Unfortunately, not all countries have the ability to undertake this, whilst others have developed contract tracing apps that can be used.

▼ **Figure 5.26** Daily new confirmed cases of COVID-19 in selected countries (data from 1 March 2020 to 6 July 2021)



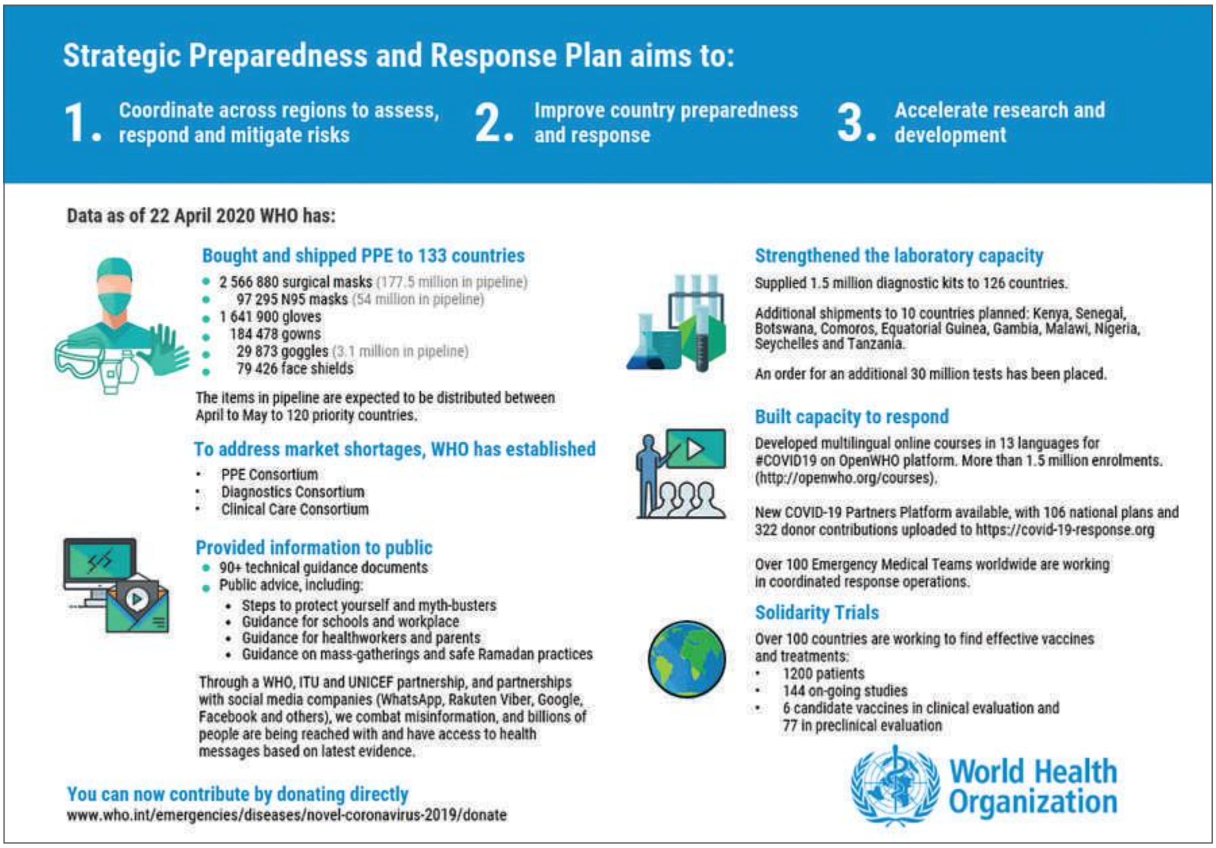


Figure 5.27 World Health Organization's Strategic and Preparedness Response Plan to COVID-19

Strategic Preparedness and Response Plan aims to:

1. Coordinate across regions to assess, respond and mitigate risks
2. Improve country preparedness and response
3. Accelerate research and development

Data as of 22 April 2020 WHO has:

Bought and shipped PPE to 133 countries

- 2 566 880 surgical masks (177.5 million in pipeline)
- 97 295 N95 masks (54 million in pipeline)
- 1 641 900 gloves
- 184 478 gowns
- 29 873 goggles (3.1 million in pipeline)
- 79 426 face shields

The items in pipeline are expected to be distributed between April to May to 120 priority countries.

To address market shortages, WHO has established

- PPE Consortium
- Diagnostics Consortium
- Clinical Care Consortium

Provided information to public

- 90+ technical guidance documents
- Public advice, including:
  - Steps to protect yourself and myth-busters
  - Guidance for schools and workplace
  - Guidance for healthworkers and parents
  - Guidance on mass-gatherings and safe Ramadan practices

Through a WHO, ITU and UNICEF partnership, and partnerships with social media companies (WhatsApp, Rakuten Viber, Google, Facebook and others), we combat misinformation, and billions of people are being reached with and have access to health messages based on latest evidence.

Strengthened the laboratory capacity

Supplied 1.5 million diagnostic kits to 126 countries.

Additional shipments to 10 countries planned: Kenya, Senegal, Botswana, Comoros, Equatorial Guinea, Gambia, Malawi, Nigeria, Seychelles and Tanzania.

An order for an additional 30 million tests has been placed.

Built capacity to respond

Developed multilingual online courses in 13 languages for #COVID19 on OpenWHO platform. More than 1.5 million enrolments. (http://openwho.org/courses).

New COVID-19 Partners Platform available, with 106 national plans and 322 donor contributions uploaded to https://covid-19-response.org

Over 100 Emergency Medical Teams worldwide are working in coordinated response operations.

Solidarity Trials

Over 100 countries are working to find effective vaccines and treatments:

- 1200 patients
- 144 on-going studies
- 6 candidate vaccines in clinical evaluation and 77 in preclinical evaluation

You can now contribute by donating directly
www.who.int/emergencies/diseases/novel-coronavirus-2019/donate

World Health Organization

Global *scale* response: World Health Organization

The Director-General declared the outbreak a public health emergency of international concern, WHO's highest level of alarm, on 30 January 2020. This was upgraded to a pandemic on 11 March 2020 as increasing numbers of countries reported cases. By April it had developed a first Strategic Preparedness and Response Plan outlining recommended public health measures needed at national *scales* and practical measures to achieve these (see Figure 5.27). WHO estimates that US$ 1.74 billion was needed for its COVID-19 response in 2020. This included finance for providing equipment and crucial supplies such as medical oxygen, ventilators, diagnostic kits and personal protective equipment (PPE) to developing countries and assisting local health systems in low-capacity and humanitarian settings. WHO is also working to improve *sustainability* of oxygen supplies by working with partners to harness solar power to run oxygen concentrators in remote *places* where electricity supply is unreliable such as Somalia.

Each week WHO provided an epidemiological update of the global, *regional* and country-level COVID-19 cases and deaths, highlighting key data and trends as well as operational reports on WHO and partners' actions in response to the pandemic. In September 2020 it announced the roll out of a rapid diagnostic test program to assist 20 African low income countries. Results for the tests will take only 15–30 minutes, rather than days. The provision of 120 million of these tests at US$5 a piece will cost US$600 million.

In October 2020, the Director-General urged leaders to take immediate action in response to second waves of the virus to prevent further unnecessary deaths, essential health services from collapsing and schools shutting again. He advised five key actions: conduct an honest analysis of the situation based on latest data; make necessary adjustments in approach where cases are rising; be honest and clear with the public; put systems in place to make it easier for citizens to comply with the measures that are advised such as support mechanisms; and lastly to share stories of hope, resilience and creativity.

Selected national *scale* responses

The extent to which the WHO recommendations have been implemented and the approach taken by different countries has varied immensely. Governments face decisions involving trade-offs: balancing the economic impact of imposing restrictions on people and businesses versus the social costs of physical and mental health and political demands for individual freedom from regulation.

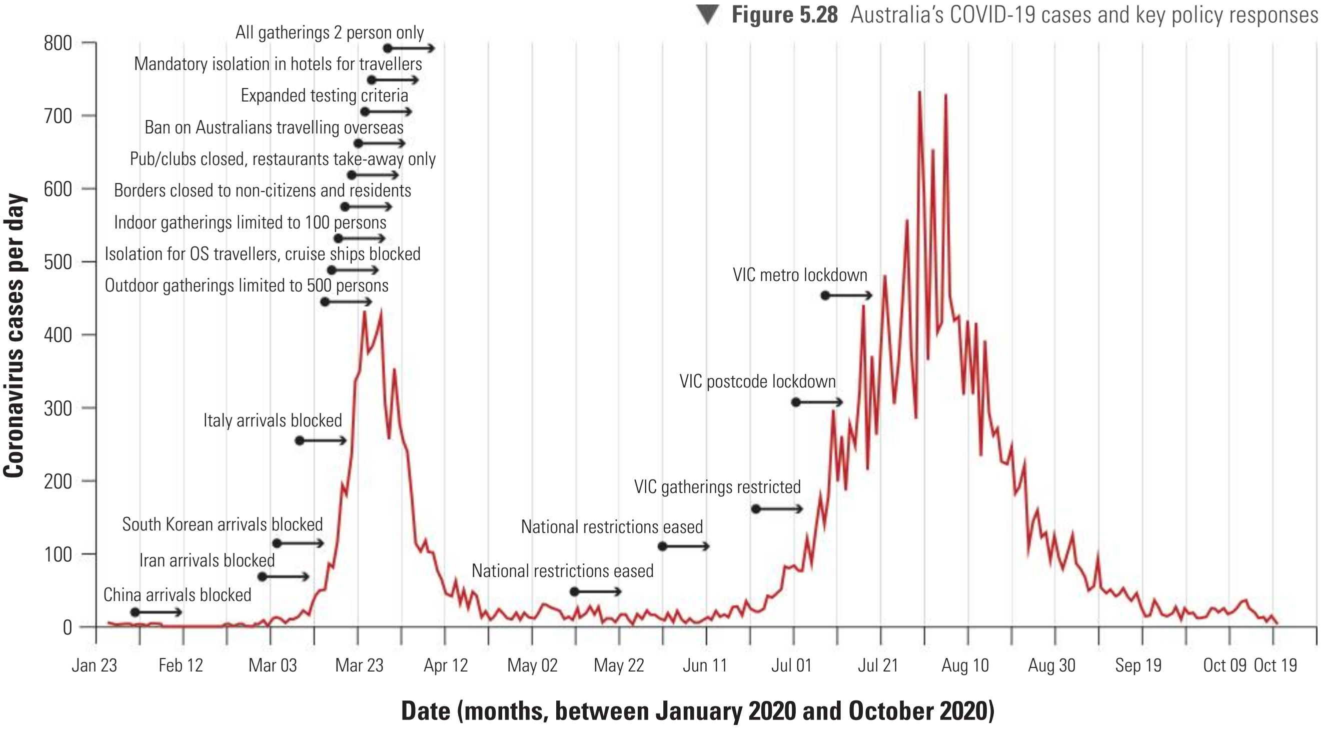
Although the source of the COVID-19 pandemic was in China the number of cases and deaths in that country has not been the highest, as Figures 5.21 and 5.22 show; the UK has a population 20 times smaller than China, yet it has seen five times as many cases of COVID-19 and almost ten times as many deaths. Having had the experience of past viruses such as SARS, China responded quickly. Wuhan was placed under a strict lockdown that lasted 76 days and public transport was suspended with similar measures put in place in other cities in the *region*. School re-openings after the winter vacation were delayed and population *movement* was limited in many cities so that only one member of each household was permitted to leave the home every couple of days to collect essential supplies. Across the country, 14,000 health checkpoints were established at public transport hubs. Within weeks, China tested 9 million people for COVID-19 in

Wuhan and it set up an effective national system of contact tracing. Manufacturing of personal protective equipment was increased and mask wearing was readily adopted. Drone surveillance was used to ensure citizens complied with rules. To reduce the risk of family members becoming infected. In February 2020, 16 special hospitals holding 13,000 beds were established in large public venues such as stadiums to isolate patients with mild to moderate symptoms (those with severe symptoms went to the usual hospitals). By March, these hospitals were no longer needed. Any people entering China were tested and quarantined. It is estimated that these measures may have prevented 1.4 million infections and 56,000 deaths.

Based on case numbers and deaths, the response of the USA has been much less effective. In March 2020, President Trump determined that the potential for widespread transmission of the coronavirus by infected individuals seeking to enter the USA was a threat to national security. *Movement* of foreign nationals who had been in China, Iran and certain European countries during the 14 days prior to arrival was banned. American citizens and permanent residents arriving from impacted areas had to travel through one of 13 airports with enhanced entry screening capabilities and then had to self-quarantine for 14 days after their arrival. To ease the economic burden for those struggling with lost wages due to the virus the Federal Emergency Management Agency (FEMA) was authorised to provide up to $44 billion from the Disaster Relief Fund for lost wage payments. Rather than a consistent national *scale* response in terms of implementing other measures to limit the spread of COVID-19, US states and cities were responsible for announcing curfews or other restrictions and safety measures. Consequently, some states such as New York and New Jersey implemented state-wide travel restrictions and California implemented a stay at home directive but more than half the states had no such regulations. By October, despite a continued surge in cases, face masks were required for the general public in 33 of the 52 states; 44 states had reopened restaurants to dine in service and only California had a ban on gatherings of more than 25 people. Due to concern about the economic impact of the virus, President Trump announced "Opening Up America Again" guidelines for the country's reopening in April 2020. Under this, states and *regions* must meet criteria relative to symptoms, cases, and hospital capacity before winding back restrictions, but this does not always appear to have been the case.

Figure 5.28 shows Australia's cases of COVID-19 and key policy responses January to October 2020. Australia recorded its first case on 25 January 2020, linked to travellers returning from Wuhan, China. Initially the Commonwealth Government took primary responsibility for managing the issue and focused on containment, screening arrivals and evacuating vulnerable citizens out of Hubei province to quarantine facilities in Australia. Australia quickly introduced restrictions on international population *movement*. Initially most cases were from returned travellers but Australia recorded its first case of community transmission in early March. This led to widespread spatial distancing measures, broader travel bans, testing, contact tracing, and quarantine. The main aim was to protect Australia's health system and prevent hospital intensive care units being overwhelmed by COVID-19 patients. Public health funding was increased by $1.1 billion, personal protective equipment was increased in supply and intensive care bed capacity was tripled in anticipation. The government also introduced economic support packages totalling $176 billion including the doubling of the JobSeeker payment and a JobKeeper wage subsidy. As most of the COVID-19 deaths were among older people the number of visitors to aged care facilities was restricted. To assist with contact tracing efforts, the Commonwealth Government launched its COVIDSafe app in April although the number of downloads fell short of the 10 million target. Though national restrictions eased in June, a second wave of infections, mainly in Victoria, led to another lockdown period in

Figure 5.28 Australia's COVID-19 cases and key policy responses



that state with significant restrictions on *movement*, online learning returning for students and the closure of the non-essential retail sector. To control the spread of the virus, many states and territories closed their interstate borders: for example in October 2020, Victorians could not travel interstate and Queensland was also closed to those from NSW (those *locations* being designated hot spots) and Western Australia was closed to everyone without an exemption certificate. Fortunately, such measures did much to bring the number of infections down significantly. 2021 saw Australia continuing to experience lockdowns and border closures when outbreak numbers started to rise.

Sweden, with a well-funded and staffed health system, adopted a less restrictive approach than many other European countries. In the first wave of the pandemic in that *region* in March 2020, Sweden did not 'lock down'. Combined with social distancing and hygiene measures, its goal was fewer contacts and protecting the vulnerable: universities and schools for students aged over 16 years switched to online learning; those aged over 70 years were urged to self-isolate; people were asked to work from home and gatherings of more than 50 were banned. However, child care, schools for younger students, shops, gyms, bars and restaurants remained open. The disease did spread rapidly in migrant communities before the ban on large public gatherings. Aged care homes were hit hard, accounting for more than half of Sweden's deaths. Its death rate per person was one of the highest in Europe: 578 COVID-19 deaths per million compared to neighbouring Denmark (112) although not as high as Belgium (875) or the UK (631). The country's chief epidemiologist estimates approximately 20 per cent of Swedes were infected, and therefore presumed immune, but this is not enough herd immunity to stop the virus. In response, Sweden resumed contact tracing and is asking people to quarantine for seven days if they live with an infected person. Its goal was to have measures in place that people can live with for at least a year before a vaccine is produced and to reduce transmission without unduly disrupting people's lives at the expense of mental and physical health.

Some local *scale* responses have included:

- To reduce COVID-19 transmission on crowded public transport, the city of Salvador in north-east Brazil is providing an extra day's holiday for every 15 days a person cycles to work.
- Residents of Kibera, a large slum in Nairobi, Kenya, created a network of 90 hand washing stations.
- Use of WhatsApp for ordering of food and household items from street vendors during times of restricted *movement* in Greater Jakarta.
- Community action to cheer neighbourhoods in lockdown in Victoria: Spoonville, poetry and fun artworks along bike paths (see Figure 5.29).

The Pause

Once grand things amused. But now a new bud flowering in my garden, two birds chattering to one another, the smell of clean wet hair - delight and reassure. My present world is infinitely less impressive and yet connects more deeply than before. Is this too what ageing brings? Grand things were never this inspiring.

Kylie McCormack

- Written in the Time of COVID-19 -

▲ **Figure 5.29** Some local *scale* responses to COVID-19: **(a)** Spoonville, **(b)** fun artworks and **(c)** poetry along bike paths

▶ ACTIVITIES

1. Refer to the text section about impacts of COVID-19. Classify each of these as positive or negative and short or long term.
2. Refer to Figure 5.26. For one of the countries shown, describe the *change* in case numbers over time.
3. Go to the Our World in Data website. Using the section on Daily new confirmed COVID-19 cases, select one other country. With reference to specific data, analyse the countries success in 'flattening the curve'.
4. View the 'Timeline: WHO's COVID-19 response' – an interactive timeline of global scale response by WHO.
   a. Provide some examples of key actions they took at differing times such as January–February; March–June; July–September.
   b. Suggest the strengths and weaknesses of these responses.
5. Undertake your own research to investigate a specific country's response to COVID-19. Evaluate how effective this has been.
6. What factors might account for the variation in the responses to the pandemic by different countries?
7. Conduct a class debate: "the rights of the individual outweigh those of the community" in relation to how this pandemic should be managed.
8. Discuss the extent to which the behaviour of public figures influences the effectiveness of responses to COVID-19.
9. Several vaccines were quickly developed in response to COVID-19. From December 2020, mass vaccination programs have become a major public health response. Outline some of the biggest challenges authorities have faced in immunising communities against the virus.
10. Suggest what long term impacts might arise from COVID-19 and the response to future pandemics.

How effective has the application of geospatial technologies been in managing disease hazards?

The use of geospatial technologies to map diseases has become extremely useful in understanding the bigger picture of public health. Use of Geographic Information Systems (GIS) has facilitated better understanding of the *distribution* and impact of diseases ranging from cholera to cancer. Epidemiologists use GIS to identify disease clusters. Use of different map layers can then show *interconnections* with various *environmental* characteristics and particular human interactions.

Use of geospatial technologies assists governments and agencies operating at local, national and global *scales* to optimise planning about where intervention should take place and to monitor their effectiveness. Such applications of GIS, in combination with other technologies such as Global Positioning Systems (GPS) and remote sensing, have been successfully employed in the monitoring and control of onchocerciasis (river blindness) in Guatemala, trypanosomiasis (sleeping sickness) in Africa, malaria in Israel and Mexico, as well as the global spread of dengue fever.

Geospatial technology was used extensively during the COVID-19 pandemic by a range of organisations including WHO, John Hopkins University and the Victorian Department of Health and Human Services (DHHS). GIS mapping and statistical data displays provided regularly updated – near real time – information for decision makers to enable them to respond more effectively. It also played an essential role for members of the public who could access this data to help keep them informed about this hazard which was impacting their lives. In the UK, the Alan Turing Institute mapped demographic characteristics such as health data and age in the city of Leeds and used this in conjunction with models of flows of *movement* to try to determine the probability of disease transmission given different scenarios in relation to restrictions on activity.

It should also be noted that *spatial associations* do not necessarily mean a causal relationship – further investigation would be needed to determine this. Likewise, to show how *changes* in one characteristic may impact the *distribution* of another feature, the relationship must be known and put into the model creating the map.

▶ ACTIVITIES

1. The European Centre for Disease Prevention and Control (ECDC) has a web-based GIS tool called ECDC Map Maker (EMMa) that supports production of disease maps. Although developed to support public health professionals worldwide, it is publically available upon free registration.
   a. Use this tool to map the *distribution* of a particular disease in a *region* or country of your choice.
   b. Describe the *distribution* pattern shown.
   c. Suggest what additional information could be provided to enhance your understanding of this disease and its management.

Invasive alien species in Australia

Overview

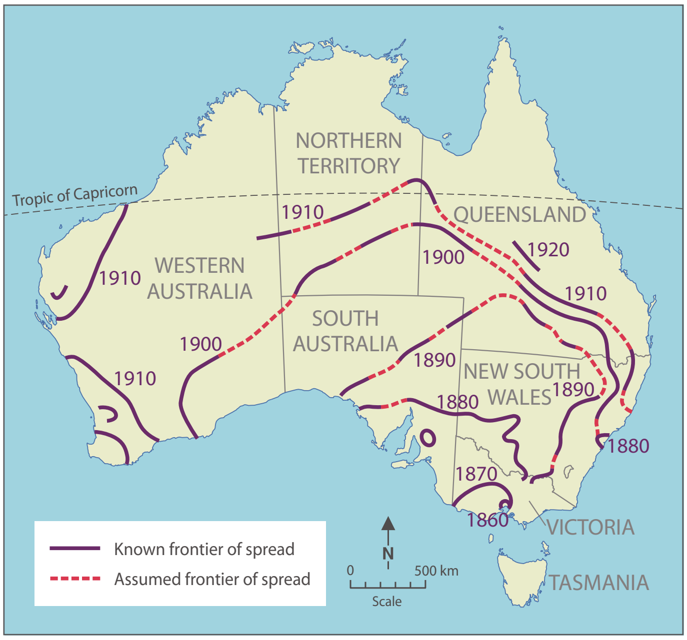
Invasive alien species (also known as invasive species) are animals or plants whose spread beyond their natural *distribution* is a threat to valued *environmental*, agricultural or other social resources due to the damage they cause. These hazards therefore threaten the ability of some *environments* to *sustain* themselves. The *movement* of these introduced species is usually due to human activity – either via deliberate or accidental *processes*. If the new *environment* is similar to its native habitat it may thrive and spread in sufficient density to harm native species. Usually such species have the ability to reproduce and grow quickly, and can adapt to new conditions allowing them to successfully disperse. Often there may not be any natural predators or competition in the new *environment* which may keep the *scale* of *distribution* in check in their source *environment*.

According to the Australian Bureau of Statistics (ABS), since European arrival in Australia in 1770 more than 2000 plants, 25 mammals, 20 birds, four reptiles, one amphibian, as well as 23 freshwater fish, several hundred marine species and an unknown number of invertebrates have been introduced to our continent. Over time, species also arrived in Australia via natural *processes* from elsewhere in the world; for example, by birds flying or seeds carried by ocean currents or the wind. In addition, non-European people played a role in the *process* of introducing species. The dingo was probably brought here from what is now Indonesia by people some 4000 years ago. However, prior to European colonisation, *movement* of alien species into Australia occurred at a much smaller time *scale* – an estimated rate of one or two species per millennium.

Many invasive species were introduced deliberately. In the early days of colonisation, animals such as pigs, sheep and cattle were brought as food supply, and some of these were released or escaped into the wild. Others were introduced to be hunted for sport: foxes were released in 1855 and, in 1859, 24 rabbits were released at Winchelsea near Geelong. Both of these animals have *changed* Australia's *environment* significantly (refer to Figures 5.30 and 5.31). Other plants and animals were introduced by acclimatisation societies with the aims of making Australia's unfamiliar *environment* feel like home, to beautify gardens and to make the land more economically productive. Many species which we consider hazards or pests today were introduced in the mid-19th Century: sparrows, starlings, carp, blackberries, para grass, camels and deer, to name a few. The agricultural industry continues to introduce foreign grasses and legumes in an attempt to make grazing lands more profitable, but a government-mandated risk assessment *process* now has to be completed prior to this occurring. And some domestic species such as pets have become wild and widely *distributed*, with feral cats among the worst threat to Australian wildlife.

Other invasive species have arrived in or spread throughout Australia accidentally. Garden plants, for example the rubber vine from Madagascar, comprise many of the worst weeds in some national parks.

▲ **Figure 5.30** Rabbits have created a hazard for the owners of this farmland



▲ **Figure 5.31** The *changing distribution* of rabbits in Australia

▲ **Figure 5.32** A large predator, the Northern Pacific sea star has been a disaster for marine life in the waters of Victoria and Tasmania. Its consumption of shellfish has affected marine ecosystems as well as commercial shellfish operations. It was first found in Tasmania in 1986 and Victoria in 1995

Aquarium fish, plants and snails have entered our waterways, sometimes after owners have dumped them, or when ponds overflowed. *Movement* of products into Australia from other *regions* may mean that insects, spiders and reptiles arrive in crates and the release of water used as ballast in bulk carrier ships has spread marine species such as the Northern Pacific sea star (see Figure 5.32). International *movement* of people can also lead to the spread of alien invasive species. Travellers may unknowingly bring in foreign seeds on clothing or illegally bring in plant and animal material from overseas.

Australia has significant biosecurity measures in place to help protect Australia's natural and human *environments* from alien invasive species. This includes quarantine and border protection measures in regard to food, plant material and animal products, risk assessments of potential threats and research on the impact of existing pests. Invasive species are the second greatest threat to biodiversity after habitat clearing. The CSIRO estimates that animal and plant hazards cost Australia at least A$7 billion per year and that 25 per cent of costs to consumers associated with food products are due to invasive weeds, pests and diseases. Effective management of the alien invasive species hazard is therefore vital in terms of economic and *environmental sustainability* (refer to Figure 5.33 showing the Victorian government management model).

▶ ACTIVITIES

1. a. Refer to Figure 5.31. Describe the *changing distribution* of rabbits over time.

   b. With reference to atlas maps showing Australia's physical features, evaluate the *interconnection* between specific characteristics of the natural *environment* and the *movement* of rabbits across the continent.

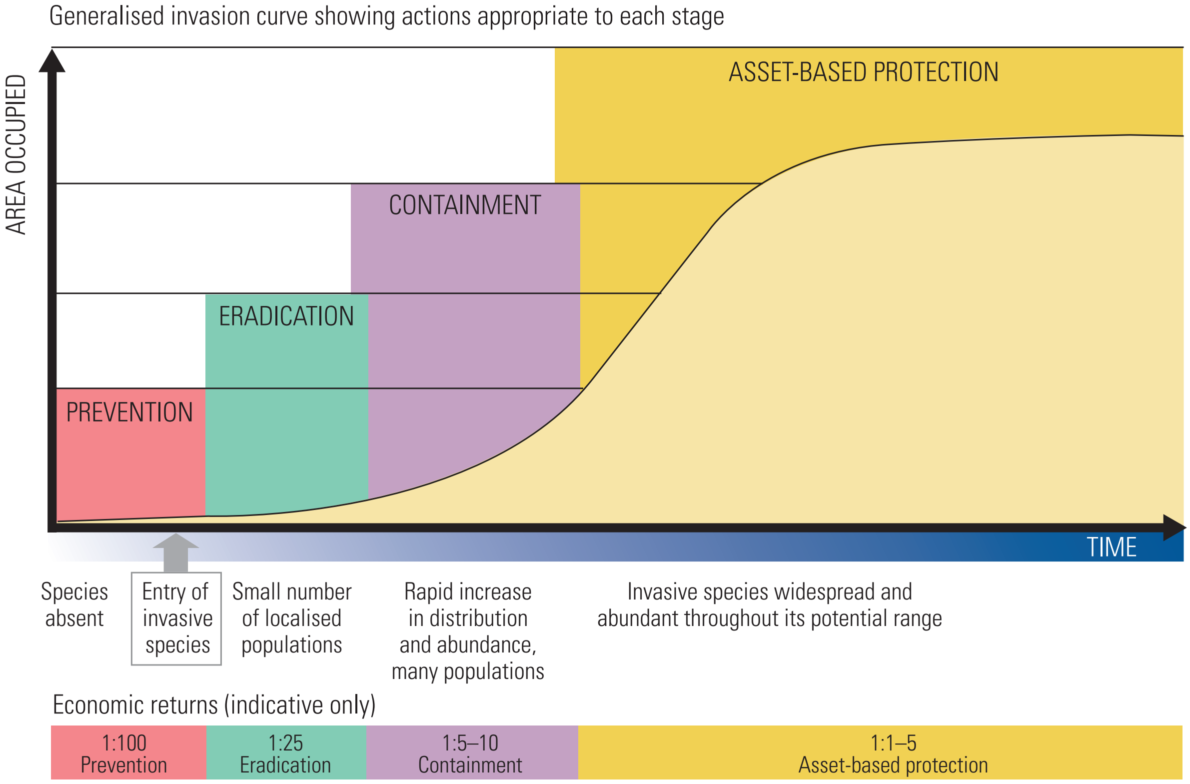
2. Use the internet to undertake research on one invasive alien species in Australia. Include information on:

   - how and when it was introduced;
   - a map of its current *distribution* and how this has *changed* over time;
   - the factors responsible for its spread; and
   - how this hazard is being managed.

3. Refer to Figure 5.33.

   a. Outline the characteristics of each of the four stages of action followed by the Victorian Government in its hazard management of invasive species.

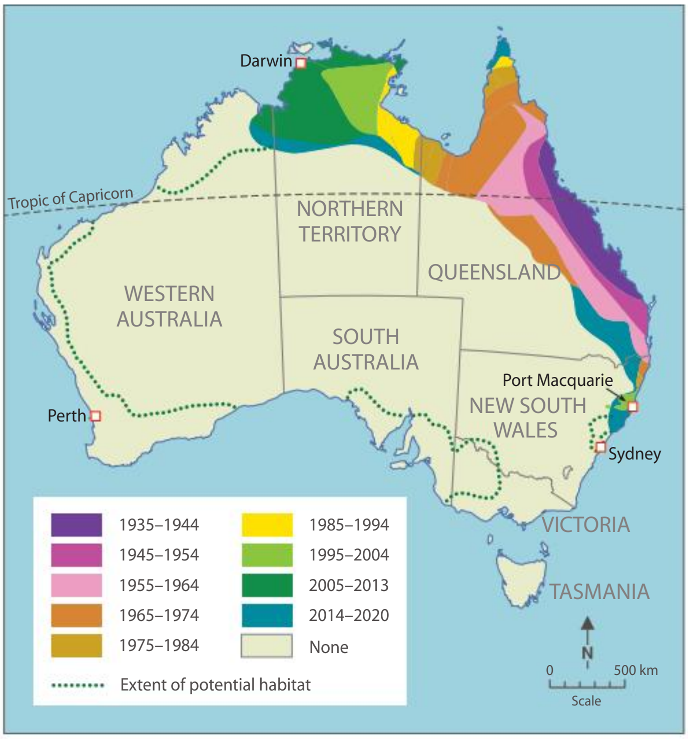
   b. Which stage do you consider to be most practical? Justify your answer.



▲ **Figure 5.33** The Victorian Government manages the hazard of invasive plants and animals by firstly assessing the risk of each species entering and becoming established, then acting appropriately to manage those risks. The four key types of action are shown in the graph. It is clear that prevention is much more economically viable than intervention at the later stages

National-*scale* hazard case study: the cane toad

The cane toad (*Bufo marinus*) is a large toad native to South and Central America but it is also considered a hazard for Australia's native animals. In 1935, 102 cane toads were transported to Australia from Hawaii (where they had previously been introduced) to control the larvae of the greyback cane beetle, a pest which was threatening the sugarcane industry. By March 1937, 62,000 toadlets had been released from Gordonvale, Cairns and Innisfail in northern Queensland. There are now more than 1.5 billion cane toads in Australia. After the toads were released they expanded their territory at a *distance* of about 10 kilometres per year in the first few decades. This rate has gradually increased to a *distance* of between 40 and 60 kilometres per year. Figure 5.34 shows the *changing distribution* of the cane toad. They reached the Northern Territory in 1984. By 2010 cane toads had advanced as far west as Kununurra, in the Kimberley *region* of Western Australia – a *distance* of over 2400 kilometres from their release site. They are also found on offshore islands such as Adolphus Island, north of Wyndham in Western Australia. Their range continues to expand, and computer modelling indicates that they could spread over most coastal areas of the continent.

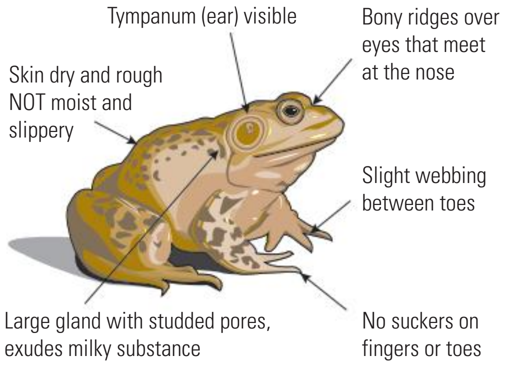


▲ **Figure 5.34** Current and predicted *distribution* of the cane toad (*Bufo marinus*)

Issues and challenges – is the cane toad a disaster?

There is little evidence to show that the cane toad had a positive impact on the eradication of the cane beetle – the original reason the species was introduced to Australia. Many Australians perceive cane toads as the worst of the invasive species in our country due to their numbers and spread.

Much of the concern expressed about the cane toad has been about the impact on Australia's wildlife. Large predators such as goannas, crocodiles, snakes and quolls are killed by ingesting the cane toad toxin when they try to eat them. As shown in Figure 5.35, cane toads have poisonous glands located behind their head. All toad life-stages are dangerous, so native tadpoles are also killed when they try to eat toad eggs, affecting the native frog populations. However, it has also been claimed that more native frogs survive as they are not being eaten by their natural predators. Research has found that species such as the yellow-spotted goanna learn to avoid toads as food. In addition, a few native species benefit; local hawks scavenging dead toads off the roads and many native rodents and keelback snakes can eat cane toads without becoming ill.



▲ **Figure 5.35** Characteristics of the cane toad

Cane toads compete with native species for food and they carry diseases which can spread to native frogs. Toads eat beneficial insects such as dung beetles and pose an economic threat to beekeepers. In addition, domestic pets such as small dogs and cats may also be poisoned by cane toads. The cane toad toxin particularly causes pain and temporary blindness if it comes in contact with the eyes.

Cane toads do have some positive uses. In South America, cane toad toxins were traditionally used to make poison for arrow tips. The toxin has also been used as part of traditional medicine in China and Japan, for instance as a hair restorer and an aphrodisiac. In Australia, cane toad carcasses have been used to make liquid fertiliser, and their skins made into souvenir and novelty items. It has also been suggested that cane toads could form the basis of a gastronomic delight – as a 'healthy food source' (see Figure 5.36). This has yet to gain popularity.

What factors account for the development of this hazard?

Cane toads are extremely successful breeders. Depending on conditions, one female can lay up to 30,000 eggs twice per year. They normally lay eggs in slow-*moving* freshwater streams or dams but they can also use brackish water and temporary pools and puddles. The eggs hatch within 48–72 hours and reach sexual maturity in 12–18 months. This *scale* of breeding over an average lifespan of five years in the wild has enabled them to quickly disperse.

Studies of cane toads undertaken by the University of Sydney have shown that they have the ability to adapt to new *environments*. They have become more resilient

▼ **Figure 5.36** Scientists are continually looking for new ways to reduce cane toad numbers

Innovative ways to deal with cane toads

Scientists and researchers are discovering innovative ways to deal with the cane toad issue.

At Sydney University, researchers have found that baby cane toads are susceptible to predation by native meat ants. They used canned cat food to attract meat ants to locations where cane toads were starting to emerge from breeding ponds. Their results showed that 98 per cent of the baby toads were attacked by the ants using this method.

Other scientists have had success using the cane toads own highly toxic poison to attract and trap cane toad tadpoles whilst repelling native tadpoles, fish and insects.

And finally, some scientists are suggesting that cane toads can be prepared and cooked for human consumption – for example, in a stir fry. Research into removing the poisonous glands could make the toads safe for human consumption.

to cope with cool dry temperatures; for instance, Renner Springs Desert Inn located on the Stuart Highway in the Northern Territory was previously thought to be too far south but is now home to toads. Researchers have also found that the strongest, fastest toads form the invasion front, developing longer legs which facilitate *movement*. Although cane toads mostly eat insects, they will eat a wide variety of food – basically whatever will fit in their mouths – including spiders, frogs, snails, reptiles, mammals and each other.

Human activities have assisted the cane toad's successful invasion. People's gardens provide water sources and breeding sites; pet food left at the back door is a food source; and street lights attract insects to enable an easy, tasty meal. Cane toads are also good stowaways. They can squeeze into small spaces during the day and may end up in material and equipment that is being transported, such as woodchips and landscaping materials from northern New South Wales or fruit from southern Queensland. It is anticipated that the increased *scale* of *movement* of trucks associated with the mining boom in Western Australia facilitated the further *distribution* of cane toads in that state. Cane toads have been found in Sydney: one shipping container from Fiji reportedly contained several live toads indicating that toads can travel across international *regions*.

What responses have been used in the attempted management of cane toads?

The following have been tried or suggested:

- Finding a biological control such as a disease or parasite – the CSIRO conducted extensive research into this in the 1990s and concluded that there were no readily available infectious agents that would control toads and not impact on Australian wildlife. However, a 2018 study from a group of Australian and international universities have found three viruses in the toad's DNA which could potentially be converted into a bioweapon to cull toads. Work on this is ongoing.

Karen Borton

Environmental Works Officer, Nillumbik Shire Council

CAREER PROFILE

I studied Year 11 Geography and would have studied it in Year 12 if my school had offered it. At university I studied Forest Science and, as part of this course, I completed a number of GIS (Geographic Information System) subjects. Other Geography-related subjects included Landscape Ecology, Processes in Forest Ecosystems and Park Management, as well as a number of other subjects where science and geography overlapped.

As an Environmental Works Officer I manage conservation reserves. In this role I plan for weed control works and rabbit control, then supervise contractors or volunteers to undertake the work. My role also involves monitoring using GIS, and applying for grants.

I spend a significant amount of my time at work mapping – some as desktop work and at other times using a tablet or GPS unit in the field. Mapping and monitoring are the most important tasks as they can show change over time, which helps us report on grants as well as justify applications for new grants. I also need to be aware of processes and changes in the landscape as part of the planning process, as well as be aware of weather patterns which will affect planting and weed growth.

I work in a team of six people who all have skills in Geography. There are a lot of jobs in land management and many are highly sought after. In this field it is helpful to have a broad range of skills, and it is good to have Geography (especially GIS skills) as part of the mix.

- Physical removal of toads via hand collecting or traps – groups such as the Kimberley Toad Busters have collected and disposed of over 3.4 million toads since 2004 with limited results.
- Toad traps – these have been largely ineffective and have caught native animals such as bandicoots and lizards.
- A proposal to release sterile males so that eggs laid by females would be infertile – to be effective, large numbers would be needed over huge areas.
- Predator taste aversion – this aims to deter native predators from eating cane toads. By dropping cane toad sausages and small cane toads into vital habitats ahead of the cane toad front, native predators are exposed to a small amount of toxin that makes them sick but does not kill them. When they later see and smell a larger adult toad, they will know to avoid it. Trials in the Kimberley *region* 2018–2021 have shown success with quolls, goannas and bluetongue lizards.
- The use of pheromone-baited traps and suppression chemicals to attract toad tadpoles which are then collected and killed. In Queensland tadpole traps have already removed more than a million poisonous tadpoles from local waterways. In 2020 the Federal Government approved funding for this as part of the $22 million Communities Environment Program.

Concerns about the impact of cane toads led to the establishment of a Parliamentary Inquiry in 2018 into the effectiveness of control measures to limit the spread of cane toads in Australia and what additional support for these measures were needed. The subsequent 2019 report made nine recommendations, five of which were agreed to in May 2020 by the Federal Government, including the research aspects and tadpole trapping mentioned above.

Responses also include educating the public so that native frogs are not mistakenly killed and ensuring freight companies are vigilant to prevent more rapid *distribution*. It is likely that cane toads will continue to pose a biological hazard for Australia in the foreseeable future.

▼ **Figure 5.37** Cane toad trivia

Cane toads can live up to 35 years in captivity.

In 2008, a cane toad named Spew survived for 40 minutes in a dog's stomach after being swallowed. Dog and toad were unharmed.

The largest toad ever confirmed weighed 840 grams. It was named Toadzilla.

It has been estimated that more than 200 tonnes of cane toad flesh is squelched on Queensland roads each year.

Toad venom is so potent that it can kill a three-metre crocodile.

How is geospatial technology being used to manage invasive alien species?

GIS is being used extensively to map plant and animal pests. For example, Biosecurity Queensland produces a comprehensive series of pest *distribution* maps that show where over 100 weeds and pest animal species occur in Queensland. This publically accessible data base shows the *distribution* of the pest and provides information on the species, together with an image. It also indicates if this plant or animal is notifiable so that people know to report this to the relevant authority for eradication. According to Biosecurity Queensland, knowing the location of weeds and pest animals is integral to effective pest management. Annual *distribution* maps are produced to aid specific research or project work. Predictive maps are also created from pest modelling programs to help with early detection programs, to assist in prevention activities and for resource planning into the future.

As you have read in this chapter, invasive species have significant economic, *environmental* and social impacts. Use of GIS data is one of a range of measures used by Biosecurity Queensland, working with local governments, communities and other stakeholders, to help reduce these impacts.

▶ ACTIVITIES

1. a. Refer to Figure 5.34. Describe how the *distribution* of cane toads has *changed* over time.

b. With reference to atlas maps showing Australia's physical features, note the specific characteristics of the natural *environment* that have a *spatial association* with cane toads.

2. Classify the impacts of cane toads as to whether they are positive or negative on people or the *environment*.

3. Visit the Cane Toad Coalition website. Evaluate the effectiveness of their current work using Conditioned Taste Aversion in the Kimberley *region* in limiting the impact of the cane toad.

4. Access the Biosecurity Queensland website (part of the Queensland Government, Department of Agriculture and Fisheries) and search for 'pest mapping'.

a. Compare the *distribution* of any two plant or animal pests at either a state level or a local *scale*.

b. To what extent is there a *spatial association* between the *distributions* of each of your selected pests?

c. Suggest what factors might be responsible for the *distribution* of your selected pests.

d. Evaluate the effectiveness of this geospatial technology tool in assisting your understanding of this issue.

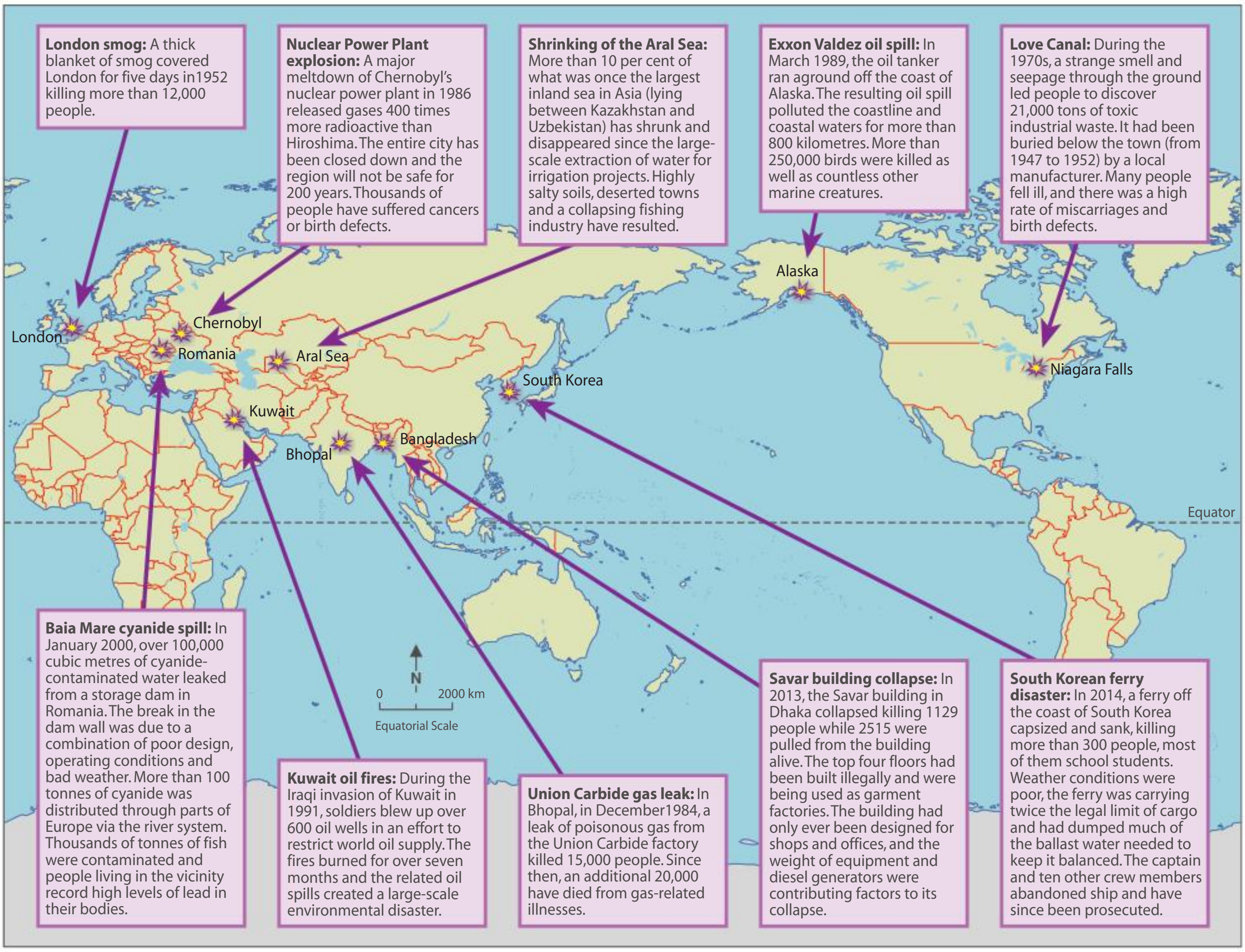
6 Technological hazards and disasters

What is a technological hazard?

A technological hazard is an anthropogenic hazard caused by human action, inaction, error or negligence. These hazards can be classified according to the type of technology at their source, as seen in Figure 6.1. Similar to natural hazards, technological hazards can result in a huge loss of life, damage to property and infrastructure, and deterioration in human wellbeing. The duration, as well as the impact, of technological hazards and hazard events vary considerably – for example, the shipwreck of an oil tanker can cause immediate *environmental* impacts and this harm may last for years. Other events may take decades to develop into a hazard or to be recognised and managed; for example, the disposal of persistent toxic waste. A technological hazard has the potential to develop into a disaster depending on the location, *scale* and nature of the hazard event.

▼ **Figure 6.1** Classification of technological hazards

Type of technological hazard	Examples of technological hazards
Industrial	These are usually related to a large-*scale* commercial business and often have *environmental* and health impacts such as oil spills and mining disasters. In August of 2020, two large explosions in a warehouse in the port of Beirut, Lebanon caused damage to at least 50 per cent of the city. Over 135 people died and 5000 people were injured. The blast, the equivalent of a 3.3 magnitude earthquake was due to poorly stored and highly explosive ammonium nitrate (a component of fertilizer and explosives).
Engineering	Poor design or construction can lead to the collapse of buildings, bridges and dams. One of the largest concrete bridges in the world, the Morandi Bridge in Genoa, Italy, collapsed in 2018 killing 43 people and leaving 600 homeless. Air pollution from nearby factories and salty sea air was responsible for corrosion of the steel cables buried within the concrete structure. Negligent maintenance and increased traffic over the year were reported as likely contributors to the collapse.
Transportation	There are many hazards associated with transportation, ranging in both *scale* and impact. Examples include transport accidents and oil spills. A Japanese ship ran aground on a coral reef off the coast of Mauritius in July 2020, spilling 4000 tonnes of oil into the reef *environment* as the ship broke up.
Energy production	The largest technological disasters have been related to energy production, particularly nuclear energy, with examples being Chernobyl and Fukushima. In May 2020, a diesel fuel tank at a power plant in northern Russia ruptured and leaked 21,000 tonnes of fuel into the surrounding subsoil and pristine waters of the Ambarnaya River and Lake Pyesino. An unusually hot summer, linked to climate *change*, thawed the permafrost (frozen soils) beneath the tank causing the rupture.



London smog: A thick blanket of smog covered London for five days in1952 killing more than 12,000 people.

Nuclear Power Plant explosion: A major meltdown of Chernobyl's nuclear power plant in 1986 released gases 400 times more radioactive than Hiroshima. The entire city has been closed down and the region will not be safe for 200 years. Thousands of people have suffered cancers or birth defects.

Shrinking of the Aral Sea: More than 10 per cent of what was once the largest inland sea in Asia (lying between Kazakhstan and Uzbekistan) has shrunk and disappeared since the large-scale extraction of water for irrigation projects. Highly salty soils, deserted towns and a collapsing fishing industry have resulted.

Exxon Valdez oil spill: In March 1989, the oil tanker ran aground off the coast of Alaska. The resulting oil spill polluted the coastline and coastal waters for more than 800 kilometres. More than 250,000 birds were killed as well as countless other marine creatures.

Love Canal: During the 1970s, a strange smell and seepage through the ground led people to discover 21,000 tons of toxic industrial waste. It had been buried below the town (from 1947 to 1952) by a local manufacturer. Many people fell ill, and there was a high rate of miscarriages and birth defects.

Baia Mare cyanide spill: In January 2000, over 100,000 cubic metres of cyanide-contaminated water leaked from a storage dam in Romania. The break in the dam wall was due to a combination of poor design, operating conditions and bad weather. More than 100 tonnes of cyanide was distributed through parts of Europe via the river system. Thousands of tonnes of fish were contaminated and people living in the vicinity record high levels of lead in their bodies.

Kuwait oil fires: During the Iraqi invasion of Kuwait in 1991, soldiers blew up over 600 oil wells in an effort to restrict world oil supply. The fires burned for over seven months and the related oil spills created a large-scale environmental disaster.

Union Carbide gas leak: In Bhopal, in December1984, a leak of poisonous gas from the Union Carbide factory killed 15,000 people. Since then, an additional 20,000 have died from gas-related illnesses.

Savar building collapse: In 2013, the Savar building in Dhaka collapsed killing 1129 people while 2515 were pulled from the building alive. The top four floors had been built illegally and were being used as garment factories. The building had only ever been designed for shops and offices, and the weight of equipment and diesel generators were contributing factors to its collapse.

South Korean ferry disaster: In 2014, a ferry off the coast of South Korea capsized and sank, killing more than 300 people, most of them school students. Weather conditions were poor, the ferry was carrying twice the legal limit of cargo and had dumped much of the ballast water needed to keep it balanced. The captain and ten other crew members abandoned ship and have since been prosecuted.

▲ **Figure 6.2** Global *distribution* of selected major technological disasters over time

The development of technology over the past 200 years has been particularly rapid and has seen an increase in the number of new inventions and hazardous substances. There has also been an increase in the frequency and *scale* of technological hazards as more and more people use the technology or are exposed to their impacts. In 2019 there were a total of 292 major disasters in the world, 99 of these were caused by human actions and technology. Figure 6.2 shows examples of the range of technological disasters that have occurred in the past century. Climate *change*, population growth, economic development and poverty can all act as contributing factors to an increase in the number and severity of technological hazards.

▶ ACTIVITIES

1. Conduct a survey, possibly with parents and/or grandparents, asking participants what they believe have been the ten most important technological advances in the past fifty years. Find out why these have been important and the impacts they have had on their lives. Indicate which of these advances produce hazards, and at what risk (i.e. high, medium or low) that a hazard event that harms people might occur.
2. Construct a table of the disasters shown in Figure 6.2 and classify them according to the type of technological hazard using Figure 6.1 as a guide.
3. Select one of the examples from Figures 6.1 and 6.2 to conduct further research. Produce a brief report that includes the following:
   - location / *distribution* map
   - type and description of disaster
   - the economic, political, *environmental* and social factors contributing to the disaster
   - the scope of impacts (consider economic, political, *environmental* as well as social)
   - responses; how was the disaster dealt with.

Why is air pollution a technological hazard?

Often invisible, and sometimes smelly, air pollution is considered to be the world's worst *environmental* health hazard. Most *places* on Earth, even including remote *regions* such as Antarctica, have felt the impacts of polluted air. The release of gases, dust or smoke into the air in harmful quantities, as seen in Figure 6.3, has the potential to become a threat to people and *environments*. The United Nations estimated the number of deaths worldwide attributed to air pollution to be 6.7 million annually. There is a strong negative (or inverse) *spatial association* between the *distribution* of income and pollution related deaths (see Figures 6.6 and 6.7). An estimated 90 per cent of air-pollution related deaths occur in low and middle-income countries, predominantly in Sub-Saharan Africa and Asia, largely because of a high incidence of polluting industries combined with less effective government regulations. Air pollution is also responsible for shortening people's life expectancy on a far greater *scale* than conflicts, smoking or diseases such as malaria.

As a technological hazard, air pollution is a result or by-product of industrial, engineering and transportation activities and energy production. Air pollution can occur naturally, such as gases released from a volcanic eruption, smoke from a bushfire or dust from a sandstorm. However, human activities generate significantly more air pollution.

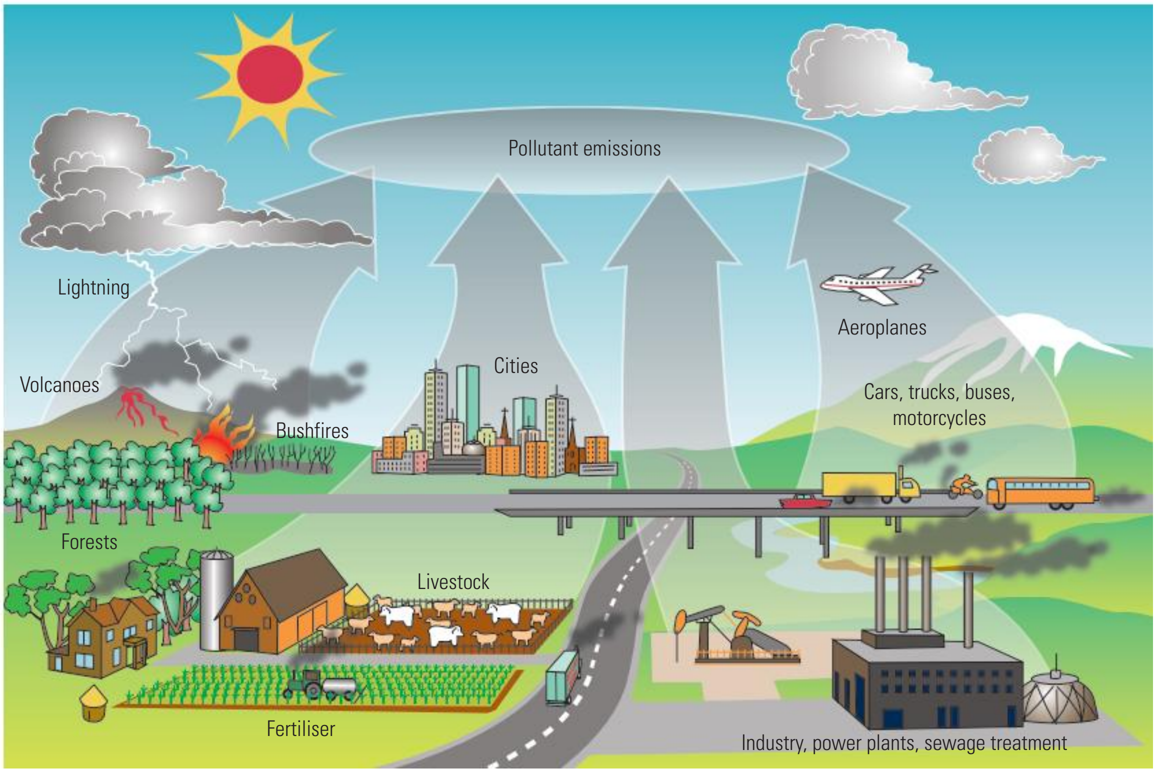
Before the Industrial Revolution approximately two centuries ago, atmospheric emissions were largely kept in check by the Earth's natural systems. Winds blew away gases and smoke, while rain cleaned the air of dust and particles. Plants absorbed carbon dioxide and released oxygen back into the air. These natural *processes* continue, but since the Industrial Revolution, increases in population and *changes* in technology have resulted in an excess of pollutants emitted to the atmosphere. Often, it is not until there is a dangerous build-up of pollutants that a hazard becomes evident, and the link between cause and impact can be identified.

What are the different types and sources of air pollution?

Some particles released into the atmosphere react with other atmospheric compounds and form aerosols (a suspension of small particles or liquid droplets in air).

▼ **Figure 6.3** Air pollution being generated from **(a)** industry, **(b)** transport and **(c)** power production

▶ **Figure 6.4** The different sources of outdoor air pollution

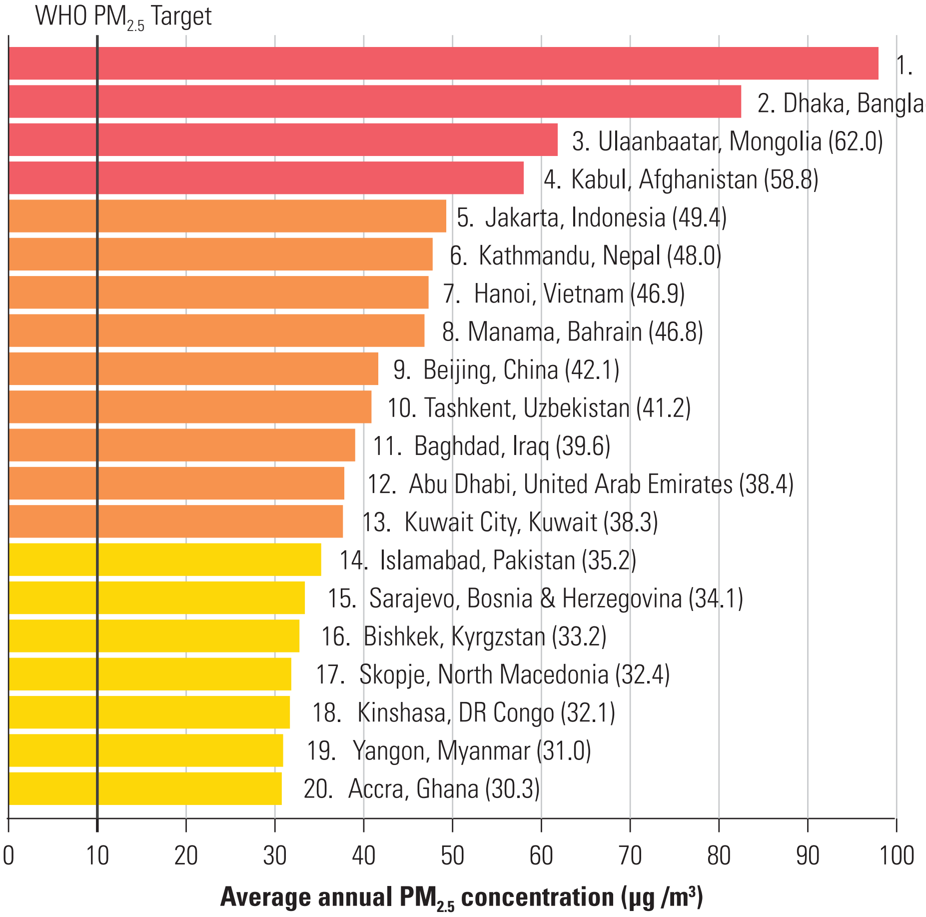


Naturally occurring aerosol examples are fog, mist, dust, salt, pollen and volcanic ash; while examples of aerosols originating from human activity are smoke, smog, haze and pollutants. Many pollutants are capable of remaining suspended in the atmosphere for long periods of time and can travel long *distances* before being deposited by wind or rain. This *process* introduces unwanted and potentially harmful chemicals into the *environment*.

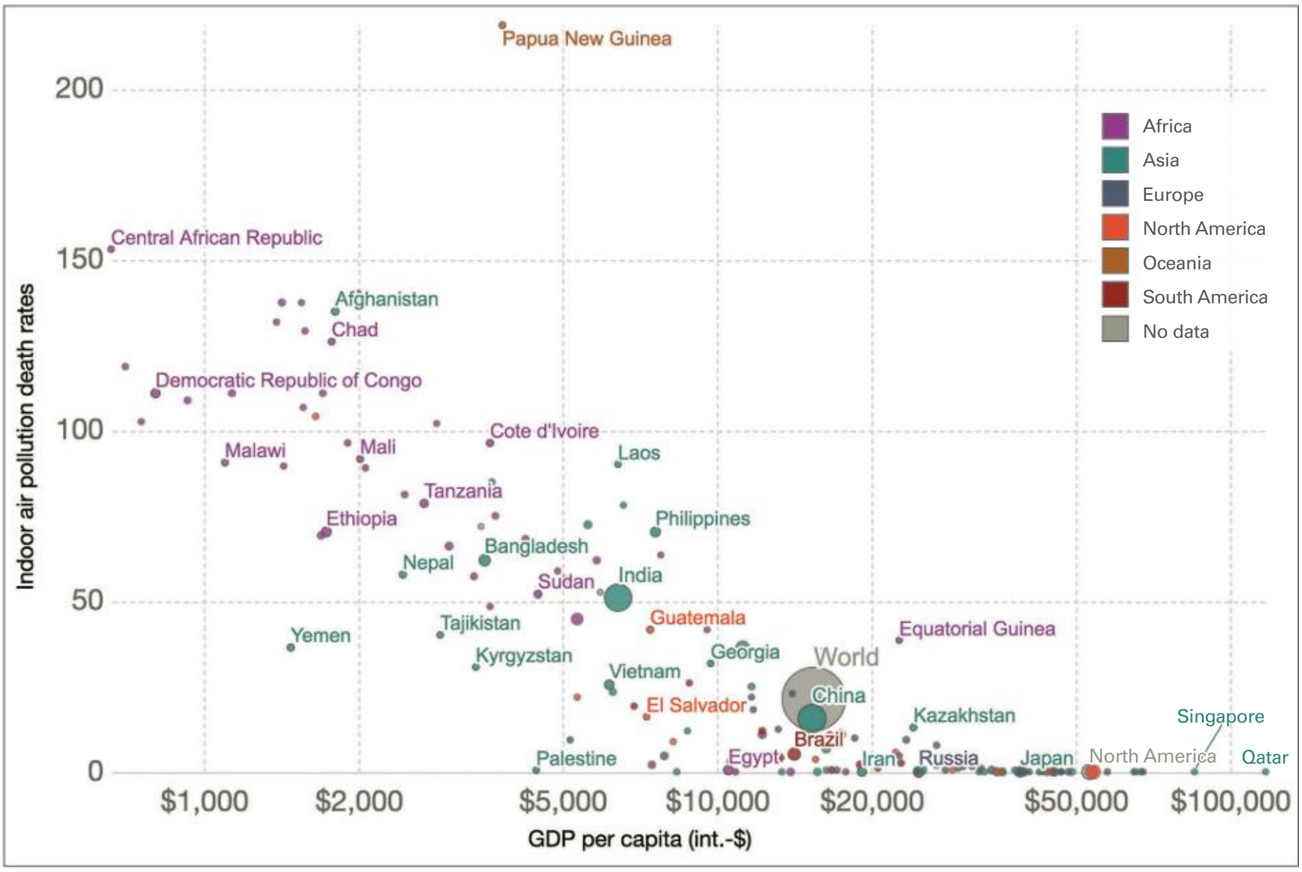
Figure 6.4 shows that pollutants that are emitted to the air come from a range of sources. The burning of fossil fuels *interconnects* air pollution with climate *change*. Figure 6.5 outlines the four main pollutants and their impacts. Other common pollutants include primary pollutants such as methane, carbon dioxide and carbon monoxide, and secondary pollutants such as acid rain formed in the atmosphere when acidic emissions of sulphur or nitrogen oxides mix with water droplets to form rain.

▼ **Figure 6.5** The main pollutants, sources and impacts

Pollutant	**Source**	**Impact**
Nitrogen dioxide (NO_2)	A noxious gas released primarily through the burning of petrol, diesel and coal from transport, power plants and industry. In the lower atmosphere NO_2 can convert to ozone that produces haze, while in the higher atmosphere it creates acid rain.	Breathing in high levels can cause damage to the human respiratory system, increasing risk of infections and asthma. High levels are also harmful to vegetation, damaging foliage and reducing crop yields.
Ozone (O_3)	Occurs when pollutants emitted by cars, power plants and refineries chemically react with sunlight. There is an *interconnection* between ozone and $PM_{2.5}$ as particulates in the atmosphere help to actually reduce ozone levels.	Breathing ozone can develop into a range of health issues such as chest pain, coughing and can reduce lung function.
Sulphur dioxide (SO_2)	A common air pollutant created from the burning of products high in sulphur, for example from: coal fired power stations, diesel fuelled vehicles, oil refineries and shipping (it can also be naturally emitted from volcanic eruptions). SO_2 is also a component of smog.	Breathing SO_2 can irritate the eyes, nose, throat and lung tissue. People who suffer from asthma and bronchitis are particularly affected. In the *environment* it harms vegetation especially during the growing season.
Particulates ($PM_{2.5}$)	The main sources are the burning of fossil fuels, agricultural fires and wind-blown dust. Presenting as fine particles, less than 2.5 microns in diameter (human hair is 50–70 microns). The World Health Organization (WHO) considers a safe level of $PM_{2.5}$ to be less than 10 micrograms per cubic metre of air (10µg/m³). The global *distribution* of $PM_{2.5}$ varies considerably as can be seen in Figure 6.6.	Fine particles can penetrate deep into lung tissue and blood affecting lung function and can worsen illnesses such as asthma and heart disease. Can shorten life expectancy and cause death. Children, the elderly and people with breathing or heart issues are vulnerable to $PM_{2.5}$.



◀ **Figure 6.6** The 20 most polluted cities in the world 2019



▼ **Figure 6.7** The correlation between death rates from indoor pollution and Gross Domestic Product (GDP) 2017

Equally important as outdoor pollution, pollution that originates within the confined spaces of homes is a serious hazard. More than three billion people, 40 per cent of the world's population, use solid biomass fuels (dried plant and animal matter) for cooking and home heating as they are the cheapest and most widely available fuel. Poorly designed stoves or open fires in confined small spaces produce soot, smoke and ash, all of which are dangerous to a person's health. More than four million deaths per year are directly linked to cooking smoke. It is largely women, children and the elderly who spend the most time exposed to indoor pollution. An hour of breathing in the smoke is said to be the equivalent of smoking 400 cigarettes.

▲ **Figure 6.8** A brown haze hangs over Delhi, India, which has recorded $PM_{2.5}$ levels of up to 153µg/m³

Indoor pollutants can also come from the fumes of paints and plastics as well as fibres from asbestos, a building material that is a significant health hazard. *Environmentally*, the practice of deforestation for fuelwood contributes to declining vegetation cover and land degradation in many *places* around the world.

While the use of solid fuels is declining across the world, there are many *regions* where the dependence is high, such as Sub-Saharan Africa where 890 million people cook with traditional fuels. There exists a strong *interconnection,* as seen in Figure 6.7, between death rates from indoor air pollution and low GDP per capita.

What are the impacts of air pollution on people?

The impacts of air pollution on people relate mainly to health issues (see Figure 6.5). Exposure to some pollutants can create irritation to eyes, throat, nose and skin. Illnesses include pneumonia, asthma attacks, headaches and dizziness. Annually, more than seven million people across the globe die prematurely from exposure to outdoor air pollution. Indoor air pollution adds another 1.6 million early deaths. Inhaling microscopic particles deep into the lungs can cause heart attacks and strokes, responsible for two thirds of pollution-caused deaths annually. The remaining one-third of deaths is due to lung cancer and respiratory diseases. The young, the elderly and those susceptible to heart and lung conditions are the most vulnerable to exposure to pollutants. Over 600,000 children under five years die each year from respiratory infections, such as pneumonia, attributable to air pollution. In fact, 90 per cent of the world's children live in *places* where air quality exceeds the World Health Organization (WHO) limits. Data from 2019 indicate that air pollution caused the premature deaths of close to half a million babies less than one month old. Exposure to pollutants can cause premature birth or low birth rate, both of which increases the risk of respiratory death and rates of infant mortality. Economically, premature deaths due to air pollution cost about $5 trillion in welfare losses globally.

There is a strong *spatial association* between the concentration of air pollution and urban areas, as these *places* have the greatest densities of industrial, commercial and domestic pollution sources. Delhi is an example of a city with serious pollution problems (see Figures 6.6 and 6.8).

What are the impacts of air pollution on the *environment*?

The main consequences of air pollution are global warming, acid rain, smog and ground level ozone. Once in the atmosphere, many pollutants are *moved* by winds, precipitated out or washed into soils and waterways, thus compounding the problem. Impacts can be evident at a range of *scales.*

▶ ACTIVITIES

1. In pairs, research the pollution type known as acid rain. How is it formed, where is it most commonly experienced in the world and what are the impacts on people and *environments*?
2. Refer to Figure 6.7.
   a. Describe the correlation pattern between death rates from indoor air pollution and income levels. Use specific examples and data in your answer.
   b. Suggest reasons for the pattern you observed.
3. Refer to Figure 6.6.
   a. With the use of an atlas and a world map outline, map the location of the capital cities with high $PM_{2.5}$ levels.
   b. Which *regions* of the world appear to have the greatest number of cities suffering high levels of $PM_{2.5}$?
   c. Describe the *distribution* of cities with high $PM_{2.5}$ levels as seen on your map.
4. 'Pollution is not a new phenomenon; it is largely controllable and often avoidable, but considerably neglected.' Write a paragraph explaining your viewpoint on this statement.

Local *scale* (less than 100 kilometres)	***Regional scale*** (500–100 kilometres)	**Global *scale***
Examples: local air pollution events, dust, gases and smog	Examples: smoke, acid rain	Example: climate *change*, and polar ozone depletion caused by CFCs blown from distant temperate *regions*

Increases in particulate matter in the atmosphere has been linked with *changes* in the intensity and *distribution* of rainfall in India and China while other locations in North America and South Asia are having more extreme droughts. Particulates also reduce the amount of sunlight reaching plants and crops, reducing productivity.

The *interconnection* between air pollution and COVID-19

The rapid spread of the virus COVID-19 in early 2020 forced the introduction of lockdown strategies across more than 89 countries, affecting over half of the world's population. The severe restrictions on economic activity and the *movement* of people had an unintended consequence of reducing air pollution. Satellite data of nitrogen dioxide (NO_2) levels showed a significant reduction during the lockdown phase across many *regions* of the world, compared to the same period the previous year (Figure 6.9). However, the levels of NO_2 increased back once lockdown ended.

Levels of $PM_{2.5}$ recorded during lockdown varied across different locations due, in part, to the *interconnection* with topography and/or climate. *Regions* experiencing colder conditions had more need for fossil fuel burning, while mountain ranges often block the clearing of polluted air. These *regions* of higher air pollution also reflected a stronger *spatial association* with areas that recorded higher number of COVID-19 fatalities. It is thought that pollution can assist in the transmission of the virus and people who are susceptible to pollution related respiratory diseases are more likely to die from the infection.

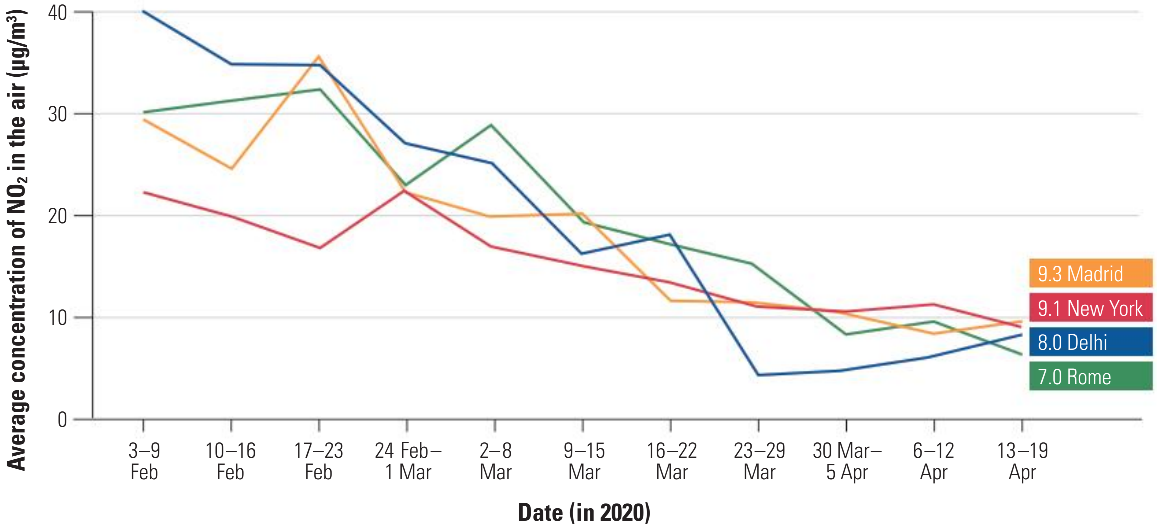


Figure 6.9 Weekly average concentration of NO_2 for selected world cities in February – April 2020

What are the responses to air pollution hazards?

Effective strategies to reduce air pollution have been successfully implemented around the world. Many countries have introduced laws to regulate dangerous emissions and promote cleaner air. Consequently, emissions of harmful pollutants such as lead, carbon monoxide and sulphur dioxide have significantly reduced. Improvements in technology and energy efficiency have also contributed.

In early 2018 the World Health Organization (WHO) and the United Nations Environment Programme (UNEP) signed an agreement to join forces on a new campaign called 'BreatheLife' to reduce air pollution for multiple health, *environment* and climate benefits. The aim is to halve the number of deaths from pollution by 2030, to achieve the UN Sustainable Development Goals (SDGs). They want to raise awareness of the health risks associated with pollutants which contribute significantly to air pollution and global warming. The campaign encourages cities to commit to reducing air pollution and share their knowledge with other cities. Additionally, it promotes increased air quality monitoring, supporting solutions and educating people.

Actions that can be taken at different *scales*:

- national *scale:* improved vehicle standards, prioritising *environmentally* clean public transport, developing cleaner energy; better enforcement and monitoring of existing legislation. For example, the UK government has banned the sale of new petrol and diesel cars by 2040, while Norway has made the cost of electric cars more affordable than petrol and diesel which are now heavily taxed.
- local *scale:* cities can promote improved systems for energy, waste, transport and housing design and promote green spaces. In Quito, the capital of Ecuador, advantage has been taken of the 30–70 per cent reduction in air pollution during the COVID-19 lockdown to promote keeping air quality within WHO guidelines. Initiatives include: improved monitoring, the growth and promotion of bicycle lanes, using electric buses and compulsory monitoring of industrial emissions.
- individual/community *scale:* stop burning waste, encourage walking/cycling to reduce dependency on burning fossil fuels for transport and adopting more efficient stoves and fuel alternatives for domestic use. In Seoul, South Korea, dedicated villages have been established as 'energy-independent' neighbourhoods. The community work together to promote high levels of energy conservation and have minimized their need for external energy sources, in fact they produce and sell solar energy back to the electricity grid.

Responding to indoor air pollution

Despite a growing awareness of the health risks of cooking with solid biomass, and programmes designed to improve household cooking methods, one-third of the world is still dependent on the fuel. Improving energy sources could bring many benefits especially for women and children who bear the burden of spending, on average, 1.5 hours a day collecting fuel, and then cooking over smoky fires. Alternative fuels, as well as harvesting wood fuels *sustainably,* could reduce the rate of *regional* deforestation. Progress is being made in India with the development of a solar powered cooking stove. Capable of storing energy for 72 hours and lightweight enough to *move* indoors or out, the stove produces the energy required to cook without the smoke, toxic gases or heat.

The introduction of more fuel-efficient stoves is not always successful. For example:

- in Bangladesh, families are offered cash incentives to install new stoves, but people would prefer to spend that money on education or food
- there is a lack of the technical support required to introduce new technologies
- in many *places*, open fires provide other benefits such as heating, lighting, repelling mosquitoes and keeping thatch roofs dry.

Acceptance by the community is important for any new technology. If local people cannot see any improved benefits over their existing method of cooking, then the rate of uptake will be minimal. A study conducted in Pakistan found a more successful approach was to support communities to develop their own *sustainable environmental* solutions by providing easier access to materials and resources.

Significantly, any increase in the number of people converting to cleaner fuels is negated by the rapidly rising population. It is predicted that 320 million people in Sub-Saharan Africa could gain access to clean cooking fuels by 2030, however the population will grow by 450 million in the same time period.

Using geospatial technology to manage air pollution

WHO has developed a new air quality model to show *places* experiencing high levels of pollution. Data has been collected from satellite measurements, air transport and ground station monitors for more than 3000 locations globally. The data is then presented as interactive maps highlighting *regions* within countries that exceed WHO limits of $PM_{2.5}$. The data can provide a baseline for monitoring progress.

Ground station monitors are expensive to build and maintain so even large cities usually only have a few and they are not always located close to local sources of air pollution or in dense traffic areas. New technology is now developing which uses micro-satellite images and weather conditions to estimate ground level $PM_{2.5}$ at the smallest spatial *scale* to date. This enables researchers to identify pollution hotspots as small as 200 metres x 200 metres within an urban area and act on it.

A new app for mobile phones has been developed that allows people to access information about real time concentrations of the key pollutants, weather and pollution forecasts as well as health recommendations for more than 10,000 cities globally.

▶ ACTIVITIES

1. Research the UN Sustainable Development Goals and identify the goals that relate to health and affordable clean energy. Do you think it will be possible for the world to meet these goals? Are some goals more achievable than others? Explain your answer.
2. Identify one each from a social, economic and *environmental* factor that might hinder the adoption of new, cleaner modes of cooking rather than using solid biomass fuels. Briefly explain each of your three factors.
3. a. Refer to Figure 6.9. Describe, in detail, the concentrations of NO_2 for the four cities over the three-month lockdown period.
   b. What does this say about the *interconnection* between human activity and air quality?

Air quality in Melbourne

As a city with over 4.96 million people, Melbourne's air quality is generally very good by world standards. This is the result of a favourable climate, low population density, coal-burning power stations being *located* a long *distance* (140 kilometres) from Melbourne's urban areas and government regulations controlling emissions. Nevertheless, the city does experience the atmospheric hazards of smog, thunderstorm asthma from pollen drift, wind-blown dust and smoke from bushfires.

Smog is a combination of smoke, pollutants and fog. Smog is directly linked to the use of petrol and diesel fuel in transport, fossil fuel–burning power plants, some industries and domestic wood fires. Weather conditions such as temperature inversions and calm winds provide ideal conditions for polluted air to be trapped over a city and for smog to form. In Melbourne this is typically April–September, months that are warm enough and with sufficient sunlight for photo-chemical smog to form which is typical of other warm climate cities such as Los Angeles. Winds can also help *distribute* polluted air to other *places*.

Smog causes grime to build up on buildings, affects the *movement* of transport, reduces visibility and affects people with respiratory diseases.

Interestingly, the burning of wood in fireplaces and heaters can be a major source of both indoor and outdoor air pollution to the extent that the Australian Medical Association are urging they be banned. Burning 10 kilograms of wood in a day using a modern, low emitting wood heater can produce around 15 grams of particulate matter compared to a truck travelling on a congested road which would produce 0.03 grams of particulates for every kilometre travelled.

Severe bushfires, whether naturally or deliberately lit, can impact directly on Melbourne's air quality. The fires in the summer of 2019–2020 produced thick smoke haze across much of the state and Melbourne. The EPA recorded $PM_{2.5}$ levels over 300μg/m^3, when anything over 177μg/m^3 is considered hazardous. Breathing in smoke causes eye and throat irritations and respiratory problems.

▲ **Figure 6.10** A layer of smog lying over Melbourne

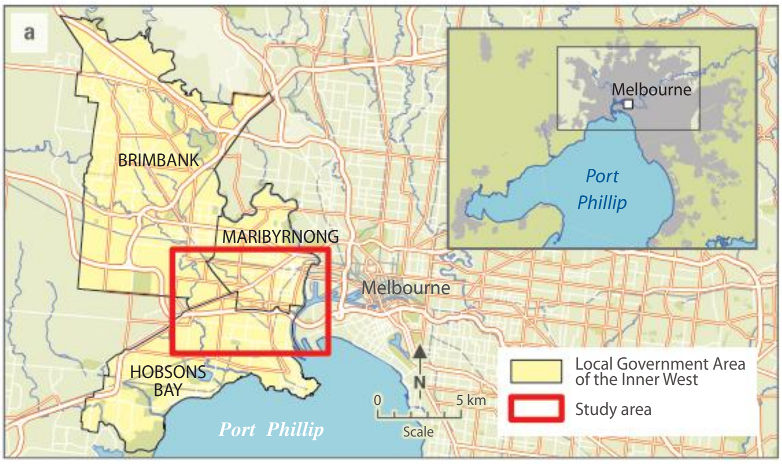
CASE STUDY

Combatting air pollution in Inner West Melbourne

Air pollution is however, unevenly *distributed* across Melbourne with the Inner West local government areas of Brimbank, Maribyrnong and Hobsons Bay (Figure 6.11 (a)) being particularly prone to poor air quality, odour and dust. Between 2010 and 2018 there have been 297 occasions when air quality has exceeded reporting standards across Melbourne, with 71 per cent of these occurring in the Inner West.

What factors have contributed to air pollution in the Inner West?

The *region*, with a population of 380,000, is located close to important infrastructure such as: the CBD, the airports, the ports of Melbourne and Geelong, the national rail network, the Westgate Freeway and other major roads. It holds a wide range of land uses including 20 per cent of Melbourne's industrial zoned land. Warehousing, transport, commercial and residential land uses are also represented.



▲ **Figure 6.11 (a)** The location of Melbourne's Inner West *region*, with major roads

Historically, the *region* has attracted industry, particularly large-*scale* manufacturing and noxious industries. These produce offensive or hazardous smoke, fumes, odours or wastes for example, abattoirs, oil refineries and landfill operations. Flat, cheap land and a local labour force have been prime locational factors.

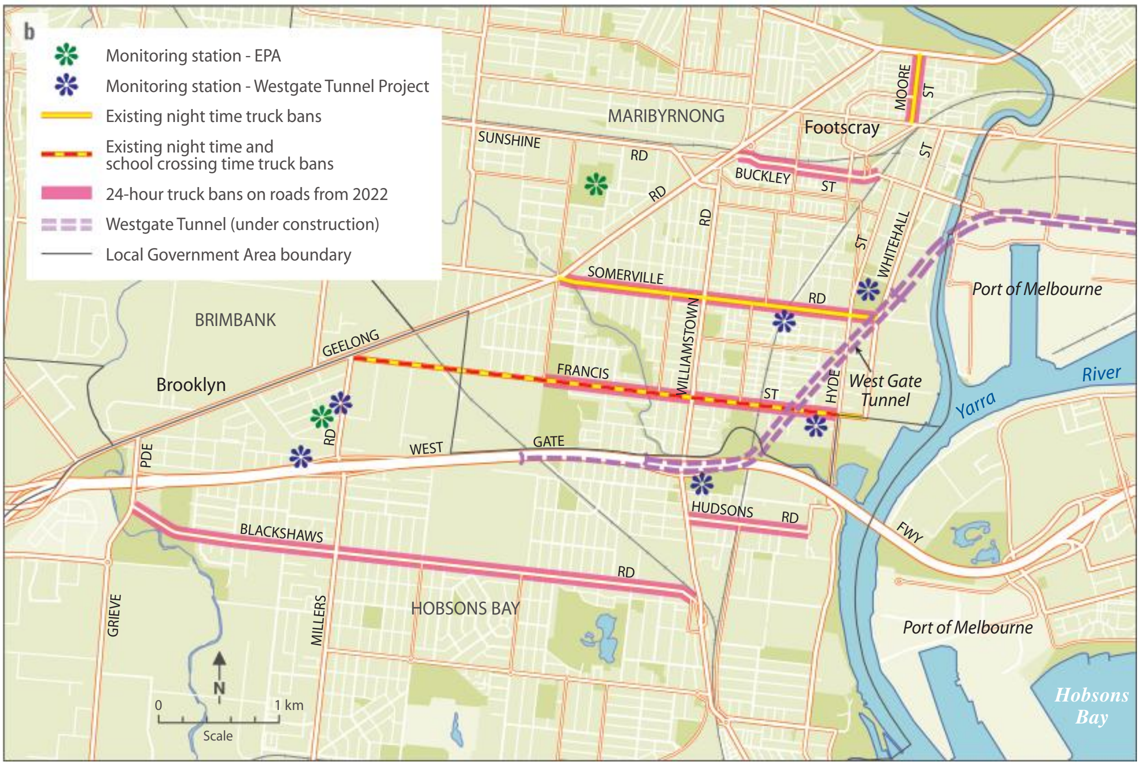
Despite regulations, there has been a lack of government action in dealing with pollution sources and its impacts in the area. The current *Victorian Health and Wellbeing Plan 2019–2023* does not have any focus on reducing air pollution. The Environmental Protection Authority (EPA) has only two long-term monitoring stations in the vicinity and both are located away from major roads (see Figure 6.11 (b)). Neither station is equipped to monitor SO_2 or $PM_{2.5}$. Concern over air pollution has led to the formation of community action groups to raise public awareness and initiate *change*.

Sources and impacts of pollution

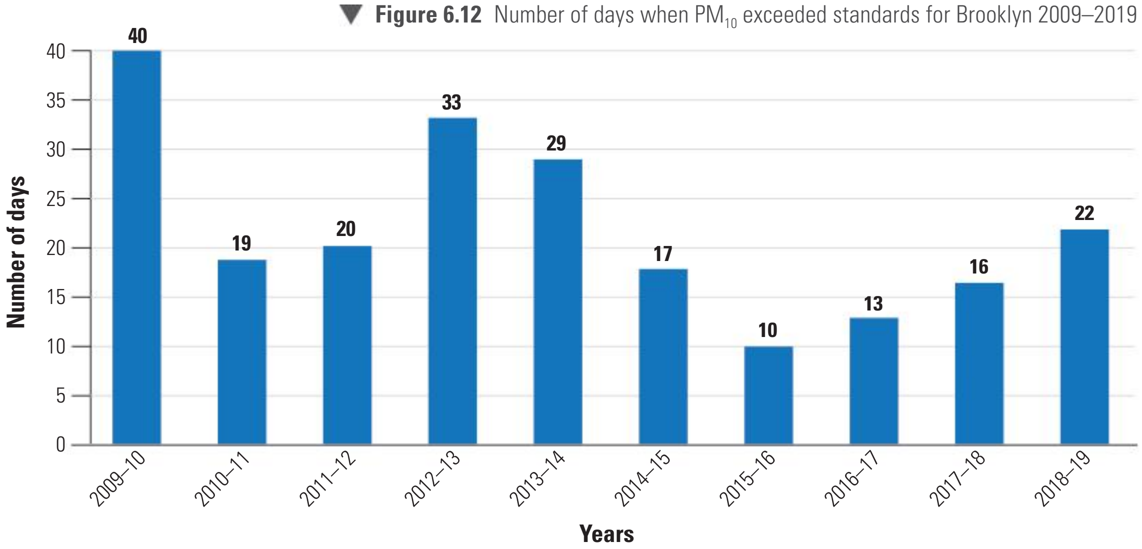
The higher rates of air pollution in the Inner West are linked to transport and raised dust from industrial and commercial sites. Poor air quality is *spatially associated* with industrial areas. For example, Brooklyn, has unacceptably high levels of PM_{10}, recording 22 days between 2018–2019 (Figure 6.12) with higher than standard readings. As winds easily disperse pollutants, air quality is compromised throughout the entire *region*.

Heavy traffic is common with 21,000 container trucks per day using the road network. The bulk of the *movements interconnect* the port with *distribution* warehouses and container yards further west.

▶ **Figure 6.11 (b)** The case study area showing roads affected by curfews and the *distribution* of air quality monitoring stations



▼ **Figure 6.12** Number of days when PM_{10} exceeded standards for Brooklyn 2009–2019



Currently, almost all heavy vehicles use diesel fuel which produces more NO_2 and particulates than regular fuel. Diesel is also linked to different types of cancers and there is no safe limit of exposure. Australia's standards for the quality of diesel fuel is one of the lowest in the developed world and the bulk of our truck fleet is old and not fitted with proper pollution controls.

The construction of the Westgate Tunnel may also contribute to the long-term pollution load. Apart from the expected increase in traffic, air quality monitoring around the site during construction is due to finish five years after completion which will significantly reduce testing and data collection. Figure 6.11 (b) shows their locations. Furthermore, there is currently no plan for the chimney stacks designed to ventilate the tunnels to have any pollution filters installed.

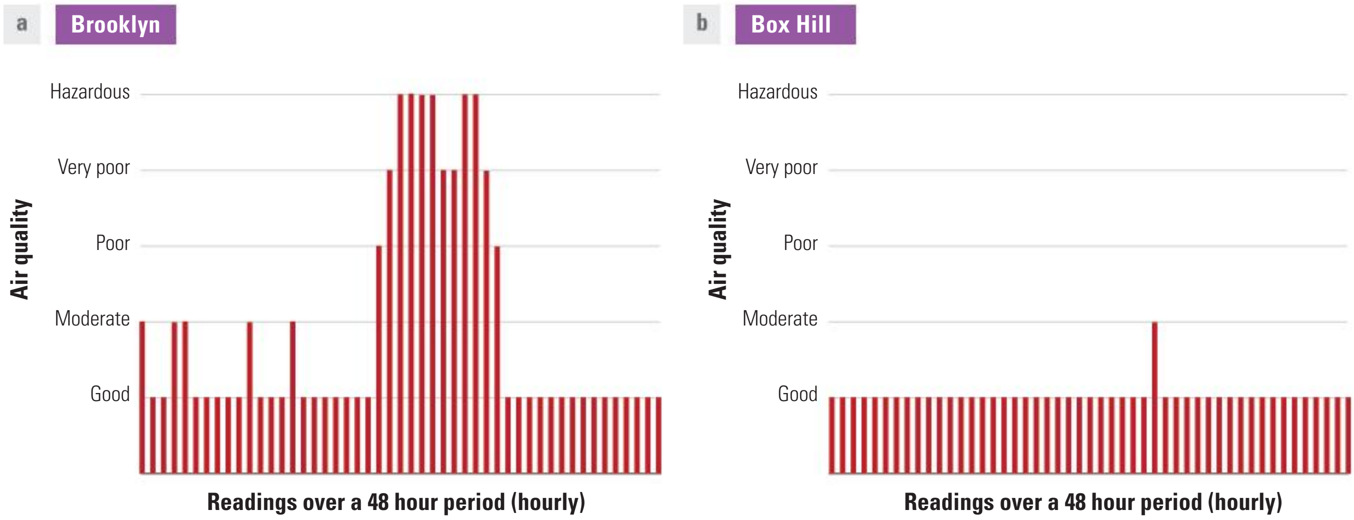
Dust is a common pollutant frequently originating from industries and their surrounding *environment*. An example is cement dust which, if mixed with water, can solidify and block up drains and gutters damaging buildings and cars. If inhaled, dust particles pose a health threat. Industrial areas also contain large areas of unsurfaced roads, open stockpiles of materials and landfill sites, all of which contribute particulates, dust and odours. Melbourne can experience many windy days which exacerbates the *movement* of dust, but the *scale* of accumulation in the Inner West is significantly higher than in other *places* around the city. Figure 6.13 compares the impact of a dust storm in June 2019 in Brooklyn (10 kilometres west of the CBD) and Box Hill (20 kilometres east of the CBD). The storm had little effect on air quality in Box Hill but reached a hazardous level in Brooklyn due to the additional dust from local sources.

Odour pollution is a regular source of complaint for local residents due to the number of noxious industries and prevailing winds. Days of high odour restrict outdoor activities and residents are forced to keep windows and doors closed. The EPA received 597 reports on odour in 2018–19 alone.

In recent years, a number of fires have occurred in factories storing toxic waste around the industrial suburbs of Melbourne. In Footscray, August 2018, a warehouse illegally storing millions of litres of highly flammable toxic waste caught fire and the explosions generated black smoke and noxious fumes across the suburbs, as seen in Figure 6.14. Local residents were advised to stay indoors, and the local creek actually caught fire from the toxic run-off. It took 16 days to put the fire out and at least 100 chemical-exposure related injuries were reported among firefighters.

The issue of poor air quality impacts adversely on the people who both work and live in the Inner West which then affects the liveability of the *region*.

▼ **Figure 6.13** The impact of a dust storm on air quality in **(a)** Brooklyn and **(b)** Box Hill (21 June 2019)



▲ **Figure 6.14** A factory fire in August 2018 sent plumes of toxic smoke over the Inner West *region* of Melbourne

Compared to other *places* in Melbourne and Australia as a whole, the local population experiences more pollution-related health problems. A study in 2019 found that these suburbs had a much higher rate of hospital admissions for diseases closely linked to air pollution than the national average. For example, hospital admissions for asthma are 40 per cent and heart failure 60 per cent higher in Maribyrnong than the general population.

Increasing population across the west from Geelong through to the CBD has boosted the number of commuter trips contributing to increased traffic and congestion. The planned expansion of the port will also cause greater *movement* of freight and containers. Truck traffic to and from the port is expected to increase to 34,000 trips per day forcing the *movement* of trucks onto narrow residential streets. Data collected by the EPA on the corner of Williamstown Road and Francis Street (Figure 6.11) between May 2020 and April 2021 revealed that levels of $PM_{2.5}$ breached the state's standard on 39 days. This is the proposed site of a childcare centre. Research predicts that children attending the centre would have a 60 per cent increased risk of developing asthma.

▶ ACTIVITIES

1. Refer to Figures 6.11 (a) and 6.11 (b). What are the advantages for industries to locate in this *region*?
2. Outline the factors that have contributed to the issue of air pollution in Melbourne's Inner West.
3. In what way/s do you think that technology has contributed to air pollution in the Inner West?
4. a. Refer to Figure 6.13. Describe, using data, the *changes* in air quality in Brooklyn over the 48 hours of the dust storm on 21 June.
   b. Compare the effects of the dust storm on Brooklyn and Box Hill.
5. Identify and describe two short term and two long term impacts of air pollution in the *region*.
6. Evaluate the effectiveness of using truck curfews, as a means of reducing the hazards associated with truck pollution.
7. What role do you think local action groups can play in dealing with *environmental* issues such as air pollution? Explain.
8. How effective do you think the West Gate Tunnel Project will be in reducing the impact of truck *movements* in the Inner West? Give reasons for your answer.

Responses to air pollution in the Inner West

As a response to the volumes of truck traffic on residential streets and organised protests from the local community, the Government introduced a curfew system for heavy trucks along several of the most affected streets which can be seen in Figure 6.11 (b). Starting in 2001 and updated several times since, trucks (apart from local deliveries) are banned between 8 pm and 6 am on weeknights and from 1 pm to 8 am on weekends. Some roads also have bans on trucks during school drop off and pick up times. Since the curfew there has been a 75 per cent reduction in truck *movements*.

The West Gate Tunnel was designed to directly link a widened West Gate Freeway to the Port via tunnels under Yarraville, with the aim of removing 9000 trucks daily from local roads. Trucks will also be banned from detouring through key suburban streets (see Figure 6.11 (b)). However, displaced trucks will then use alternative routes such as Sunshine Road and Williamstown Road where traffic is expected to double to 5000 vehicles per day. Any house, school, business or sporting facility within 200 metres of these roads will be in the diesel pollution fallout zone.

The Victorian Transport Association and the Maribyrnong Truck Action Group proposed a plan (Smart Freight Initiative) to extend curfew hours for older more polluting trucks, while newer cleaner and quiet trucks would have curfew times reduced by three hours. Speed limits would also be reduced from 60 to 50 km/hr. The government is proceeding with reduced speed limits on key streets as well as improving pedestrian safety with pedestrian barriers. Road resurfacing will help reduce traffic noise, but nothing is being done about improving truck emissions to European standards.

In early 2020 the State Government approved a $125 million investment for new rail tracks to the Port of Melbourne. This would reduce some road congestion in the local area and improve efficiency for freight *movement*.

To meet the needs of concerned citizens, the Government established the Inner West Air Quality Community Reference Group. Representatives from the community and local councils investigated and submitted a report in 2020 on local air quality with a series of recommendations for going forward. Time will tell as to which recommendations will be accepted and acted upon.

It appears that a consequence-based approach to *environmental* protection is taking place in the Inner West rather than looking at the issues of preventing pollution in the first place.

CASE STUDY Tackling air pollution in China

The hazard of air pollution in China became a full-blown national disaster over the winter of 2013 when 70 per cent of the country's largest cities recorded pollution levels higher than both national and global standards. The thick, dark toxic smog that blanketed northern China for weeks, was responsible for 90,000 deaths and impacted on more than 460 million people. By 2015 a government report stated that the air quality in 265 of the 338 major cities in China exceeded the national health standard. An eight-day smog event over Beijing in January 2017 recorded $PM_{2.5}$ readings of more than 500µg/m^3, more than twice the daily level considered hazardous to health (>250µg/m^3) and far surpassing the WHO guideline of 10µg/m^3.

What factors have contributed to the pollution hazard?

Many of China's *environmental* issues are linked to decades of rapid economic development, industrialisation and urbanisation. While the economy and cities have boomed, it has been at the expense of land, water and air quality.

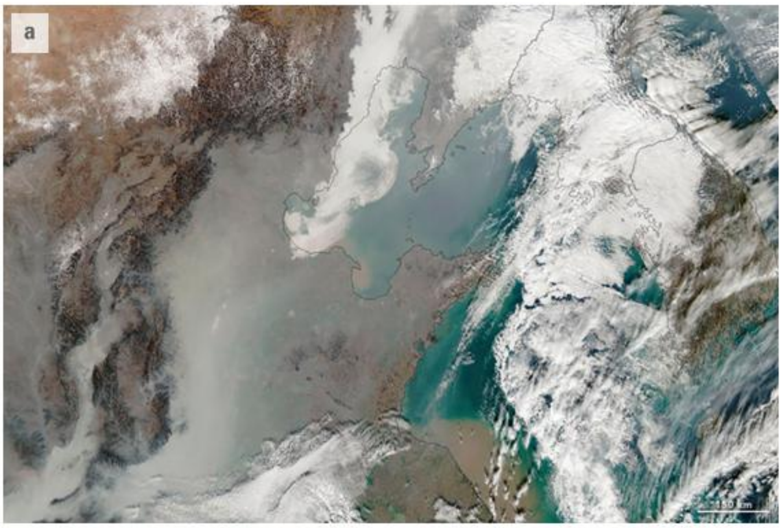
Traditionally the country has been dependant on coal, a cheap, plentiful and highly polluting energy source for its electrical, domestic and industrial use. Currently the use of fossil fuels (predominantly coal) provides 69 per cent of China's energy and accounts for 27 per cent of the world's greenhouse gas emissions. China is now the world's largest greenhouse gas emitter.

Places experiencing high levels of pollution are *spatially associated* with large urban areas and heavy manufacturing *regions* specialising in such activities as coal mining, power, steel and concrete production. Severe pollution events are more common in central and northern China, (see in Figures 6.15 (a) and 6.15 (b)), especially in winter when low temperatures increase the demand for electricity and home heating while low wind speeds and stable atmospheric conditions allow pollutants to accumulate and react with each other, creating thick, soupy sulfurous smog. Geographically, the northern *regions* are surrounded by mountains which trap pollutants and prevent them dispersing. In spring, prevailing northerly winds blow sands from the Mongolian deserts contributing to lower air quality. The impacts of climate *change* are also significant with weakening winter monsoon climate patterns over East Asia affecting the strength of cold fronts and decreasing wind speeds.

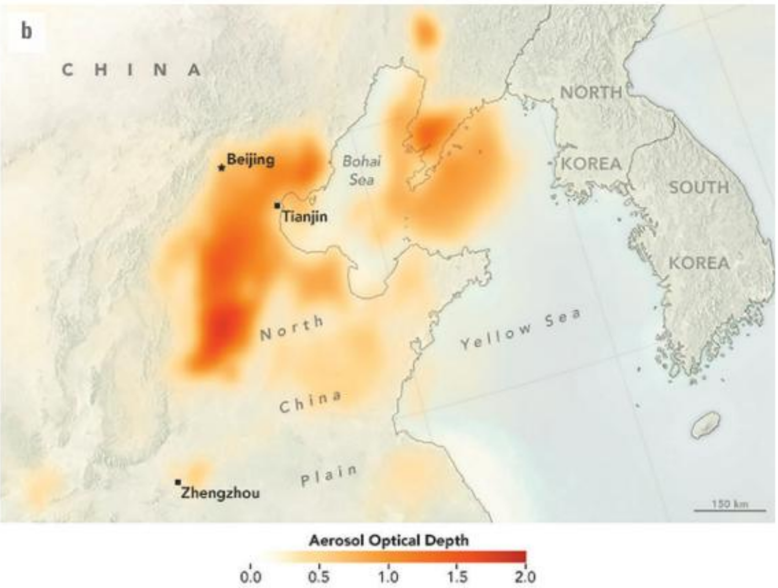
How is geospatial technology used in the management of air pollution?

Air quality and the severity of smog incidents can be analysed using satellite imagery and measurements of aerosol optical depth, or, how much sunlight the smog particles prevent from reaching Earth's surface. The data can be mapped allowing authorities to respond by issuing alerts for *places* most affected, closing schools, airports and recommending residents to stay inside.

During the COVID-19 pandemic, satellite images were able to detect *changes* in air quality over China. For three months transportation and much of the economy was shut down resulting in a visible reduction in nitrogen dioxide (NO_2). Across the country the decrease was in the order of 10–30 per cent. By May 2020, once lockdown was ended, NO_2 levels resumed as the economy returned to normal. Figure 6.16 shows this spatial *change* over time for central and northern China.



▲ **Figure 6.15 (a)** Smog over northern China on 18 December 2016. Smog is shown as a grey haze. The bright white areas are cloud or fog



▲ **Figure 6.15 (b)** Aerosol optical depth measures how particles in the atmosphere can block sunlight. The higher the number, the greater the amount of sunlight that is blocked

What are the impacts of air pollution in China?

It is estimated that air pollution in China is responsible for over one million deaths per year. The incidence of lung cancer has risen sharply, especially amongst non-smokers. During the haze event in December 2015, the health effects were the equivalent of smoking 60 cigarettes per day. China has among the world's highest incidences of cigarette smoking, and this predisposes smokers to further health damage from other forms of air pollution. If air quality met the WHO standards it is suggested that three million premature deaths could be prevented.

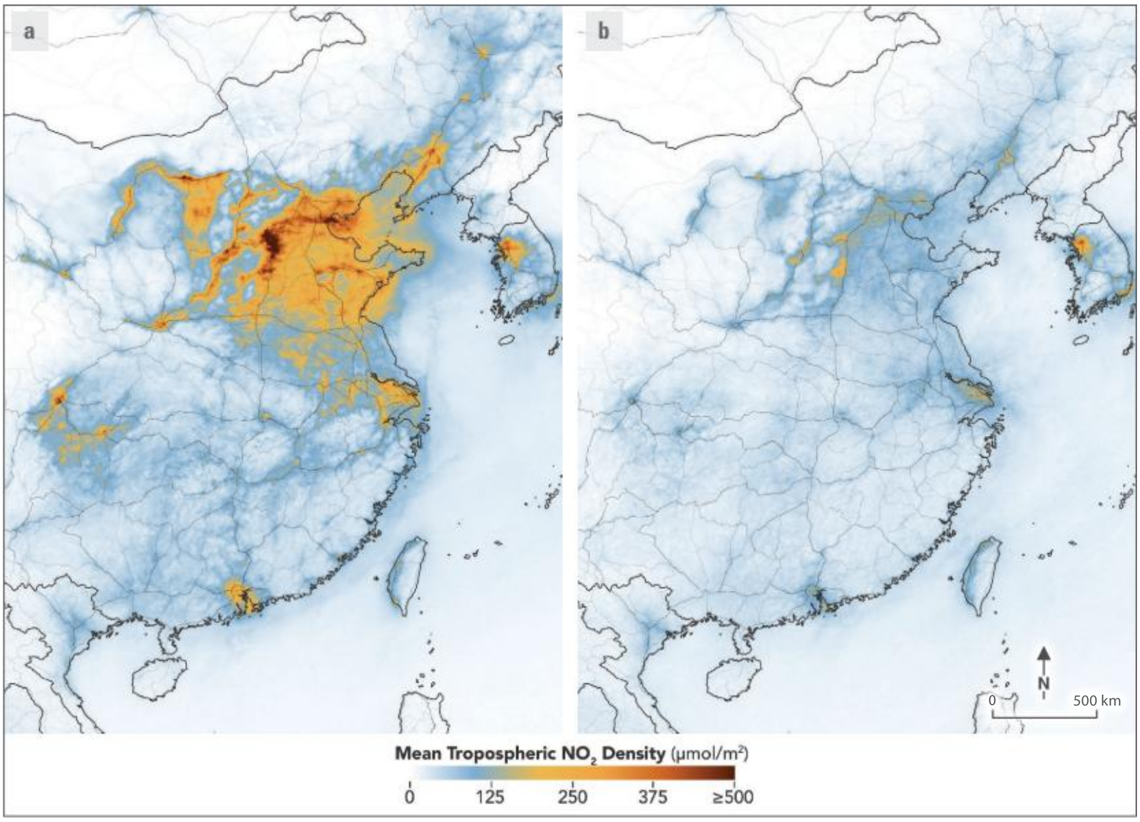


Figure 6.16 *Distribution* of NO$_2$ over central and northern China in **(a)** 1–20 January 2020 and **(b)** 10–25 February 2020

Social and economic disruption occurs during severe smog hazard events as schools and some industries are forced to close, flights are cancelled, outdoor construction stopped and tens of thousands of people leave the polluted cities for cleaner air further south.

The economic effects of air pollution are difficult to calculate, but one figure has estimated at least $US38 billion is lost each year due to the impacts on health, lost productivity and reduced agricultural yields.

What have been the responses to the hazard?

The rapid development of China has wrought intense levels of air pollution that have created significant economic, social, political and *environmental* issues. Public anger and the use of Chinese social media to protest over deteriorating air quality put considerable pressure on the Government so that by 2014 the government declared a 'war on pollution'. A range of policies and strategies to improve air quality has been implemented and constantly updated, such as:

- the shutting down of old inefficient power stations and the banning of new ones in the most polluted *regions* including city clusters of Beijing-Tianjin-Hebei and the Pearl and Yangtze Deltas
- restricting the number of cars on the roads in large cities while promoting the use of electric cars, taxis and buses
- developing more extensive public transport networks
- the tracking and measuring of air quality in more than 400 cities (Figure 6.17 (a)) which is available to the public. People are also able to report factories breaching emission limits via social media
- the introduction of a four-colour alert system to warn the public of smog hazard. During periods of a red alert, factories and schools are closed and people are warned to stay inside
- large-*scale* investment in renewable and nuclear energy sources
- reducing the use of coal in homes and switching to gas or electricity
- heavy fines for companies for breaching new *environmental* laws
- the introduction of large-*scale* reforestation programmes such as the Great Green Wall to reduce sandstorms and dust pollution.

How effective have these responses been?

Air quality

Changes in pollution are *distributed* unevenly across the country with the focus *regions*, such as Beijing and Shanghai, improving while pollution has actually increased in other *regions* in the south and north-east, reflecting an *interconnection* with sharp increases in industrial output and coal fired electricity generation (see Figures 6.17 (a) and 6.17 (b)). Many of the improvements in air quality, particularly around Beijing have resulted from the replacement of coal with natural gas and electricity and stricter emission regulations in winter (smog season). Often large-*scale* industries counterbalance this with increased production in summer.

Current research is now identifying increasing pollution levels, emissions 3.6 times higher on the outskirts of large urban centres as many of the high polluting industries chose to relocate rather than modernize or pay heavy fines. Many of the *environmental* rules and regulations are less strict in *regions* outside of large cities and they can attract new business and employment opportunities.

Concentrations of PM$_{2.5}$ have fallen 27 per cent at the national *scale*, although this figure fluctuates both seasonally and annually. The first two months of 2019 (winter) saw a nationwide average of PM$_{2.5}$

at 61μg/m^3 with only 83 cities out of 337 reaching the national standard of 35μg/m^3 still higher than the WHO recommendation of 10μg/m^3. At the local *scale*, levels of $PM_{2.5}$ for Beijing have dropped from 89.5μg/m^3 in 2013 to an average of 42μg/m^3 in 2019. According to a UN report 'no other city or *region* on the planet has achieved such a feat', the result of 'an enormous investment of time, resources and political will'.

The reduction in $PM_{2.5}$ has effectively *changed* the chemical composition of the atmosphere. Particulates act as a type of sponge soaking up the radicals that form ozone, so a reduction in one pollutant has actually created an increase of another with ozone pollution increasing by 11 per cent. Both ozone and NO_2 – which has only decreased by 9 per cent – are more difficult to reduce with traditional methods such as filters in chimney stacks.

The incidence of dust storm pollution, particularly in northern China, could increase in response to *changing* global temperatures, intensifying wind patterns and desertification as part of climate *change*.

Use of coal

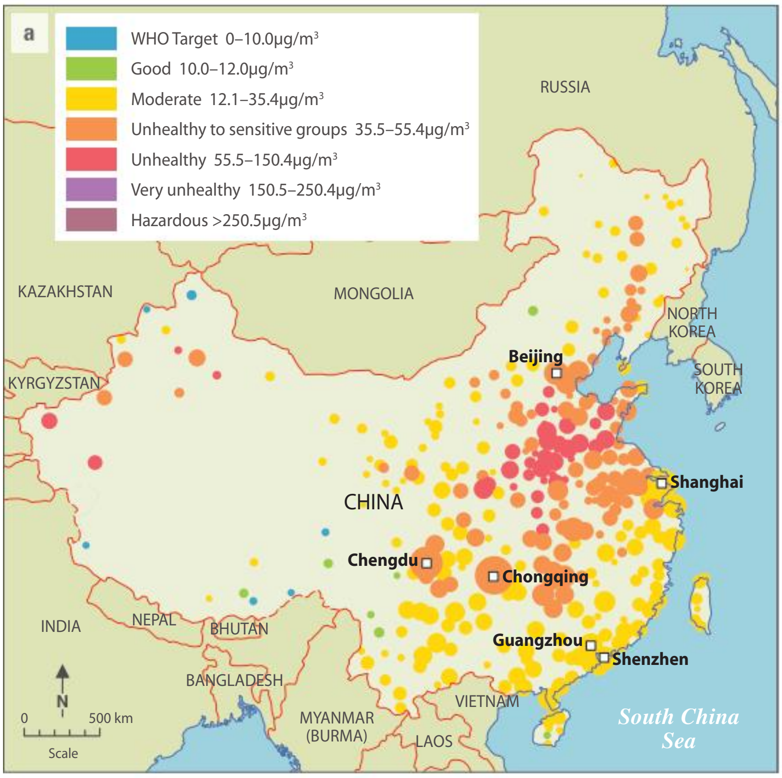
Over the last decade, the country set an ambitious plan to reduce its reliance on fossil fuels and push for cleaner energy sources. Nevertheless, recent trends indicate a *change* in direction with previous bans on the construction of new coal plants lifting (ten new plants opened in the first half of 2020) and the consumption of coal has been increasing steadily since 2017. There is also reduced pressure on the closing of old, inefficient power stations. This is contrary to the Paris Climate Accord where more than 30 countries agreed to reduce coal fired power by 63 per cent by 2030 and totally phase it out by 2037. China now possesses roughly half of the world's coal power capacity and coal fired plants under development.

Alternative energy

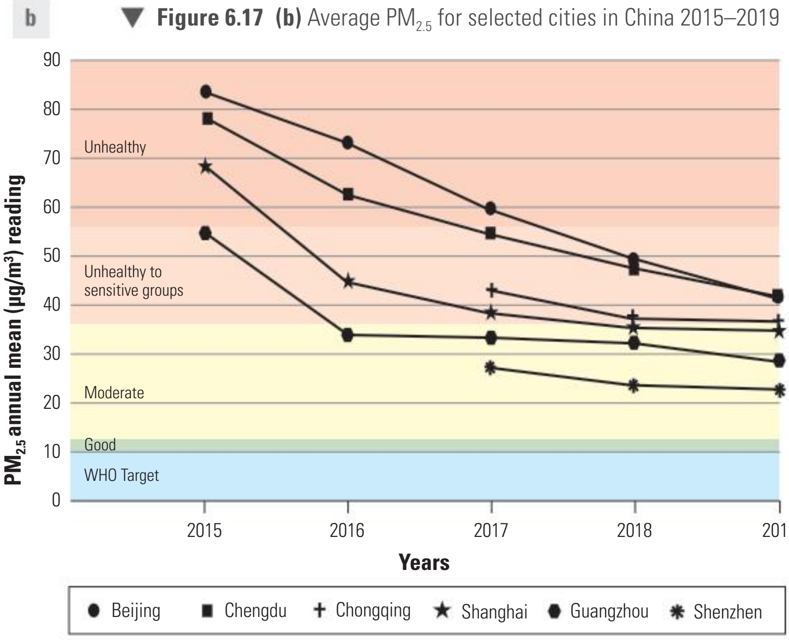
Due to the *environmental* issues related to fossil fuels, the country is heavily committed to alternative *sustainable* energies. The country now has 48 nuclear reactors (up from 36 in 2017) with another 12 under construction.

Since 2012 China has increased installing wind and solar power to have the world's largest renewable energy capacity. While renewables currently represent 21 per cent of the country's energy source, only 9 per cent is used, owing to the fact that *places* that best suit wind or solar power are not necessarily *spatially associated* with highly populated or industrialized *regions*. One third of the renewable energy produced in the sunny, windy provinces of Xinjiang and Gansu in the northwest of the country cannot be used as it cannot be stored or economically delivered the thousands of kilometres to the mega cities of Beijing or Shanghai. The amount of electricity that can be produced by renewable sources is also weather dependent and thus more variable than for fossil fuel energy.

▼ **Figure 6.17 (a)** *Distribution* of cities with real time monitoring of $PM_{2.5}$ in 2019



▼ **Figure 6.17 (b)** Average $PM_{2.5}$ for selected cities in China 2015–2019



Transport

Large-*scale* technological improvements have been made in China's transport network in an effort to reduce vehicle emissions. Ninety-nine per cent of the world's electric bus fleet (over 400,000) is in China. One thousand electric buses theoretically save 500 barrels of diesel per day, compared to 1000 electric cars saving 15 barrels of oil. In the past ten years China began to expand its subway system across the country and within cities. Beijing and Shanghai have the world's two largest subway train networks. High speed trains now connect two hundred Chinese cities with 35,000 kilometres of rail, expanding by a minimum of 2000 kilometres per year.

ACTIVITIES

1. a. How have human activities contributed to the hazards of air pollution in China?
   b. What features of the natural *environment* compound the hazard in northern China?
2. Refer to Figures 6.15 (a) and 6.15 (b).
   a. Use the *scale* to calculate the approximate area affected by dense smog on 18 December 2016.
   b. If a westerly or south-westerly wind was to blow, what other countries in the *region* may be affected by China's air pollution?
   c. How would the use of geospatial technology, as seen in Figure 6.15 assist in identifying and assessing the impacts of air pollution? What other spatial information would be useful?
3. Examine the information in Figure 6.17 (a). With the use of an Atlas map of China, describe the *distribution* of those *places* affected by 'unhealthy' air pollution in 2019.
4. Research a current population *distribution* map for China. Describe the *spatial association* between *regions* of high population density and unhealthy levels of air pollution as seen in Figure 6.17 (a).
5. Select three of the Chinese Government's responses to air pollution and evaluate their effectiveness using the criterion of *sustainability*.

CASE STUDY

The hazards of the South-Eastern Asia fire haze

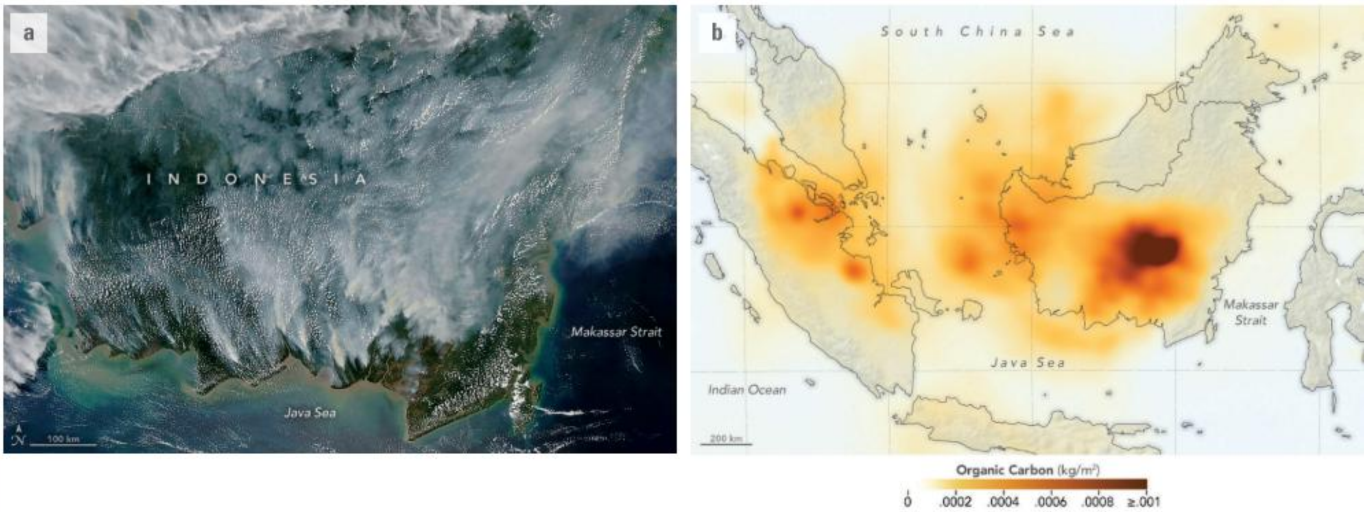
Each year, across South-East Asia, the smoke from burning forest fires, typically originating from Indonesia, creates hazardous haze pollution. Haze is a combination of pollutants that includes soot particles, dust, carbon dioxide and other toxic gases, as well as fine particulate matter ($PM_{2.5}$).

What factors contribute to haze pollution?

The main cause is the annual *process* of burning vegetation to clear land for agriculture, ranging from small-*scale* 'shifting agriculture' to large-*scale* palm oil and pulp plantations. The spatial *distribution* and length of time the haze remains is totally dependent on weather conditions – anything from several weeks to an entire dry or burning season (see Figure 6.18). During the monsoon season strong, south-westerly winds blow the smoke across other countries, creating a *regional* transboundary hazard. During an El Niño period, the hot, dry conditions increases the magnitude, intensity and duration of the hazard; 2015 and 2019 were particularly severe haze years. La Niña years typically bring to the *region* wetter weather and a reduced risk of fires spreading. The minute haze particles can stay suspended in the atmosphere, travelling large *distances*, eventually being dispersed by rain. Despite burning being illegal in Indonesia, it is the cheapest and fastest method of clearing land and is therefore widely used.

Both tropical forests and peat swamp forests are burnt. Peat is organic material, made up of deep layers of rotting plant matter that has accumulated. For example, in Central Kalimantan it can take 140 years for peat to form to a depth of 0.5–1 metres, while depths of 8–10 metres can take 13,000–25,000 years to form. Canals are dug to drain and dry the peat in preparation for burning, as seen in Figure 6.19. The water table is lowered at least 50–60 centimetres below the surface for oil palm trees and up to one metre underground for pulp and paper species. Wet peat is an excellent carbon sink absorbing CO_2 but if allowed to dry out it continually releases carbon to the atmosphere. It is also very flammable and, once alight, can burn for long periods of time – even years – releasing significant amounts of carbon. While the

▼ **Figure 6.18** The extent of peatland fires over South-East Asia in September 2019. **(a)** Satellite image on 14 September 2019 showing the *scale* of smoke haze from numerous peat fires and **(b)** the *distribution* of carbon from the fires on 17 September 2019



fires start on the surface they can *move* underground, to where the fuel lies, making it difficult to extinguish and requiring vast quantities of water. The smouldering (flameless) fires generally burn at lower temperatures and produce more visible and thicker smoke than from a typical forest or grassland fire. The acrid smelling smoke also contains higher amounts of CO_2 and particulates. Peatlands comprise less than 20 per cent of the country's land area but contribute 67 per cent of fire emissions.

What are the impacts of the haze hazard?

The annual clearing season creates many *environmental*, economic and social *changes.* Clearing peatlands is a contributing factor in deforestation and the loss of biodiversity. After clearing, there is a higher risk of erosion (see Figure 6.19) and streams can contain up to 550 times more sediment than before burning, unshaded streams suffer from increased water temperatures. The frequency of droughts and floods also increase. The loss of soil moisture can create subsidence where the land actually sinks or caves in.

The draining of one hectare of peat will produce an average of 55 tonnes of CO_2 yearly, the equivalent of burning 22,000 litres of petrol. Peat fires contribute to 40 per cent of Indonesia's greenhouse gas emissions. Economically, there is the loss of valuable timbers and the high cost of fighting the fires.

During a haze event, the smoke is hazardous to people's health in both the short and long term, especially for people with chronic respiratory illnesses. Seasonal forest and peatland fires now challenges Indonesia's economic and social development by creating considerable threats to the *environment* and the health of its people.

The 2015 burning season was a disaster. A state of emergency was declared across six provinces in Indonesia as putrid, smelly smoke from more than 100,000 fires blanketed parts of South-East Asia for weeks. Air quality near the fires exceeded the maximum level of 1000 units on the International Pollution Standard Index (PSI), which is three times the level classified as 'hazardous'.

The toxic smoke was responsible for more than 100,000 premature deaths in the *region* and caused widespread eye, skin and respiratory complaints. Visibility was often reduced to less than 50 metres.

School closures impacted on more than five million students while businesses and transport systems were disrupted. The fires cost Indonesia more than $A20 billion dollars which includes the direct costs of fighting the fires and loss of crops, houses and infrastructure as well as indirect costs associated with industry, tourism and trade.

On a similar *scale*, the 2019 fires (see Figures 6.21 and 6.22) made headlines as smoke haze registering 208 (very unhealthy) on the Air Quality Index, once again affected millions of people, closed schools and spread as far as Singapore and Malaysia. Figure 6.22 illustrates the number of fire hotspots during the fire season. An estimated 1.65 million hectares burned with a US$5.2 billion cost to the economy. Forty-two per cent of fires detected by satellites were on peatlands. The fires destroy forests, national parks and farmlands affecting local livelihoods and employment opportunities. Forested *regions* do not recover after fire and so get converted to plantations and individual farms.

▼ **Figure 6.19** A peat swamp smoulders during a fire haze event. On the left, channels can be seen draining the peat swamps. Once drained the vegetation dries out and is then burnt to provide clear land for planting palm oil trees which are visible in the bottom right

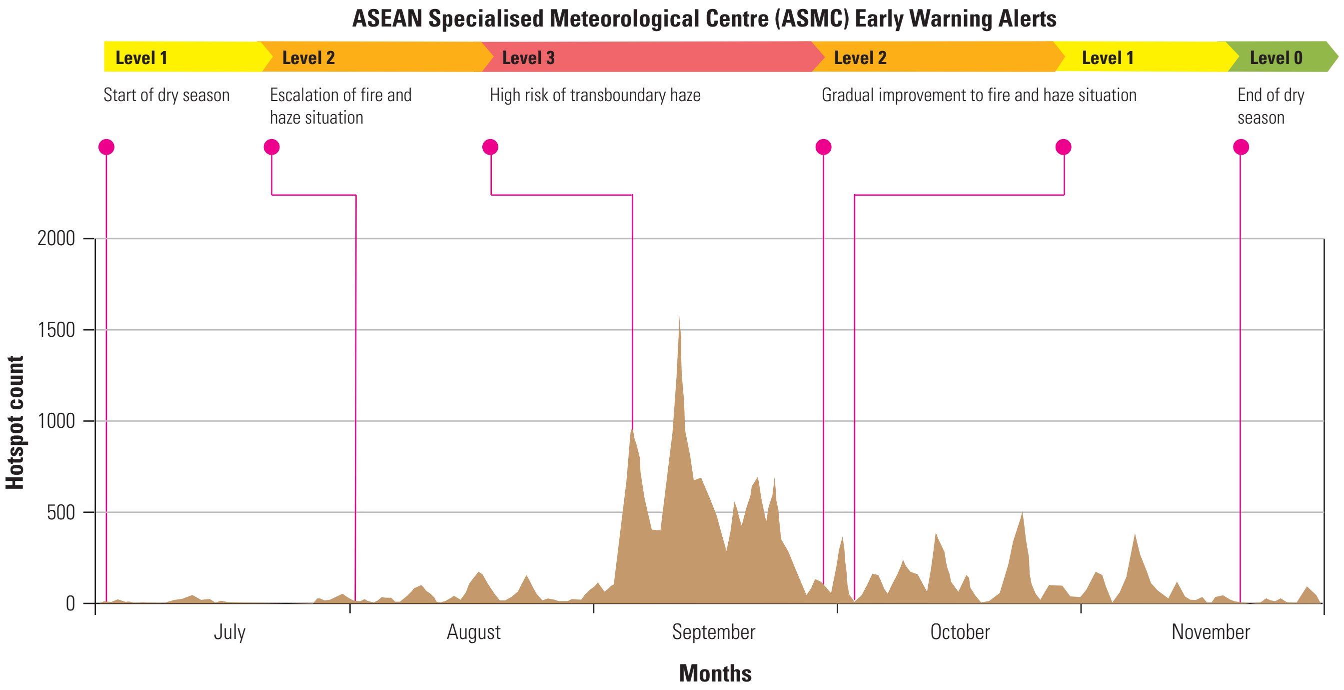
▼ **Figure 6.20** Peat fires occur in other *places* in the world, including Victoria

Peat fires in Victoria

The massive bushfires in January 2020 also started a peat fire in Sarsfield, Gippsland. The 20 hectare fire burned for more than a month releasing potentially dangerous amounts of carbon monoxide, sulphur and nitrogen. The Environment Protection Authority installed air monitors to record gases while fire fighters used drones and helicopters to identify hot spots. Water was pumped from the mains and nearby river. In the Western District, around Camperdown, three peat fires covering 74 hectares burned for nearly a month in 2018. More than 2000 people in the local area were warned of carbon monoxide poisoning risks, while fire fighters wore special face masks to protect against particulates and had to undergo twice daily health checks.

▼ **Figure 6.21** Firefighting on smouldering peatlands in south Sumatra 2019. Fires can smoulder for weeks at a time releasing acrid smoke and gases, reducing visibility and threatening the health of people down wind of the fires

▼ **Figure 6.22** Number of hotspots detected in the southern ASEAN *region* July – November 2019 and the corresponding early warning alerts. Most of the fires were over Kalimantan and Sumatra, Indonesia (*Source:* ASMC)



Level 0	No transboundary smoke haze / stand down
Level 1	Dry season
Level 2	Increasing risk of transboundary haze in the region: ▶ Escalating hotspot activities with moderate to dense smoke haze observed over 2 or more consecutive days ▶ Dry weather persisting ▶ Prevailing winds blowing smoke haze from the hotspots towards neighbouring ASEAN countries.
Level 3	High risk of severe transboundary haze in the region: ▶ Significant and persistent hotspot activities with widespread moderate to dense smoke haze observed over 2 or more consecutive days ▶ Dry weather persisting ▶ Prevailing winds blowing smoke haze from the hotspots towards neighbouring ASEAN countries.

Regular transboundary haze events have created political tensions in the *region* and countries affected by the annual pollution hazard demand better responses from Indonesia. There has been limited fire prevention and control of fires and minimal law enforcement, consequently peatlands are degrading.

What have been the responses to haze pollution?

Regional responses

In 2002, members of ASEAN (Association of South-East Asian Nations) adopted the world's first *regional* agreement aimed at preventing and mitigating transboundary haze pollution. The primary goal was for a haze-free ASEAN *region* by 2020.

After twenty years, little progress has been achieved. Firstly, the agreement has little power to settle disputes or inflict penalties. The Indonesian government does not disclose information about land ownership, so it is difficult to determine responsibility for fires. Secondly, the focus has been on combatting fires rather than preventing them. Thirdly, there is the need for a more cooperative approach to balance economic development with *environmental* management. Compounding the issue is the fact that many of the companies associated with palm oil production have links to Singapore or Malaysia.

On a positive note, cooperation has enabled the establishment of the ASEAN Specialised Meteorological Centre (ASMC) which provides a central point for data collection. Using long range forecasting and remote sensing, meteorologists are able to monitor, assess, predict and provide early warnings of transboundary haze events.

National responses

While the Indonesian Government has been responsible for granting land licenses in forested and peatland *regions* there has been insufficient action taken to prevent or penalise those involved in illegal clearing. Indonesia is the world's largest producer and exporter of palm oil, (a very profitable and highly demanded product) and, as such, has a vested interest in the industry's expansion. However, it cannot always be considered an *environmentally sustainable* industry.

The Government placed a five-year ban on any new plantation leases and promised to cut its greenhouse gas emissions by 29 per cent by 2030. The Peatland Restoration Agency (BRG) was established to restore 2.5 million hectares of dry peatland by 2020 and halve the number of fires by 2020. Peatlands are a unique ecosystem and have to be flooded at all times. The only *sustainable* and permanent way of preventing peat fires and the hazard of smoke haze is to raise water levels and find ways to use the land fully saturated.

Restoration needs to focus on the three Rs:

- rewetting – blocking 250,000 kilometres of drainage channels and canals to raise water levels
- revegetation – replanting cleared areas with native species and finding alternative crops to create incomes
- revitalisation – providing alternative livelihoods and economic incentives for the communities who have traditionally relied on clearing peat forests.

More stringent enforcement of regulations and laws is needed and empowering communities to prevent and tackle fires by providing training and equipment as well as upgrading early response fire monitoring systems (see Figures 6.21 and 6.22).

Since the program's introduction, the rate of deforestation in Indonesia has started to decline but still the fires continue. Much of this is due to communities' resistance to *change* because slash and burn is the preferred and cheapest method for clearing land. Some communities have taken to clearing blocked canals to allow for boats to access plantations, while other villages refuse to plant native trees due to their slow growth, preferring the more economical oil palm which only take five years until cultivation.

Providing alternative clearing techniques on suitable land, such as small hand tractors, would benefit local people as would promoting productive use of peatlands, such as paludiculture – farming with plants suitable for wet soils, such as purun (a grass that can be woven), pineapples or even fish farming.

Local responses

A multi-faceted approach is being used in central Kalimantan to facilitate community-led peatland restoration. A combination of Government, UN and NGO's are financing and supporting local communities to restore water into peatlands to reduce the impacts of fire and land degradation. The focus has been on:

- blocking drainage channels and constructing dams to provide water to the peatlands
- providing grants to local communities in return for people actively engaging in restoration works
- training local fire brigades
- reforestation of the cleared peatlands.

Large-*scale* planting of the nyamplung tree has been encouraged. These trees have many benefits:

- they can be used as a biofuel reducing people's dependence on polluting diesel fuel
- can be sold as additional income
- they are an excellent building material
- the plant's flowers provide medicinal honey
- the fruit can be used for making tamanu oil [skin care].

The project has the potential to be a model for community-led *sustainable* development in other *places*, providing social, *environmental* and economic benefits.

How does geospatial technology assist in managing haze hazards?

Using satellite imagery, daily maps of the *region* are created using a Fire Danger Rating System (FDRS), which calculates the risk of fires starting and spreading in a specific *location*. Data is collated using a range of indicators such as temperature, humidity and rainfall. Fire hotspots can be identified allowing for fire warnings, and companies and government agencies can direct resources to *places* that are most vulnerable to fire: this can be viewed in Figure 6.22.

Global Forest Watch is an online, forest monitoring and alert system that uses satellite images and geo-tagged social media conversations. Volunteers from around the world analyse hundreds of thousands of images and maps to identify the source of fires. Because of these activities, individuals and companies can be charged with illegal clearing. Drones are also used to obtain imagery of the immediate impacts of fire damage.

The SMOKE Policy Tool is an application that has been designed to prevent premature deaths from toxic haze. Satellite data creates an *interconnection* of land use, land cover and patterns of fire emissions. Decision makers will be able to predict any *movement* of smoke towards large population centres. Rather than determining the priority of firefighting based on the number of hotspots, this data would prioritise locations where firefighting and peatland restoration should be focused, directly upwind of vulnerable populations across three countries. The east coast of South Sumatra and southern coast of West, Central and South Kalimantan would be the focus.

▶ ACTIVITIES

1. With the use of Figure 6.18 (a) and an atlas, describe the *distribution* of smoke haze. Use the names of islands and countries in your answer.
2. Refer to Figure 6.18 (b). What was the predominant wind direction for the day the satellite image was taken?
3. Refer to Figure 6.22. With the use of data, describe the *interconnection* between the number of hotspots and the fire warning level.
4. What have been the *environmental*, economic, and social impacts of clearing peatlands in Indonesia on people and the *environment*?
5. What are the difficulties in preventing and managing transboundary pollution? (Figure 6.18 may help.)
6. Describe how the three Rs could reduce the smoke hazard in the South-East Asian *region*.
7. Explain the *interconnection* between economic and *environmental* needs with respect to peatlands in Indonesia.
8. What role can local communities play in the management of peatlands and reduction of fire hazards in Indonesia?
9. Construct a table to compare the strengths and weaknesses of national and *regional scale* responses to the fire haze pollution in Indonesia.
10. How can the use of geospatial technologies help to manage the effects of air pollution in South-East Asia?

CASE STUDY The hazards of human-induced earthquakes

Earthquakes are a major hazard affecting millions of people globally. Chapter 3 looked at this hazard as a natural *process*. It now appears that human activities can actually generate earthquakes or 'induced seismicity'. These can be triggered by the construction of a large reservoir, by mining, drilling for geothermal energy or injecting fluid waste into underground rock formations. At least 750 *locations* globally have experienced earthquakes caused by human activities in the past 150 years, as Figure 6.23 shows. Most natural earthquakes occur along lines of weakness, or fault lines deep in the Earth's crust. These are commonly *spatially associated* with locations where tectonic plates converge. Earthquakes triggered by human activity can occur at great *distances* from plate boundaries, yet their physical characteristics are the same as naturally occurring ones.

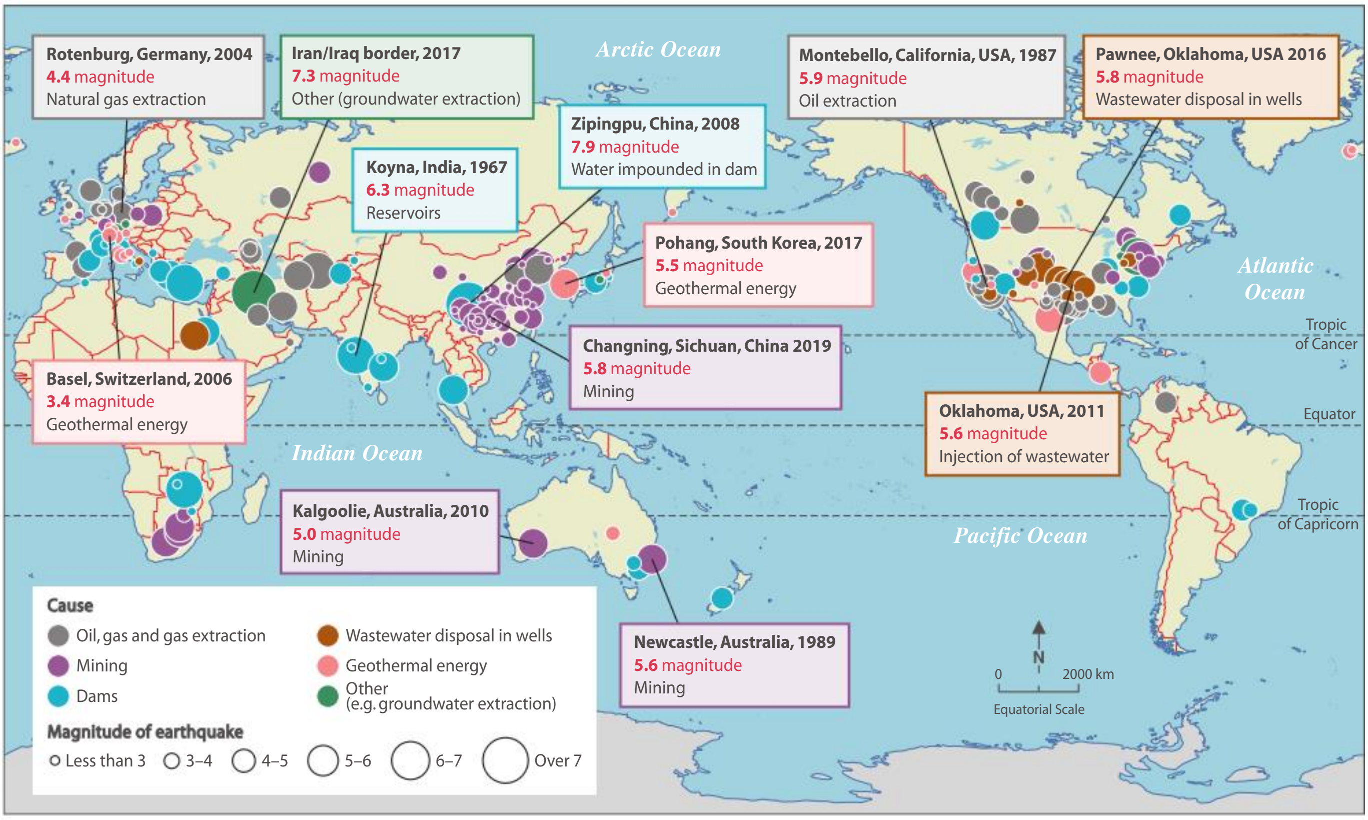
The role of human activity in initiating earthquakes

East of the Rocky Mountains in the United States is not usually regarded as an earthquake-prone *region.* From 1973 to 2008, 20 earthquakes of magnitude 3.0 or higher were recorded per year. This increased to an average of 318 per year from 2009–2015. In 2015, 1010 were recorded. This increased seismicity coincides with a significant increase in the volume of hazardous wastewater being pumped underground and the extraction of oil through the fracking *process* across several states including Oklahoma, Colorado, Texas and Arkansas. Figure 6.24 shows the *change* in the number of earthquakes in just one state.

Earthquake hazards related to oil and gas fracking

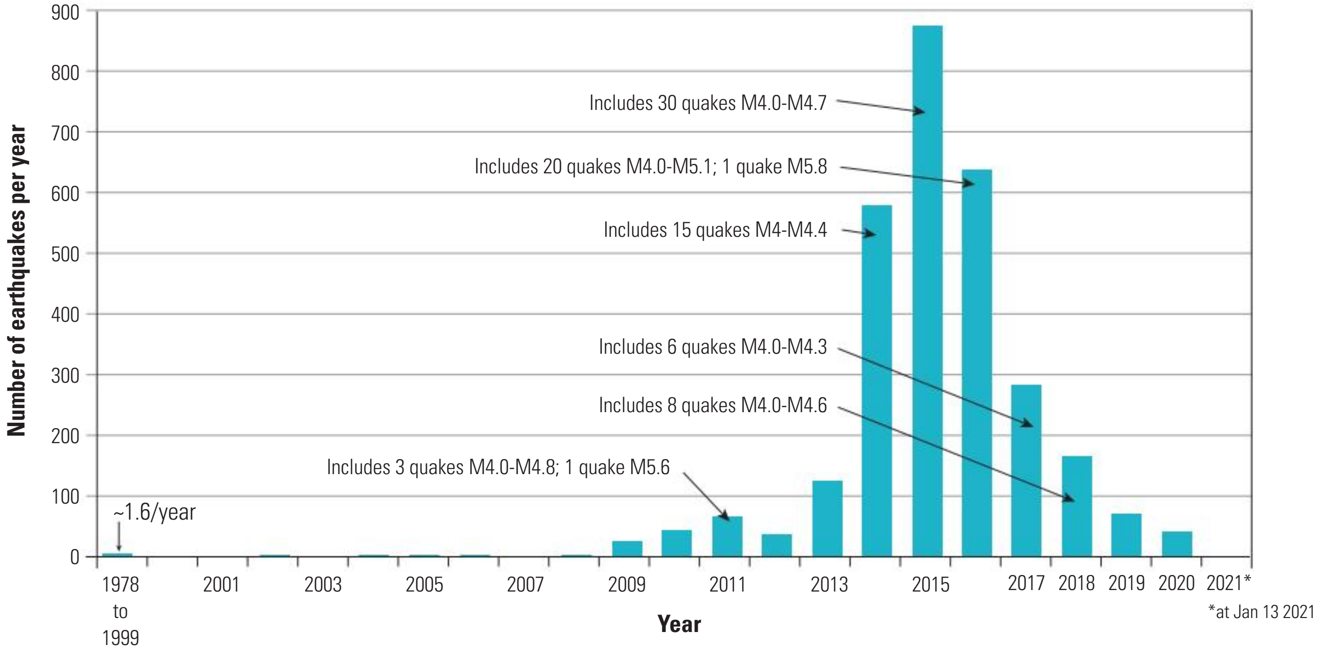
New technologies allow the extraction of oil and gas from previously unproductive reservoirs deep underground. Large quantities of water, chemicals and sand are pumped under pressure through rock layers, typically shale (a porous sedimentary rock), to fracture the rock and force the gas and oil to the surface. These new extraction methods have enabled the United States and Canada to have gas security for the next 100 years and, in some *places*, to generate electricity with less than half the CO_2 emissions as coal-fired power stations. There are considerable *environmental* concerns associated with fracking, including the hazards of increased human-induced earthquakes which tend to be more shallow than natural ones (less than five kilometres deep) but the shallower it is the stronger the shaking. Fracking is responsible for several earthquakes recently in the Siuchuan Basin of China, including a 4.9 magnitude earthquake in the village of Gaoshan in February 2019 when two people were killed and twelve injured from the collapse of old buildings. A magnitude 5.8 earthquake on 17 June 2019 in Changning County, China, that killed at least 13 people and injured 220 is also suspected of being fracking related. Western Canada has also recorded mid-size fracking earthquakes, but these are not *spatially associated* with major settlements.

Fracking also increases the risk of groundwater pollution and the problem of dealing with the large quantities of toxic waste. Excessive amounts of water are used in the *process* of fracking so it cannot be considered a *sustainable* practice. For every barrel of oil extracted there could be anything from 10–20 barrels of wastewater produced.



▲ **Figure 6.23** Global *distribution* of human-induced earthquakes

▼ **Figure 6.24** *Changes* in the number of earthquakes with a magnitude of 3.0 and greater in Oklahoma 1978–2020

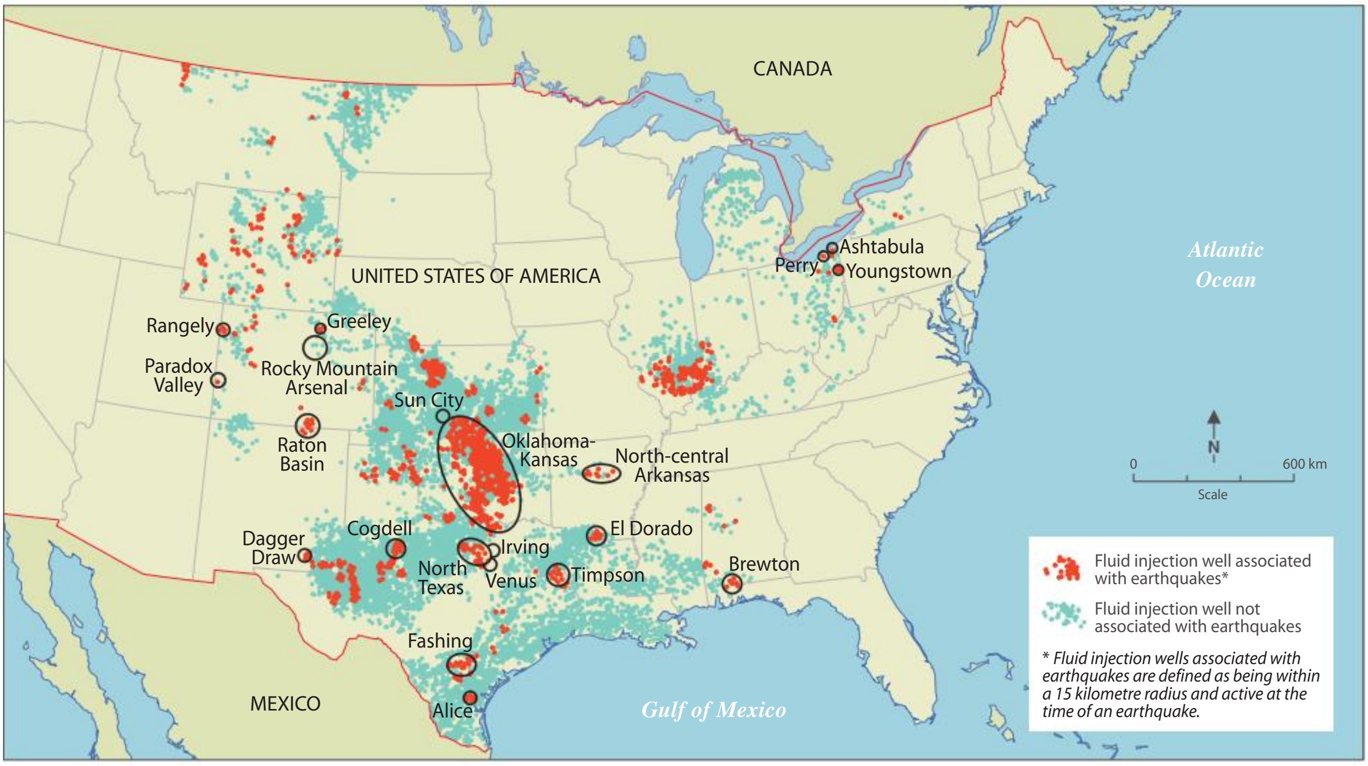


Earthquakes and hazardous waste disposal wells

Traditionally, any industrial, mining, military or domestic hazardous waste fluids were deposited into rivers, oceans, wetlands or spread over waste land. The subsequent *environmental* and health issues that developed were *unsustainable* and triggered the need for improved laws and pollution-control methods. An alternative and permanent location for toxic waste is to bury it by using old wells, previously used for drilling oil and gas, or to drill new ones. The *process* involves waste fluids being injected under extremely high pressure, deep into underground rock formations. Presently, there are more than 740,000 underground waste injection wells *distributed* across the US. Figure 6.25 shows a *spatial association* between the *distribution* of induced earthquakes and injection wells across eastern USA. Approximately 7.6 billion litres of fluid are pumped underground each day in the USA.

What happens underground?

Wells are designed as tubes of concrete and steel extending underground for a *distance* of between several hundred metres and up to two kilometres. The depth of the well depends on the toxicity of the material and the need to deposit the waste below any aquifers used for drinking water. Waste injected into the well will seep into the natural tiny pore spaces of the surrounding rock. Some rocks, such as sandstone, limestone and shales, are quite porous so that vast quantities of fluid can be forced into the pores and fractures. The waste water is then held beneath other layers of impermeable rock.



** Fluid injection wells associated with earthquakes are defined as being within a 15 kilometre radius and active at the time of an earthquake.*

▲ **Figure 6.25** The *spatial association* between induced earthquakes and disposal wells in eastern USA

Impacts of waste disposal wells

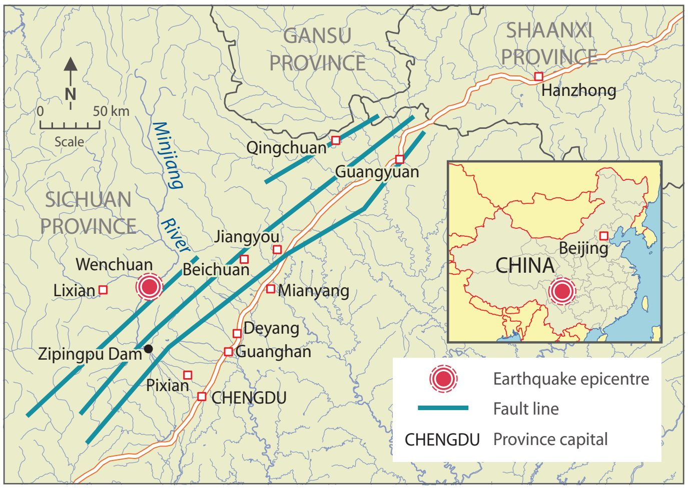
It is now believed that the force of injecting waste and the build-up of highly saline wastewater can increase pressure within rock layers weakening existing fault lines so that they slip, and release stored tectonic stress as earthquakes. Not all disposal wells produce earthquakes; it depends on the underground rock structure, the presence of faults and volume of waste injection. The largest earthquake in Oklahoma's history, a magnitude 5.8 earthquake in 2016, was directly linked to wastewater injection. The tremors from the earthquake were felt in six states. Impacts were relatively small-*scale* but would have been much worse if it had occurred in a more densely settled location. Currently, some *places* in Oklahoma are actually more tectonically active than the city of San Francisco which sits across the San Andreas fault line, on the edge of the Pacific and North American crustal plates.

Most earthquakes suspected of being triggered by injection wells are shallow and therefore usually less powerful than natural earthquakes. Geoscience researchers are now discovering that despite a reduction in injection rates in *places* such as Oklahoma and Kansas, earthquakes are getting deeper. It is suspected that the dense waste water is actually sinking deeper into rocks below the wells, putting pressure on surrounding rocks.

How are disposal wells monitored?

After the earthquake in 2016, 35 wells suspected of contributing to the earthquake were closed and energy producers were requested to cut wastewater disposal amounts by 40 per cent. A 'traffic light' system has been put in place for granting injection well permits. Using seismic data, induced earthquakes are monitored and if earthquakes occur above a given magnitude, waste injection is reduced or stopped. A green light *region* can have a normal drilling permit, a yellow light requires additional review and a red light indicates a complete ban.

An 'earthquake hazard forecast', in the form of seismic maps, has been produced for central USA that include human-induced earthquakes. It is calculated that more than seven million people in the *region* face increased hazard risks with a 5–12 per cent risk of an earthquake causing buildings to crack or collapse. The maps assist in developing emergency plans and building safety standards. Ultimately, the local citizens could face increased insurance and building costs.



▲ **Figure 6.26** The *distribution* of fault lines and epicentre of the Zipingpu disaster

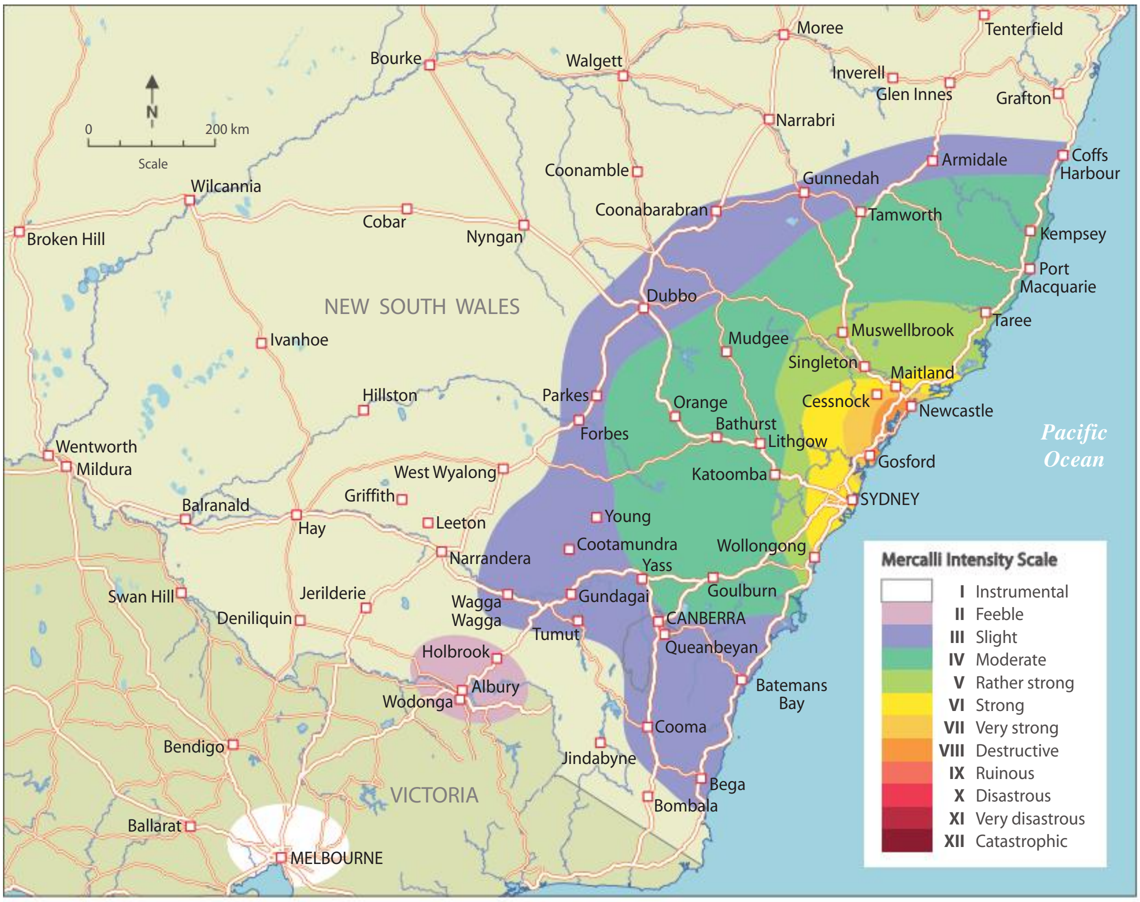
Earthquake hazards related to dam construction

The biggest human-induced quakes recorded have been related to the construction of large-*scale* dams. Globally, more than 100 earthquakes have been triggered by dams. Once a dam wall is constructed the valley behind is flooded and the sheer weight of this water can create instability in the surrounding rock. Water seeps into the cracks and fissures in the rocks, and when the pressure of the water increases it lubricates and allows slippage along the fault line. This was the suspected cause of the Koynanagar disaster in India in 1967 where 150 people died. Similar suspicions arose from a magnitude 7.9 earthquake in Sichuan, China, in 2008 which killed 80,000 people. The Zipingpu Dam holds 315 million tonnes of water and is located at a *distance* of less than 500 metres from a fault line and 5.5 kilometres from the earthquake epicentre. Figure 6.26 shows the *distribution* of fault lines in the dam *region*. The dam is one of 400 dams in the same earthquake hazard zone.

In all, almost half of China's new dams are in *regions* of high to very high seismic risk. In China, it is a legal requirement to conduct an Environmental Impact Assessment (EIA) for each proposed dam. However, many of the regulations are outdated and there is considerable red tape and corruption. EIAs are given only to individual dams, not a series of dams that 'cascade' down a river. Since rivers tend to flow along fault lines, there is sometimes a strong *spatial association* between river valleys and earthquake activity. There could be the risk of an earthquake damaging one dam and then the water flooding down the valley to damage further dams, creating a large-*scale* disaster. The design of dams and associated buildings, such as hydro-electricity plants, always takes into account seismic activity. In the event of an earthquake any one of a number of different hazards can develop, from landslides to cracks in dam walls.

Earthquakes caused by groundwater removal

The worst earthquake in Spain in half a century struck the town of Lorca in 2011. The earthquake registered 5.1 on the Richter Scale and its focus was only one kilometre deep. The impacts of the disaster included nine deaths, 300 people injured, collapsed and damaged buildings, and a repair bill of millions of euros. Geologists suspected the cause to be the over-pumping of groundwater. In the past 50 years the *region* has become an important agricultural centre for Europe, producing and *processing* fruits, vegetables and meat. Vast quantities of water for irrigation have been pumped from an underground aquifer, to the extent that the water table has dropped by 250 metres. At some point the reduction in pressure on the rock created a stress release creating an earthquake.



▲ **Figure 6.27** The use of the Mercalli Earthquake Intensity Scale to show the extent of the Newcastle earthquake

Earthquakes caused by mining

Australia's largest earthquake disaster occurred in Newcastle, New South Wales, in 1989. The magnitude 5.6 quake killed 13 and injured another 160 people while thousands of buildings were damaged. Figure 6.27 shows the *distribution* of the earthquake intensity. Recent research suggests that the earthquake was the result of more than 200 years of underground coal mining in the *region*. Along with the extraction of coal, groundwater had to be pumped out to prevent the mines from flooding. For each tonne of coal mined, four times more water needed to be extracted. This creates *changes* in the stress level of the surrounding rock triggering *movement* along a fault.

▶ ACTIVITIES

1. Refer to Figure 6.23. Describe the *distribution* of human-induced earthquakes triggered by mining activity.
2. Refer to Figure 6.24 and describe the *change* in the number of earthquakes (>3.0 magnitude) for Oklahoma.
3. Outline some of the benefits and drawbacks of storing toxic wastes underground compared to storing, burning or recycling the wastes on the surface.
4. a. Explain how human-induced earthquakes occur.
   b. Using Figure 6.25 describe the *spatial association* between the *distribution* of induced earthquakes and fluid injection wells in Oklahoma.
5. Refer to Figure 6.27. Use the *scale* to measure the furthest *distance* from Newcastle that the earthquake was recorded.
6. a. Using the data provided below, construct a pie graph to show the main causes for human-induced earthquakes.
   b. Describe your completed graph using data.

Cause of human-induced earthquakes	Percentage
fracking	33
mining	25
water reservoirs	16
oil and gas extraction	11
geothermal	6
waste fluid disposal	4
nuclear explosions	2
others (research, groundwater extraction, construction)	3

Source: https://inducedearthquakes.org/

What are the hazards related to nuclear power?

What is nuclear energy?

Nuclear energy was first conceived as a weapon during World War II and then developed as an energy source in the 1950s. In 2020 there were 440 nuclear power plants *distributed* globally.

Nuclear power is a very efficient, reliable source of energy. Compared to the burning of fossil fuels it does not produce large quantities of CO_2 and other greenhouse gases, making it a much cleaner alternative. Unlike hydro-electricity it does not require a vast quantity of stored raw material, thus reducing the expense of *moving* raw materials such as water, coal, gas and oil long *distances* via pipes, ships, rail or road.

What is nuclear waste?

Typically, over the lifetime of a nuclear power plant the amount of high-level radioactive waste would fit into an Olympic-sized swimming pool. The problem is there are no permanent facilities for storing high-level waste anywhere in the world. Once the power plant becomes too old or inefficient, it must be de-commissioned as it is highly radioactive. The average lifespan of a nuclear reactor is 40–60 years.

The International Atomic Energy Agency (IAEA) defines a nuclear accident as 'an event that has led to significant consequences to people, the environment or the facility'. Examples include people being exposed to large doses of radiation, the release of radiation into the *environment* or the meltdown of the core of a nuclear reactor from excessive heat.

The hazards associated with nuclear energy can be large-*scale* and have an impact over a very long time. Figure 6.28 demonstrates the various ways in which radioactivity can affect both people and the *environment*.

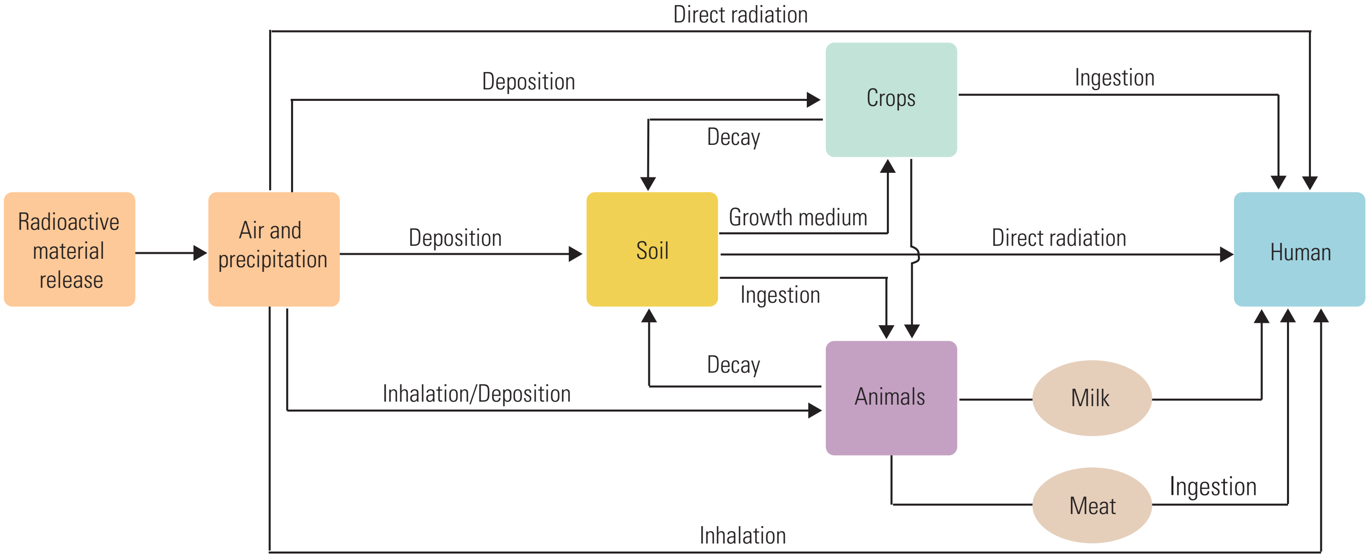
Chernobyl nuclear disaster

In April 1986, a failed safety test in a nuclear power plant in Chernobyl (former USSR) led to an explosion that blew up part of a reactor. The subsequent fire burned for a week and sent a radioactive cloud over the *region* and much of Europe. The amount of radioactive material released was calculated to be 400 times more than the Hiroshima atom bomb. The World Health Organization (WHO) estimates that 4000 deaths will result over time – from the initial disaster, radiation poisoning and cancers.

A 30 kilometre exclusion zone was established, forcing the evacuation of hundreds of thousands of people, many of whom have never been allowed to return. Dozens of towns and villages have been left abandoned. Trees in surrounding forests were destroyed and animals and plants suffered from mutations and stunted growth.

A concrete shell was constructed over the damaged power plant and then replaced in 2016 by a huge steel containment shield. Within this, workers are still trying to clean up the site and remove all radioactive material. Today, a new solar power plant, opposite the old ruined site, has started generating clean *sustainable* power. Tourism is a growing industry as people, on carefully guided tours come to view the ruins of deserted towns. *Environmentally*, much of the exclusion zone has evolved into a wildlife sanctuary as plants and animals have slowly adapted and are able to survive without human interference.

▼ **Figure 6.28** The *movement* of radioactivity through the Earth's spheres



▶ CASE STUDY Fukushima nuclear disaster, Japan

Japan is a country with limited natural energy resources and so has been dependent on importing 90 per cent of its energy requirements. Nuclear power offers Japan a small but significant alternative energy source to fossil fuels, and by 2011 was providing 30 per cent of the country's energy needs. Figure 6.29 shows the *distribution* of the main nuclear power plants.

▲ **Figure 6.29** The *distribution* of Japan's main nuclear power plants (as at 2018) and the location of the earthquake epicentre

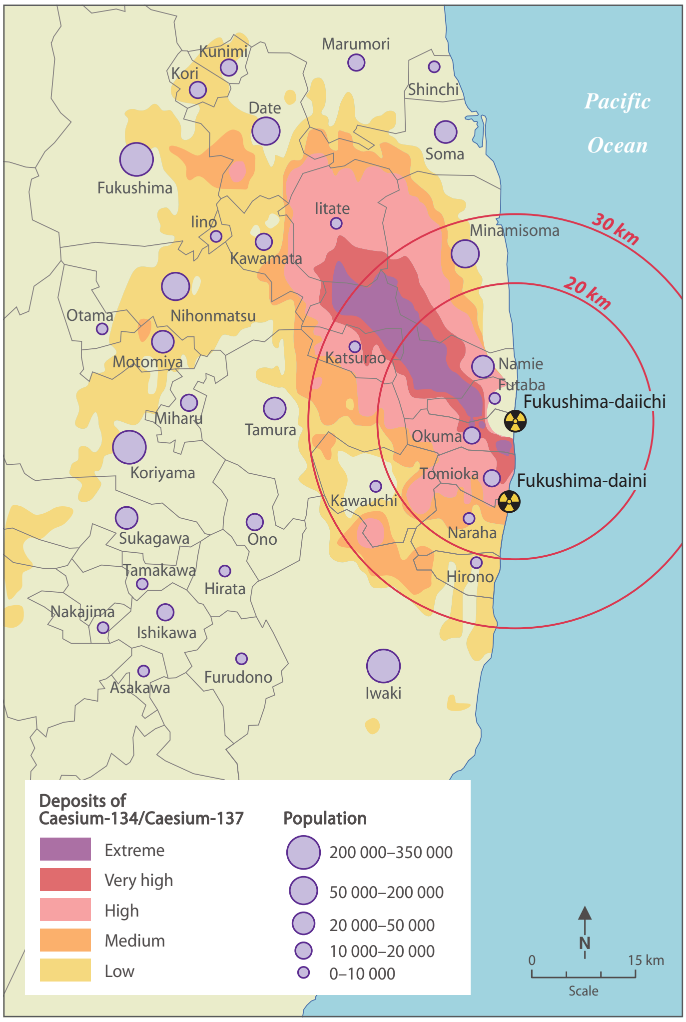
A magnitude 9.0 earthquake which triggered a tsunami struck the east coast of Japan on 11 March 2011 (Great East Japan Earthquake, page 48), seen in Figure 6.29. The three nuclear reactors at Fukushima were automatically shut down when powerlines were damaged. The tsunami flooded the powerplant and destroyed the backup generators and batteries. Without power, the operators were unable either to monitor the situation or to effectively cool (by pumping water) the reactors still generating radioactive heat. Temperatures as high as 2800°C melted much of the core and fuel rods in three of the reactors. Radioactive gases were vented to the atmosphere while hydrogen explosions caused significant damage to the buildings, further hampering disaster management.

Unlike previous nuclear accidents (largely caused by human error or design faults), in this instance an *interconnection* occurred when a natural disaster set in motion a large-*scale* technological disaster.

What were the impacts of the disaster?

Impacts on the *environment*

Radioactive gases, for example caesium, were vented from the power plant and dispersed by winds to the surrounding *region*. Initially, winds blew the radioactive material out to sea but a *change* in weather brought south-westerly winds and rain which precipitated much of the contamination to the ground. The *distribution* of caesium can be seen in Figure 6.30.



▲ **Figure 6.30** The *distribution* pattern of caesium released from the nuclear disaster

Caesium can *move* through the *environment* via the water cycle and can contaminate water, plants and soil, concentrating up the food chain in a *process* called bio-accumulation. Eating contaminated food can lead to a build-up in organs, with children being more susceptible than adults. By 23 March radioactive contamination of Tokyo's drinking water was detected at twice the acceptable level for children. Contamination was discovered in a wide range of food products including spinach, tea leaves, milk, beef and freshwater fish caught at a *distance* of 200 kilometres inland from the plant. Agricultural products that have caesium levels above legal standards cannot be sold or exported. Radioactive areas are difficult to clean up as water from melting snow and run-off collects contaminants which can then be *moved* via rivers to the coast.

Large quantities of both freshwater and seawater were used to cool the reactors down and much of this water was discharged or leaked into the ocean. Initially, coastal fishing was banned, but has since recommenced. However, the public perception of 'safe' has meant that demand for local fish is only 8 per cent of pre-disaster levels.

Figure 6.31 Radioactive waste from the Fukishima site

Waste	Current storage
Accumulated 64,700 m³ discarded protective clothing worn by clean-up workers. Ongoing collection.	Compressed and stored in 1000 steel boxes. May eventually be incinerated.
80,000 m³ of trees cut down from the plant site after radioactive gases released. The entire area has been paved over to seal in contaminated soil.	Stockpiled and eventually will be incinerated.
Explosions during the initial meltdown filled the area with concrete, steel, pipes and hoses. Over 200,000 m³ rubble now collected.	Stored in custom made steel containers, the equivalent of 3000 standard shipping containers.
1537 nuclear fuel rods (used for fuel in reactors).	Currently still in original cooling ponds inside the destroyed reactors. Highly radioactive and require constant water cover. Still working on plans for their disposal.
A rough estimate of 117 tons of molten fuel and debris accumulated beneath the reactors after the meltdown.	It is not safe to send humans anywhere near this and several robots have been destroyed by radiation. There is no current technology to deal with this waste.
More than 1.1 million tons of contaminated cooling water is being treated and stored in 1000 large tanks on site as seen in Figure 6.32 The water has originated from the initial explosions and firefighting, cooling the reactors and groundwater seeping on to the site.	By 2022 all of the tanks will be full. There is a strong possibility water will be released into the ocean. At least 17 years would be needed to dilute the water to a safe level for dispersal. There is great opposition from fishermen, residents and environmentalists concerned over the possible health impacts and the negative image it will give the *region*.
The *process* of decontaminating the water accumulates radioactive sludge in the filters.	Currently stored in 3519 containers. Experiments being conducted with mixing it with iron or cement, then this will have to be stored in some manner.

Figure 6.32 Storage of radioactive waste water in large tanks on site at the crippled power plant

Impacts on people

The hazard event of contamination from the power plant forced the *movement* of more than 160,000 people living in *places* up to 40 kilometres away. The evacuation, initially started with a three kilometres radius, extended to 20 and then 40 kilometres by mid-May. Many of these residents will never be permitted to return. The evacuation prevented radiation exposure and to date there are no recorded deaths from radiation, although incidences of cancers and other long-term health issues are still a possibility.

There were many cases of evacuation stress among the evacuees, with over 1000 deaths reported. Approximately 90 per cent of the deaths were in people aged over 66 years, with 70 per cent occurring within the first three months after the disaster.

These premature deaths were related to the physical and mental trauma of being forced to *move* from homes and living in temporary shelters, as well as the delay in obtaining medical support due to the enormous destruction caused by both the natural and human-induced disasters.

By 2020, 46,000 Fukushima residents remained displaced, with 24,000 denied access to the 'no-go' zone (an area covering 337 square kilometres) because of high levels of radiation. In *places* where the evacuation orders have been lifted, only 13 per cent of original residents have returned. There are several reasons for the slow return:

- many people still fear high levels of radiation, especially young families who do not wish to raise children in the affected *region*
- slow recovery of essential infrastructure such as shops, restaurants and medical services
- some have now established themselves in other *places* and prefer to stay
- a lack of employment opportunities as 50 per cent of companies lost their customers during the evacuation.

Additionally, 27,000 people who chose to voluntarily evacuate have now had their government housing assistance stopped, which may force them to return out of financial necessity.

Tourism to the affected *region* is now possible and the Summer Olympics in 2020 (postponed to 2021 due to COVID-19) started the torch relay in Fukushima with the hope of *changing* people's perception of the *place*.

No-one has been able to accurately calculate the value of abandoned farmland, cities, towns, businesses and houses within the 800 square kilometres 'exclusion zone'. Estimates of the economic losses have ranged in *scale* from US$250 billion to US$500 billion.

What were the responses to the disaster?

National *scale*

Since the disaster, the Japanese government and nuclear industry have been faced with a multitude of technical, economic, political and social challenges. The decommissioning and dismantling of the Fukushima power plant is expected to take at least 40 years with an estimated cost of $US188 billion and employ more than 7000 people in the *process*.

Large-*scale* efforts are needed after any nuclear accident to prevent the release and *movement* of radioactive materials into the atmosphere or into the ground. One of the biggest problems is what to do with the radioactive waste that accumulates daily. Figure 6.31 gives an indication of the *scale* of this waste.

Another concern is the *movement* of groundwater from surrounding hills which was seeping into the reactor buildings at the rate of 151,000 litres per day. To prevent the groundwater from becoming contaminated an 'ice wall' was constructed around the plant. Fifteen hundred pipes were laid deep in the soil and refrigerant was pumped in to create a barrier of frozen soil, effectively preventing any further *movement* in or out of the site. Despite some leakage the ice wall has effectively reduced the volume of water to less than 200 metric tons per day. Figure 6.33 shows the location of the storage tanks and ice wall.

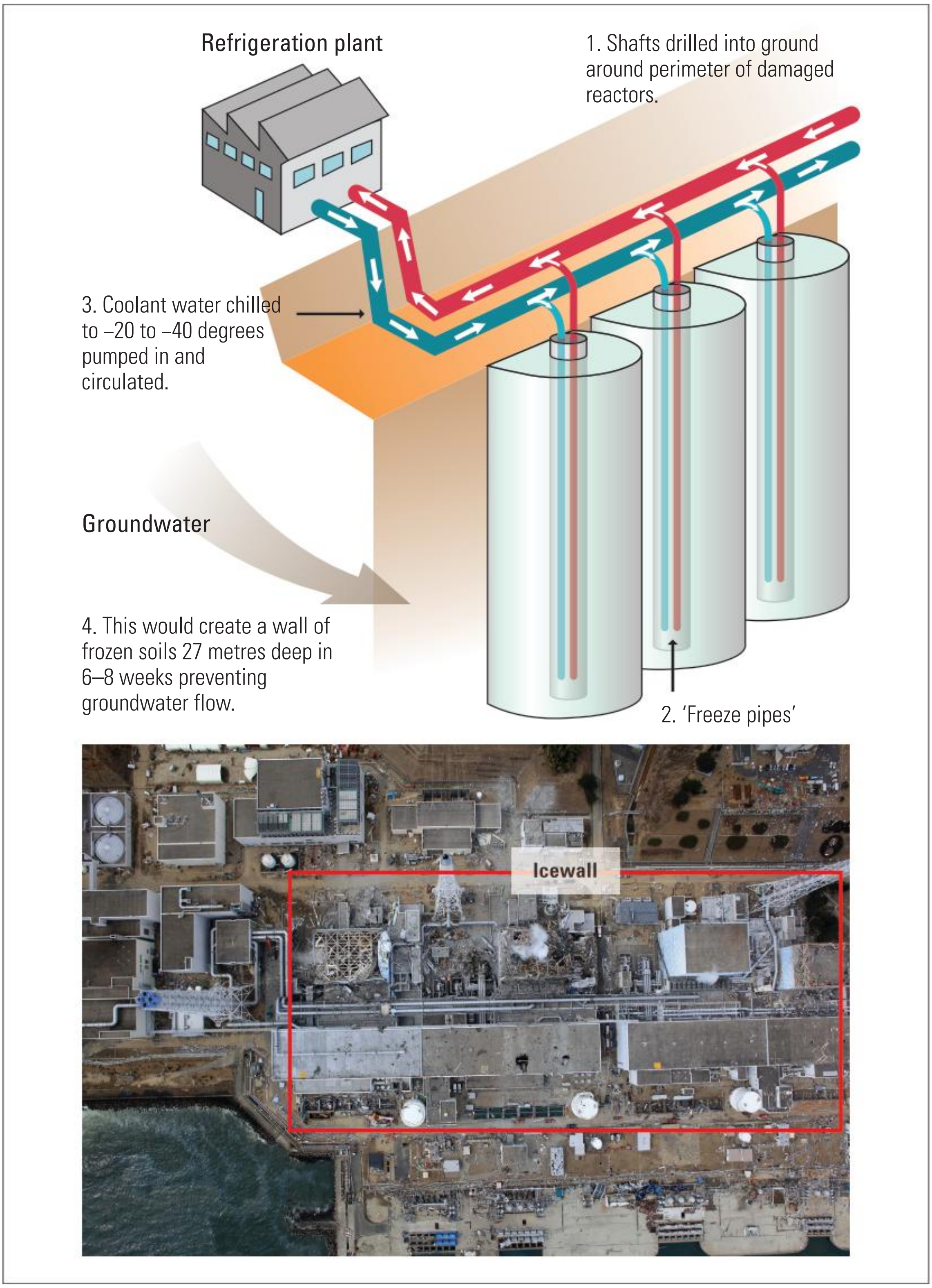


Figure 6.33 The location of the ice wall and storage tanks

Also necessary is the decontamination of the surrounding *region* to make it safe for people to return and resume a normal life. Mostly farmland and residential areas have been targeted, with forested areas deemed as being too difficult to clean up. Forests cover 75 per cent of the land area within the radioactive fallout zone.

To date, this *process* has cost $US26.5 billion. At least 75,000 workers have been involved in scrubbing roads, walls, roofs, gutters and drain pipes of buildings. Trees, shrubs, grass and topsoil has been stripped from the *environment*. Contaminated top soil has had to be scraped to a depth of five centimetres and bagged up (see Figure 6.34). Some of the soil is buried in gigantic pits while elsewhere the 2667 bags are stockpiled on unused land. The soil will need to be stored for at least 30 years and must be protected from leakage and storm damage. In 2019, the heavy rains from Typhoon Hagibis washed away 90 bags of soil. Intensive searching recovered 50, but more than half had leaked their contents into local rivers.

Local residents, who do not want to live near a toxic waste dump have been promised by the government that it will be *moved* from the *region* to a permanent site by 2045. As yet, there is no alternative site.

At the time of the disaster all nuclear power plants were shut down. The government has now permitted nine plants to restart having passed stringent new testing. Currently, nuclear energy accounts for only 1.7 per cent of Japan's electricity, compared to 30 per cent prior to the disaster. The aim is for nuclear to supply 20–22 per cent of the country's energy needs using 30 reactors by 2030. This target is unlikely to be met due to local opposition and legal challenges. The country also faces both internal and external criticism for its *unsustainable* reliance on fossil fuels, being the third largest importer of coal after India and China.

Global *scale*

International support was given to assist Japanese authorities with the disaster. Technical advice and specialised equipment – for example, surveillance drones, remote cameras, high pressure pumps and radiation monitoring equipment – was sent. The United States, in particular, continues to work with Japan on the decommissioning of the plant and *environmental* remediation.

Nuclear power plants across the world are carefully designed to withstand earthquakes, especially as

CAREER PROFILE

Kathryn Walker

Catchment Analyst, Wimmera Catchment Management Authority

Unfortunately, Geography (or Environmental Science) wasn't offered as a VCE subject at my secondary school, but I did study Geography at university. I studied a Bachelor of Environmental Science, completing a double major in Geographical and Environmental Science and Ecology and Conservation Biology. The Geography component was quite varied and included GIS (Geographical Information Systems) and remote sensing, climatology, sustainable cities planning, soil and vegetation relationships and even the geopolitics of climate change.

I use GIS to create maps of catchment features to analyse spatial relationships and help my organisation to make regional natural resource management decisions. This includes interpreting flood-modelling data, building maps of priority actions and collating information about onground works. I'm also involved with monitoring catchment conditions at a regional scale, which is reported against the Wimmera Regional Catchment Strategy. My role is based in the GIS team, so I work quite closely with other geographers/spatial scientists. I also work with hydrologists and hydro-ecologists.

Studying Geography provided me with an understanding about how different natural processes, such as the water cycle, interact with one another and I can apply this to a natural resource management context. I use this knowledge to help the organisation develop integrated catchment management activities.

I like how Geography incorporates a variety of natural science disciplines and shows how they interact with each other and the human environment. As a geographer, I'm exposed to subjects like geology, hydrology, climatology, soil science, biology and climate-change science. It's a very dynamic and variable field.

There is a variety of career opportunities for geographers from local government, research, defence, natural resource management etc. Try to have a think about what sort of industry you would like to work in and research the job requirements, then tailor your studies accordingly. In this field, lots of jobs will list experience in GIS as a desirable skill. I would encourage enthusiastic geographers to volunteer or go on placement while studying.

20 per cent of them are operating in *regions* of significant seismic activity. In the case of Fukushima, no-one had predicted or sufficiently prepared for the *scale* of the tsunami following the earthquake and planned sufficiently for the loss of multiple power sources in the event of an accident. Japan is one of the most experienced and well-equipped countries when it comes to preparing for natural disasters. Yet the *scale* of the combined natural and human disaster was beyond their expectation and capabilities.

The global nuclear community is still learning the lessons from the disaster. The design of new nuclear power plants now takes into consideration severe external hazards, while mobile systems for providing electricity or cooling water are being developed. Safety standards have been tightened, peer reviews of power plants and international cooperation have all been improved. Such steps are taken to improve emergency preparedness and response as well as winning back public support for nuclear energy. Many countries, particularly in Europe are planning to phase out nuclear energy.

How has geospatial technology assisted in the responses?

The inside of the damaged power plant is highly radioactive, so it has been impossible to view the extent and *scale* of the damage caused by the reactor melt downs and explosions. Remote controlled robots are being developed to enter the crippled plant to send back images of the damage and, specifically, the state of the fuel rods. Early attempts with robots failed as they were damaged by radioactivity.

Satellites are used to safely study the *changes* in vegetation and other land cover around the evacuation zone. The most significant *change* has been the conversion of abandoned farm land to natural vegetation. Trials have been done with unmanned aerial vehicles (UAV) armed with radiation detection devices. These are used to create 3D contamination maps and can even capture, in real time, the *movement* of contaminated water. Drones are being used as remote radiation imaging systems. They are compact, inexpensive, and well suitable to small-*scale* work such as identifying radioactive 'hotspots' including rain gutters and cracks in the road. Information can be visually represented on 3D topographic maps.

Future of the *region*

A group of investors is now working towards *changing* the Fukushima *region* from a nuclear energy centre to an alternative energy hub. Ten wind farms and eleven solar power plants are planned for construction on some of the contaminated farmland and forested areas. Once operational, these could generate two thirds of the equivalent output from one nuclear reactor. The target is to create *sustainable* renewable energy to supply 100 per cent of the *region's* electrical needs by 2040 and supply electricity via a new grid to Tokyo.

▼ **Figure 6.34** Decontamination to the local *environment* in the Fukushima *region* in **(a)** September 2012 and **(b)** March 2014

▶ ACTIVITIES

1. Study the information provided in Figure 6.28. Describe the different pathways that radioactivity can take to affect people.
2. a. Create a tracing of the map in Figure 6.29 showing the *distribution* of major nuclear power plants in Japan.
   b. Locate in your atlas or online, a map showing the *distribution* of the major crustal plates that affect Japan. Create an overlay to show this information on the map you created in part a.
   c. Describe the *spatial association* between the *distribution* of plate boundaries and nuclear power plants in Japan.
   d. What does this association mean for the nuclear industry in Japan and other *places*?
3. a. Refer to Figure 6.30. Using the *scale* provided, calculate the approximate area affected by extreme caesium fallout.
   b. What was the predominant wind direction for the day these readings were taken?
4. What potential hazards are unique to nuclear power plants accidents?
5. In what ways is the public perception about radiation safety affecting the recovery efforts after the Fukushima disaster?
6. a. Refer to Figure 6.34. Describe the *environmental changes* that have taken place between September 2012 and March 2014.
   b. Suggest two challenges that might exist if people were allowed to return to this *place* and continue farming.
7. a. Compare the advantages and disadvantages of nuclear energy.
   b. Is nuclear energy *sustainable*?
8. a. What is the purpose of exclusions zones after nuclear disasters?
   b. How effective are they as a response to a nuclear disaster?
9. Research the Chernobyl nuclear disaster and draw up a table that compares the similarities and differences in the responses to the nuclear incidents.
10. Extension activity: conduct some research on another technological hazard – dead zones in the Gulf of Mexico. Provide a map of the issue, outline the causes and possible solutions.

7 Exploring hazards in the field

You may not realise it, but individuals, organisations, local councils and even governments are conducting fieldwork and gathering data in order to explore questions and solve geographic problems. Fieldwork is research undertaken in the field – that is, at a specific site – using specific field techniques as opposed to the kinds of research you might conduct in the classroom or in a library. Fieldwork gives you the opportunity to carefully observe and measure characteristics and *changes* of human and natural *environments* and to record your observations. Fieldwork commonly starts with problems that you wish to explore at a location.

In Unit 1 Geography, fieldwork helps us to understand a particular site that is, or is likely to be, impacted by a hazard or a hazard event. This can be seen in Figure 7.1, where students are investigating the *distribution* and *scale* of introduced weeds (in this case pasture grasses) in a wetland ecosystem. Winton Wetlands, located near Benalla in north-east Victoria, occupies over 8750 hectares, of which approximately 1800 hectares is used for farming and agriculture. Introduced pasture grasses can have a detrimental effect on native flora (such as cane grass) in the *region*. In order to investigate this biological hazard, students are using a transect along which to collect soil samples and to identify vegetation species. They will then be able to determine whether revegetation efforts are having the desired effect and what else could be done to reduce the negative impact of introduced species.

Another hazard that fieldwork could be conducted about are level crossings. Figure 7.2 shows a level crossing on Bell Street in Preston in Melbourne's north. A level crossing is a location where roads and railway tracks cross at substantially the same level. Level crossings are an example of a technological hazard. Risk taking behaviour at level crossings is a significant issue, with more than 60 collisions between train and road vehicles in the last decade in Victoria.

▲ **Figure 7.1** Students conducting fieldwork at Winton Wetlands, Benalla

Figure 7.2 Level crossing maintenance on Bell Street, Preston where high levels of traffic congestion occur

Erosion is an example of a geological hazard you might conduct fieldwork on in a variety of *environments*, from the farm to the coast. At Inverloch, located 140 kilometres south-east of Melbourne, locals are trying to defend the local Surf Life Saving Club from erosion that has pushed the shoreline back 50 metres inland in seven years (Figure 7.3).

The discolouration of Five Mile Creek in Essendon in May 2020 (shown in Figure 7.4) could also be investigated using fieldwork techniques. When hazardous material and chemicals drain into waterways, they can significantly damage natural ecosystems as well as cause economic losses (for example, the cost of cleaning the spill).

The fieldwork investigation, no matter where it is based or what kind of hazard is chosen, will include an examination of the geographic characteristics of the location, the factors affecting the risk level of the hazard, an exploration of the impacts of the hazard on the community, and a description of some of the responses and mitigation efforts put in place.

Figure 7.3 Erosion of the foreshore at Inverloch, Victoria

Figure 7.4 Bright green liquid in Five Mile Creek, Essendon

ACTIVITIES

1. When seeking to understand hazards and disasters, why do you think it is important to conduct fieldwork? Refer to specific hazards that you might have studied in class in your answer.
2. In Figure 7.1, students are using a transect to collect soil samples and to identify vegetation species. As a class, discuss what other information you would need in order to further explore the impact of introduced species in a *region* such as Winton Wetlands.
3. Refer to Figure 7.2 showing a level crossing. In relation to hazards, what questions could be asked about a level crossing in a particular location? Attempt to incorporate Geographic Concepts in your questions. For example, to what extent does a level crossing affect the *movement* of road traffic during peak hour?
4. Refer to Figures 7.2, 7.3 and 7.4 and describe the factors that may affect the risk level for people, *places* and the *environment* or the impacts of a hazard event in the location.

Fieldwork locations

As Geography is a spatial study (i.e. examining the *distribution* of things in a particular space), the location where fieldwork will be undertaken is a key parameter. *Places* that have experienced hazards, or are at risk of experiencing a hazard, will be impacted in *environmental*, social and economic ways. Fieldwork should assist you in understanding, analysing and evaluating the various factors affecting the risk level for people, *places* and *environments*. Fieldwork sites are generally chosen as an easily accessible and clearly evident example of the geographical patterns and *processes* that you seek to understand – in this case showing evidence of particular hazards at a local *scale*.

You may have some influence on the choice of fieldwork site or your teacher may select the site for you. Before going out in the field you will need to spend some time understanding the site. You will need a map that shows the location of your site in relation to its *region*. Maps can also be used to explore different features of the site and its surrounding *region*. You need to think about why the site was selected, the hazards affecting it and the types of research questions you might want to explore.

Examples of locations associated with hazards and hazard events could include:

- Geological hazards (see Chapter 3) such as erosion and landslides. For example, along river banks, cliffs, on land denuded of vegetation or in mountainous areas.
- Hydro-meteorological hazards (see Chapter 4) such as bushfires and floods. For example, fire locations across the state or river and creek flooding locations in both rural or urban areas.
- Biological hazards (see Chapter 5) such as hazards associated with living organisms. For example, plant/animal invasion of blackberries, rabbits or thistles.
- Technological hazards (see Chapter 6) such as hazards associated with the built *environment* and transportation. For example, pedestrian crossings or contaminated soil resulting from industrial use.

Figure 7.5 shows the *distribution* of landslide susceptibility in Victoria which is an example of a hazard you might explore during fieldwork. There is a strong *spatial association* between steep coastal *regions*, such as the Great Ocean Road, and *regions* with a high to very high susceptibility of landslides. In 2016 alone, over 180 landslides occurred along the length of the Great Ocean Road. Landslide events resulted in significant impacts on public infrastructure, tourism and the economy. The occurrence of landslides in this location was studied as part of the Great Ocean Road Resilience Project. A result of this study has led to an attenuator, which is a giant steel mesh net designed specifically to catch falling rocks that break away from the cliff face, being installed in August 2020 (Figure 7.6). This *process*, from understanding the causes and consequences of the hazard or hazard event at a specific location, to responses and risk management techniques, is one that you will follow as you conduct fieldwork. Examining *spatial association* allows us to investigate the possible causes of different *processes* – for example, landslide hazard is greatest in areas with steep slopes such as near the deeply eroded cliffs and along the steep geological fault lines along which the Great Ocean Road was built. Other, flatter, coastal *regions* may have very little, or no, susceptibility to landslips.

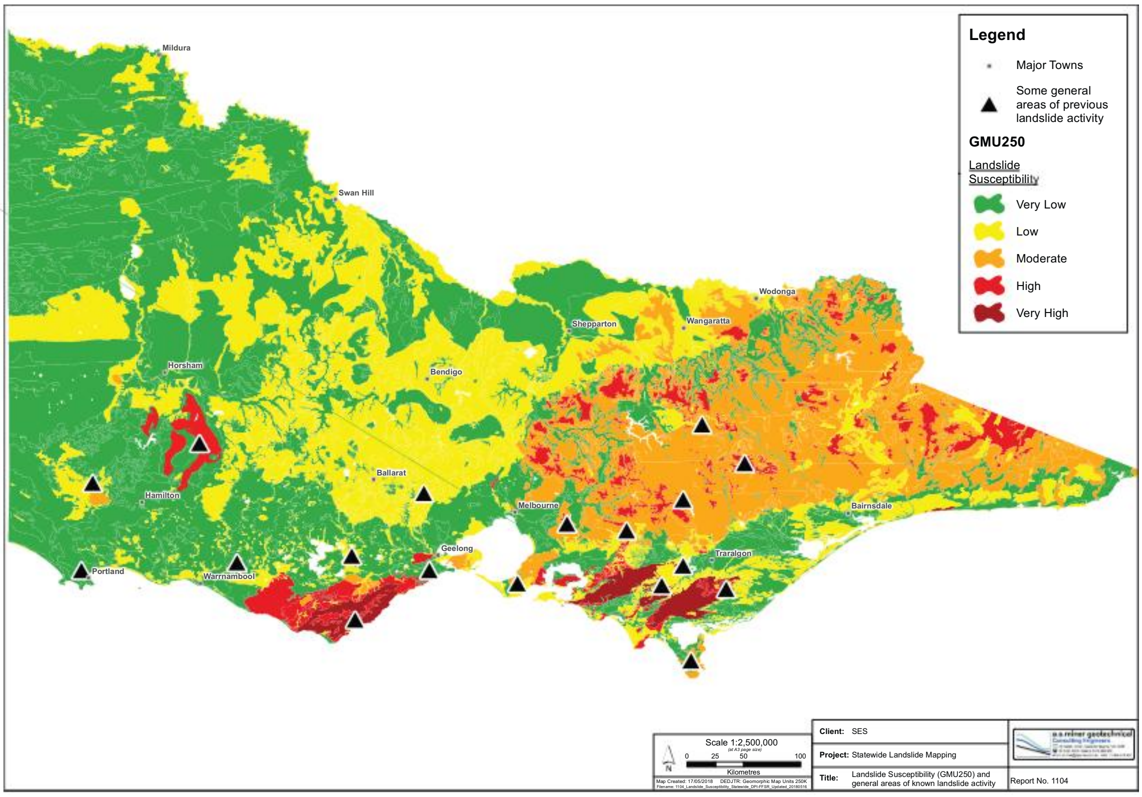


Figure 7.5 Landslide susceptibility in Victoria

Figure 7.6 An attenuator used to stabilise the 160 metre cliff face at Cumberland River on the Great Ocean Road

ACTIVITIES

1. Discuss with other members of your class, hazards that exist in the *region* of your school.
   a. Classify the hazards that you identify using geological, hydro-meteorological, biological and technological criteria. An example could be tripping hazards such as cracked or uneven footpaths that could cause injury.
   b. In what ways could your school manage the risk associated with the hazards you have identified?
2. Refer to Figure 7.5. Describe the *distribution* of *regions* with a high to very high landslide susceptibility.
3. What factors could contribute to a *region* having a high susceptibility to landslides? Consider the *spatial association* between landslides and other *environmental* as well as human-created features and *processes*.
4. Brainstorm, through the creation of a mind-map, some of the possible impacts of landslides along the Great Ocean Road. Categorise the impacts as *environmental*, economic and social.

Developing your fieldwork plan

Fieldwork is a significant type of a geographic inquiry. Figure 7.7 shows a commonly used framework for geographical inquiry involving the following steps:

- ASK geographic questions
- ACQUIRE geographic resources
- EXPLORE geographic data
- ANALYSE geographic information
- ACT on geographic knowledge

The five stages of the geographic inquiry *process* mirror the steps you will take as you undertake fieldwork and write your fieldwork report.

Once you have a location, the next step is to get to know the site. Knowing the characteristics of a fieldwork site, including the connection of the site to the surrounding *region*, can assist you in working out what further information you might need to gather from secondary sources and what primary data you will need to collect to explore a hazard in your selected location.

The graphic organiser in Figure 7.8 has been designed to assist you with the first stage of preparing for your fieldwork and developing your fieldwork plan. Start by defining the hazard you are investigating and describing the location (both relative and absolute) of your fieldwork site. Use secondary sources, such as articles, maps, books and websites, to learn about the geographic characteristics of your site and to help you refine your area of interest, research question and hypothesis.

Figure 7.7 The five stages of the geographic inquiry *process*

Figure 7.8 Before fieldwork

STEP 1: Before fieldwork

Hazard/hazard event	
Defining the hazard	
Location of fieldwork site	

Characteristics of fieldwork site

I am investigating … because I want to find out who/what/when/whether/why/how …

Because I want to find out …

Because I want to find out …

I am investigating …

Because I want to find out …

Because I want to find out …

Hazard diamond ranking: can be used to rank causes or impacts of hazards

Research question:

Hypothesis:

Asking Geographic questions and developing a fieldwork hypothesis

Now that you have explored the fieldwork site, you can develop your research question. Geographers begin with a broad area of interest within the location which are often called topics. In order to conduct your fieldwork, you need to construct a carefully and clearly defined research aim, question and hypothesis. These will guide you through what data you need to collect in order to respond to the question and write your fieldwork report.

Brainstorming a range of questions will assist in refining your topic and opening up different avenues of exploration. Good geographic questions range from "Where have hazards occurred at this location?" to "How have hazard events *changed* the location?" to "What is the impact of these *changes* on people and the *environment*?" Asking geographic questions is the first stage in the geographic inquiry *process* and is a crucial part of your fieldwork and fieldwork report.

At the beginning of your investigation, sometimes it is hard to get past the first step of naming your topic. A useful way to test your progress, is to explore your topic and to flesh out the details, like the steps shown in Figure 7.9.

Your research question will form the basis of your hypothesis. The hypothesis should be a statement on a single topic arising from your research question. For example, if we chose the last question in the table, we could develop a hypothesis such as invasive weeds in Ringwood Lake Park have a larger impact on bird watchers than on picnickers. In Geography, the hypothesis typically involves an observation about *spatial association*, how one variable causes another to occur or the impact of one variable across the study area. To make testing most effective, and to avoid confusion, limit your hypothesis to the variables of cause and impact. If there were multiple sites, geographers might investigate how cause and impact varies with location (or *scale*), however, this is likely to be beyond the scope of fieldwork at a school level. The influence of 'location' on causes and impacts might be listed as a 'further question'. Further questions will form as a result of prior reading and class discussion, questions that may be best answered after visiting a site and collecting data.

Ethical dilemmas and fieldwork

Where possible, your fieldwork data collection should be designed in a way to increase its credibility and reliability and to avoid unnecessary bias and ethical issues. It is important to sample your data in a planned way to ensure that data can be trusted to give an accurate representation of the investigation. The ethical treatment of people and the natural *environment* in fieldwork is a fundamental principle of good research practice. When undertaking fieldwork, the chance of harm to yourself, to other people and to the *environment* must be limited as much as possible. Harm can be defined as both physical and psychological. This is particularly important when undertaking fieldwork on the impact of hazards on a community where people may have experienced traumatic experiences of a hazard event such as a flood or bushfire.

▼ **Figure 7.9** Steps to follow to flesh out your topic

		Example
Location	Where	*Ringwood Lake* (pictured below)
Hazard	What type of hazard	*Biological – invasive plants*
Your topic	What you are investigating	*I am investigating weeds around Ringwood Lake.*
Your question	What you don't know about it	*I want to find out: (you only need 1 question)* *What weeds are found around Ringwood Lake?* *How are weeds distributed around Ringwood Lake?* *What has been done to manage weeds around Ringwood Lake?* *How do plant invasions affect indigenous vegetation around Ringwood Lake?* ***What is the impact of weeds on recreational activities around Ringwood Lake?***
Your rationale	Why you want to know the answer to your question	*I want to understand the impact of weeds on people who use the Ringwood Lake Park.*

ACTIVITIES

1. Refer to the geographic inquiry *process* (Figure 7.7) and think back to fieldwork that you have undertaken at school. Briefly outline how your previous fieldwork experience aligns with the geographic inquiry *process*. Consider the questions you asked, the resources and data you gathered, how you analysed the information and what you did with your new knowledge.
2. Refer to the graphic organiser in Figure 7.8.
   a. Name and define the hazard/hazard event you will be conducting fieldwork about. Describe the relative and absolute location of your fieldwork site.
   b. Do an internet-based search, using reputable and credible websites, to further explore the hazard/hazard event and geographic characteristics of your fieldwork site.
   c. Make a list of the factors that cause the hazard and use the graphic organiser to rank the importance of these causes. Justify your decisions.
3. Consider the following fieldwork questions:
   - "What were the impacts of the Black Saturday Bushfire on the town of Marysville and how has the natural and human *environment* recovered since?"
   - "How are weeds dispersed in the Shire of Nillumbik and what are the impacts of weeds on indigenous plants and the biodiversity of the natural ecosystem?"

   a. Select one of the questions above and use the following 'question criteria' to help you further refine and explore the question:
      - Is the question substantial and significant?
      - Is the question specifically and precisely worded?
      - Is the question practical and manageable (time constraints, access to the site, etc)?
      - Does the question allow for different fieldwork techniques in order to collect primary data?
      - Are there any ethical concerns that the question raises?

   b. Create a hypothesis for the research question you have chosen. Remember that hypotheses usually take the form of a reasonable statement on a single topic that can be tested. Compare your hypothesis with those created by two other members of your class.
   c. How might you collect 'good' data to help you to test the hypothesis? What primary and secondary information do you need?
   d. Create a flow diagram or map out the fieldwork *process* using one of the research questions.
4. Use the table in Figure 7.9 to test various research possibilities for your selected fieldwork location. This table should help you evaluate a range of generic topics before refining one into your research question. Geographic Concepts should be used to help you generate questions.

Gathering Geographic resources

The second stage of the geographic inquiry *process* involves acquiring geographic resources. This includes both primary data and secondary data sources.
In the planning stages, thoroughly prepare the kinds of activities you will be undertaking on your field trip. This will ensure that your fieldwork experience provides you with sufficient data to respond to your research question and to test your hypothesis.

The graphic organiser in Figure 7.10 aligns with the second stage of the inquiry *process*, planning your fieldwork and research. Use it to outline the primary and secondary data sources that will assist you in responding to your question. Remember that you will be asked to justify these choices.

Quantitative and qualitative data

Your fieldwork should be designed to gather both quantitative and qualitative data.

- Quantitative data refers to the kind of data that you can measure and count and can be recorded in terms of numbers. This includes counts, statistics collected by government and maps you have made showing the location of a characteristic.
- Qualitative data generally refers to information about the qualities of phenomena and is useful in understanding why people behave in particular ways. These qualities might or might not be quantifiable and are often subjective because they involve opinions such as people's attitudes, observations, knowledge or feelings. Examples of qualitative data include interviews, field sketches, photographs or observations such as "There was a lot of rubbish in the area around the playground".

Primary data sources

Primary data is the data you collect in the field in order to answer your research question. You want to ensure that you collect appropriate data that helps you to test your hypothesis. After formulating your hypothesis, make a list of ways in which you might collect primary data in the field. It is important to have multiple sources of data which ensures credibility of your findings and conclusions. Consider using a combination of the primary fieldwork techniques shown in Figure 7.11. Each technique listed in the table have their own strengths and weaknesses. For example, photographs and sketches can help illustrate and highlight features, characteristics and *processes* relevant to your fieldwork site. However, you also need to consider what is not shown in the photograph or sketch and the impact this might have on responding to your research question.

Figure 7.10 Planning fieldwork and research

STEP 2: Planning fieldwork and research

Primary data collection

Data collection technique, including materials	Justification: How it helps you respond to the research question

Secondary sources

Secondary source 1

Title:

Author:

Secondary source 1

Title:

Author:

What do the sources tell you about the topic of investigation?

Source 1

Source 2

In what ways are the sources connected to your primary data?

Source 1

Source 2

How do the sources help you respond to your research question?

What further information do you need? What is missing?

This is not to suggest that only two secondary sources are to be used.
This should only be used as an example and more sources should be added to it.

▼ **Figure 7.11** Primary fieldwork data collection techniques

Fieldwork technique	Description and purpose
Field observations	General notes taken of the site of investigation. These are things that you notice as you interact with, and move through, the site.
Photographs	Photographs of areas within the field work site that help illustrate certain features of the site and investigation including evidence of patterns and *processes*.
Sketches	Annotated sketches of the site can be used to show the *interconnection* (including *spatial association*) of features as well as important *processes*.
Counts	Counts of vehicles or people *moving* through a predetermined point within an indicated time frame. Count of trees or other elements found within the area.
Transects/cross sections	A line along which a record is made of the location of particular features used to determine the differences in land cover over a given area. Plant species should be identified.
Quadrats	A small area randomly selected is identified and the physical components of the *environment* are catalogued. This includes all the living and non-living, organic and non-organic material in an area (usually a metre square). The contents of different quadrats can be compared.
Habitat assessment rating	Different aspects of the *environment* are rated such as noise, building condition, greenery etc.
Questionnaire	A set of short written questions, often multiple-choice, asked to people who are affected by a phenomenon in a given *region*.
Interviews	Usually a 1:1 discussion with a chosen person to provide more in depth and detailed information on the investigation focus.

Annotating photographs and field sketches

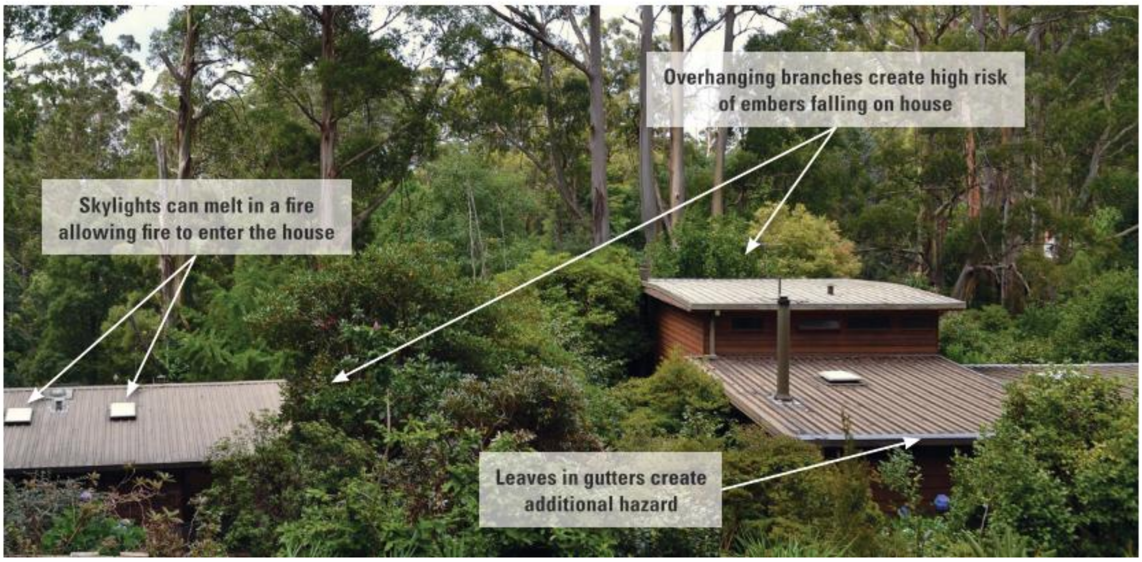
Make photographs taken during the field trip more useful by adding annotations (Figure 7.12). These could include labels of *places* or features, notes about your observations on the day or notes about the landscape or geographical features of the location.

Field sketches can be created by hand from your observations during the fieldtrip or from photographs you take. There are also applications that can do this for you. Figure 7.13 shows a photograph taken and a field sketch drawn with annotations of the *environmental* features.

Constructing transects

Transects are constructed usually by groups of students allocating tasks to different members of the group. They can be used to show the location of elements of both the living and non-living *environment* that occur along the transect. Depending on your hypothesis, your transect may be only examining one element such as an invasive plant species or it may look at two or more elements such as wider evidence of animal and plant species. You might also use the transect to measure and record evidence of other hazards you are studying e.g. indications of pollution or erosion so that you can compare those *processes* with their impact on the *environment*, such as soil, flora or fauna, that you are observing. Measure a *distance* of 50–100 metres with each student (or pair) completing 5–10 metres. Mark the beginning and end with a marker that can be easily removed and does not interfere with the natural *environment*. A suggestion is a piece of ribbon tied to a low branch, or stake or stick, at each end

▶ **Figure 7.12** Example of annotated photograph



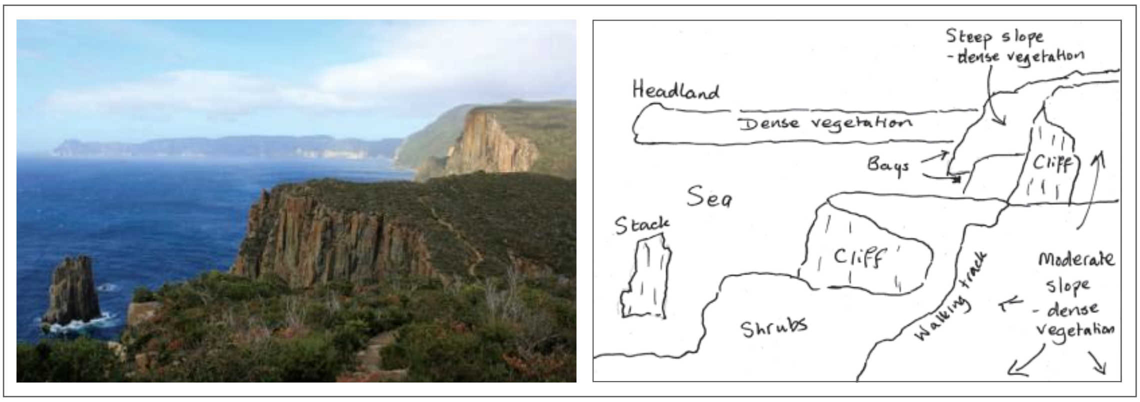
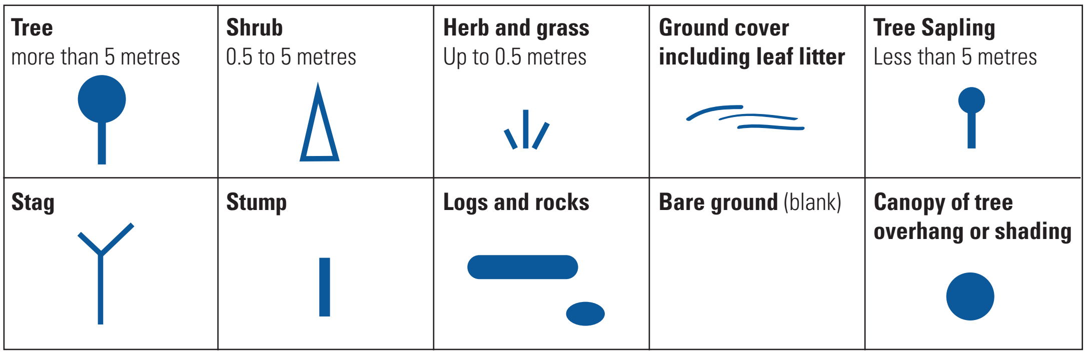


Figure 7.13 Example of annotated field sketch



Tree more than 5 metres	**Shrub** 0.5 to 5 metres	**Herb and grass** Up to 0.5 metres	**Ground cover including leaf litter**	**Tree Sapling** Less than 5 metres
Stag	**Stump**	**Logs and rocks**	**Bare ground** (blank)	**Canopy of tree overhang or shading** ●

Figure 7.14 **(a)** Key to use for Transect

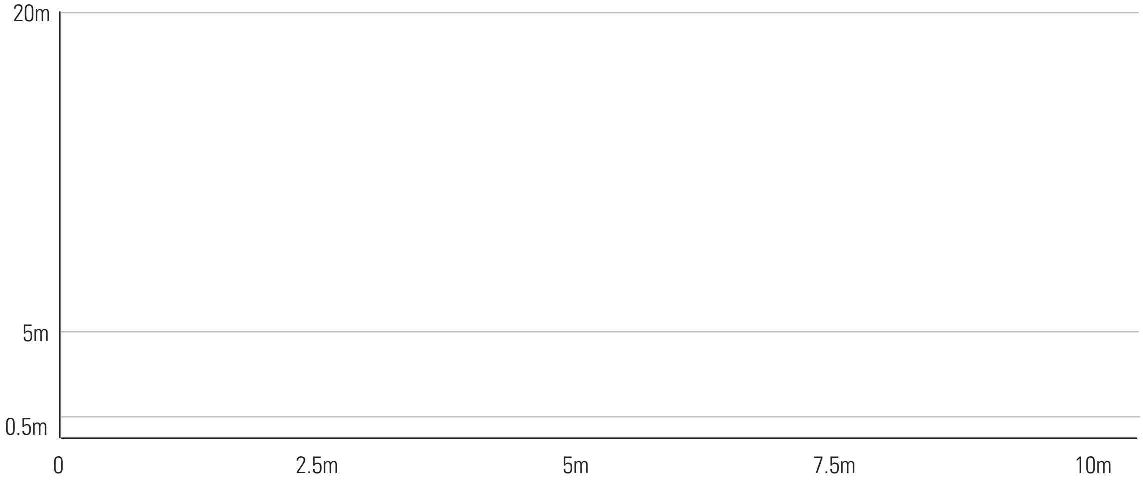


Figure 7.14 **(b)** Transect

of the transect. Each student (or pair of students) could be allocated 5–10 metres of the transect. Use Figure 7.14 or draw a 10 centimetre line on a piece of paper which represents the section of the transect that you have been allocated. Mark along the line the various features that intersect with the transect line in its correct position. Look for features on the ground (both organic and inorganic material) and immediately above the transect line (such as the tree canopy). If you have a reference guide with you, you may be able to identify some of the species in the field. You could also photograph elements for identification once you are back at school or use an app that automatically identifies the species. You can also make notes about details of the features, including reference to size and *scale*, that might assist you to identify them later. Once back in class, combine the individual sections to create a full transect.

Secondary data sources

Secondary data is information that someone else has previously collected and made available. Secondary data was used in exploring the characteristics of your location and informing your development of the research question and hypothesis.

When researching using secondary sources, it is vital that you determine the credibility of the source, check carefully whether the source can be trusted and ensure that it gives you information that you actually need. In order to read critically you need to evaluate sources, ask questions, synthesise information and take good notes. Remember to keep coming back to your research question!

Secondary data could include online databases (e.g. Australian Bureau of Statistics (ABS) or Atlas of Living Australia) and may also include news articles, internet searches, videos and perhaps even plant and animal guides. It is important that you justify how the combination of secondary sources and techniques were used to help answer the research question.

Maps, including ones created using geospatial technology such as GIS, are especially valuable in helping you understand the site, because they give you a powerful view of *distribution* patterns, *scale*, *spatial associations*, and how things may have *changed* over space.

Geospatial technology as a data source

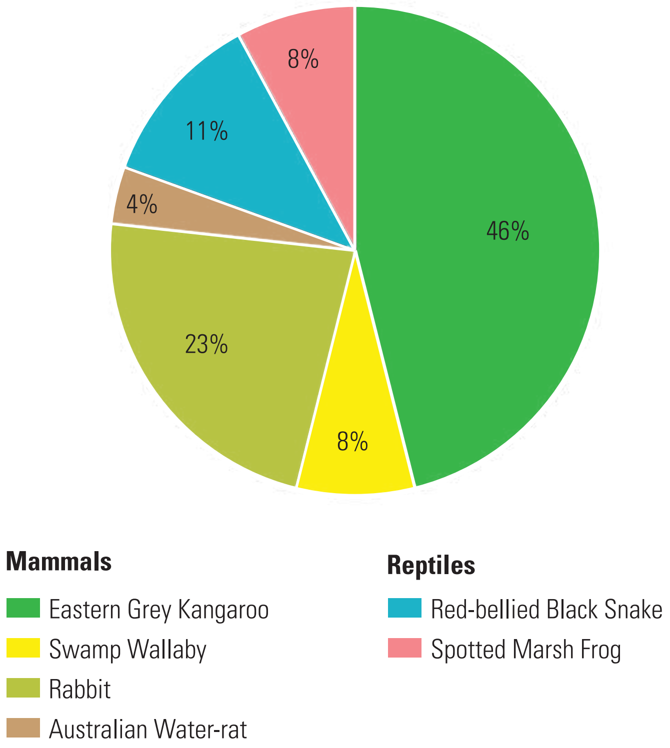
The most important application of geospatial technology is to help geographers identify and analyse spatial patterns and *processes*. To accomplish this, the systems pull together large amounts of information and produce complex models and analyses that would not be possible to create manually. The skills developed in investigation, collection of data, interpretation, analysis and communication of geographic information are enhanced through the use of geospatial technologies, both in the classroom and in the field.

One way to utilise geospatial technology during fieldwork is through the use of a GNSS or GPS. There are many mobile applications that come with GNSS or GPS features that allow you to save your exact location (good for recording where photographs have been taken or survey data has been collected). You can also use this technology to create a track or route (which may include time, *distance* and speed) of locations explored while conducting fieldwork (this is useful for when you might be collecting data across multiple sites).

▶ ACTIVITIES

1. Make a list of primary data collection techniques you have used on field trips in the past.
   a. Review your list and asterisk the techniques you think will be useful in collecting your data for your Hazards field trip. Justify your choices. Are these techniques quantitative or qualitative?
   b. For each of the data collection techniques you will use, identify the equipment that you will need to take on the field trip. Make sure your teacher can help you to find equipment.
   c. If you are unsure of any of the techniques listed in Figure 7.11, either ask your teacher to explain it to you or refer to a field technique manual.
2. Investigate secondary sources that you will use to test your hypothesis. Identify the information that you expect to gather from these sources. Briefly explain how these sources help you to respond to the various aspects of your research question and hypothesis.

▼ **Figure 7.15** A pie chart and table showing the number of identified animal species and relative percentage during fieldwork



Mammals	Count	Reptiles	Count
Eastern Grey Kangaroo	12	Red-bellied Black Snake	3
Swamp Wallaby	2	Spotted Marsh Frog	2
Rabbit	6		
Australian Water-rat	1		

Exploring and analysing the Geographic data

Once you have returned from your fieldwork, it is time to *process* the data you have collected. During the *processing* phase you will begin to explore what the data is telling you. This is the third stage of the geographic inquiry *process*. Reduce and visualise your data by turning the data into figures that you will later use in your field work report.

Figures could include:

- graphs
- maps
- tables
- flow diagrams
- photographs
- sketches
- transects.

These will help you to summarise large amounts of key information. It is important to explore the data in a variety of combinations.

Figures 7.15 and 7.16 show two different ways of reducing and visualising data collected in the field. Figure 7.15 is a pie chart and table of the number of identified animal species. Figure 7.16 is a table with a list of birds identified with example photographs. You will have to make careful decisions about the best way to display your data in order to help you analyse the information and respond to your research question.

Analyse each data set individually and then see if any data sets can be combined or displayed together. For example, if you were studying the hazards at a particular intersection you will have collected information about

Figure 7.16 Names of identified bird species with example photographs taken during fieldwork

Bird species observed during fieldwork		
Red Wattle Bird Cockatoo Magpie Pacific Black Duck Australian Wood Duck Great Cormorant Common Bronze Wing Eastern Yellow Robin Straw Necked Ibis Australasian Swamp Hen	 *Eastern Yellow Robin*	 *Australasian Swamp Hen*

the number of pedestrians that cross the intersection as well as the number of cars crossing the intersection in different time periods while you were in the field. You will have constructed graphs to show this data. By discussing the graphs with reference to a map of the intersection, and maybe a photograph of traffic flow, you will be able to identify risk levels associated with the hazard at different points in time and specific *locations*. You should try to get road and pedestrian counts done by authorities and compare it to your data which was collected over a limited time period on a certain day of the week.

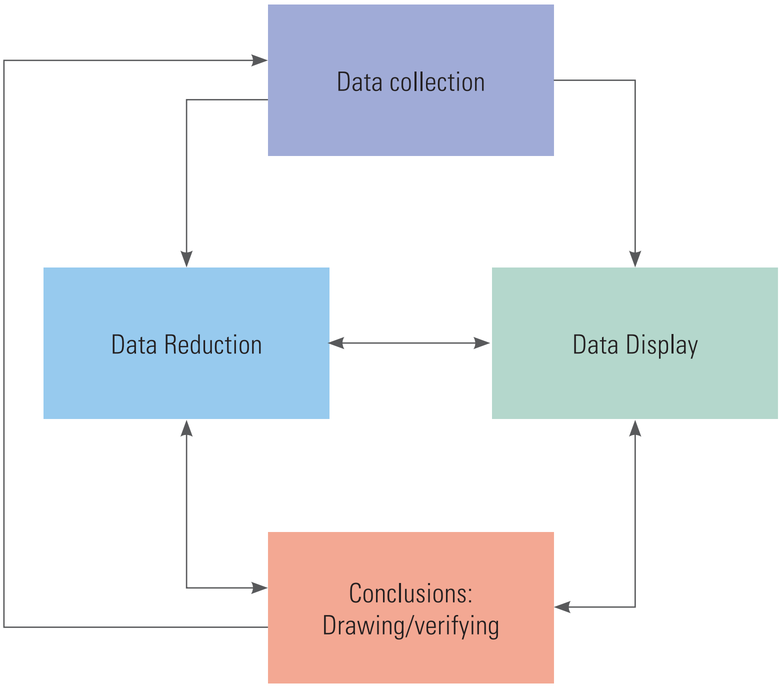
Initial conclusions are tentative and will need to be verified as you continue to analyse the data and check it against secondary sources. Continue to review your research question and hypothesis: if your data is not sufficient you should note this down for the evaluation section of your report. A useful way to think about data *processing* and analysis is to use this interactive model of data analysis (Figure 7.17).

Once your data has been *processed*, you are now in a position to analyse your findings. A useful way to analyse data is to take the 'PQE and I' approach. You will be familiar with the PQE approach to describing trends and *distribution* patterns. The first step is to identify the general pattern that emerges from the data and then to quantify the pattern using evidence gathered in the field. You should then describe any significant exceptions to the general pattern if relevant. The 'I' stands for implications which is where you explain what the data means in relation to your research question and hypothesis. This is also where you should make connections with secondary sources. Make sure you highlight comparisons between the primary and secondary data. This is the fourth stage of the geographic inquiry *process*.

This can be easily done when you are using a GIS to create layers of information and data in order to identify links between different factors that contribute to a hazard event or the impacts of the event. Look for the relationships between layers of information and identify patterns by *changing* the map symbols, altering the sequence of layers, or zooming in to specific parts of the map.

Figure 7.18 can be used to help you to *process* your data and to draw conclusions.

Figure 7.17 Interactive model of data analysis



ACTIVITIES

1. Refer to Figures 7.15 and 7.16 that show different ways to reduce and visualise primary data. In small groups discuss the strengths and weaknesses of each figure. Consider what information you can get from them as well as what might be left out.
2. Use the graphic organiser in Figure 7.18.
    a. List the figures that you have created from your collected data. For each figure, note the conclusions that can be drawn from the data.
    b. Fill in the 'analysis' section of the graphic organiser with some of the key findings of your investigation. Include primary data and secondary sources that support the finding.
    c. Gather together some data, such as images, maps and graphs, and ask questions about conclusions that can be drawn from them.

Figure 7.18 After fieldwork

STEP 3: After fieldwork

Data processing

Selected data for report figures	What does the data tell you about your research questions/hypothesis?

Data analysis

Key finding/theme	Primary data that supports	Data that doesn't support	Secondary data that supports and explains

Conclusion

To what extent has your analysis answered the research question?

Evaluation

What were some of the limitations of your fieldwork?

What future research could be undertaken?

What further questions does your fieldwork raise?

Fieldwork report

The fieldwork report is the culmination of the geographic inquiry *process* and is one part of taking action based upon your geographic knowledge. Sharing your geographic knowledge with a broader community, including your class and school, will help inform others about the risks and impacts of hazards. From the analysis of your findings, you might consider sharing your results with your local council, individuals, organisations and businesses that may be affected by the hazard.

Fieldwork report structure

The best reports flow from one section to the other where the sections may be seen as a series of logically-linked sections, as shown in Figure 7.19.

Your fieldwork report, of approximately 1500–2000 words, must include the following sections:

- definition of the topic including the research question
- primary sources and techniques used to collect data
- secondary sources
- a presentation of the *processed* data and information
- an analysis of the *processed* data and information
- a conclusion
- an evaluation of the techniques used
- referencing.

It is vital that you use a wide range of Geographic Concepts throughout your report. Using these concepts appropriately will help you fulfill the requirements of the report as well as show a deeper level of geographic analysis and understanding.

Definition of topic and research question

In the introduction, set the scene by providing a context for the type of hazard you are examining and the fieldwork location. Without going into too much detail, you should attempt to highlight why this particular hazard is significant and important in the location where you undertook fieldwork. By the end of the introduction, you should be in a position to introduce your research question and hypothesis.

For example, if you were investigating the Black Saturday bushfires in Marysville, you might start with the location of Marysville (be quite specific, e.g. relative location and *distance* to Melbourne) before moving on to a brief description of some of the geographic characteristics of Marysville. This could include geographical, *environmental* and human features and the history of bushfires around Marysville. You could then introduce your research question: “What were the impacts of the Black Saturday Bushfire on the town of Marysville?”

A brief hypothesis and justification of hypothesis should be included here.

Primary sources and techniques used

In this section you should outline and justify your choice of primary data collection methods. You need to connect your chosen primary data collection methods to your research question and state how they will help you to test your hypothesis and answer the question.

Secondary sources

You need to outline the types of secondary sources you used both in the preliminary research on your chosen hazard and fieldwork site as well as to supplement and explain what you found in the field. You should justify your choice of secondary sources by stating how their use will help you to test your hypothesis and answer the research question.

You need to keep a list of all secondary sources used during the investigation (to develop and present an accurate bibliography) and use a conventional referencing style, such as Chicago or APA, when you compile your report. Keeping track of your secondary sources as you go makes referencing easier.

Presentation of *processed* data and information

This section will form the main part of your report and you will be expected to demonstrate your ability to use a range of presentation techniques such as mapping, field sketching, graphing, annotating photographs, photography and identification of plant species, textual referencing to any primary data that you have collected, timelines and so on. All the information you present must be correctly sourced and should use correct geographic conventions.

▼ **Figure 7.19** Steps of fieldwork report writing

Follow these guidelines for including figures in Geography fieldwork reports:

- Place the figure within the text, not at the end.
- Always refer to the figure in your report, e.g. "Numerous bird species were identified during fieldwork, including a wedgetail eagle, pelicans and cormorants (see Figure 7.16)".
- Include appropriate titles for each figure.
- Figures should be ordered (and numbered) according to first usage (Figure 1 should come first and be referred to first in the report).
- Provide the source of your figure. If the information in your figure was collected by you on your field trip the source will be field data, date.
- Maps must include BOLTSS: border, orientation, legend, title, source and *scale*.

▼ **Figure 7.20** Examples of a photographic data presentation where **(a)** is a weak example and **(b)** is a better example

a

Figure 1: Forest and waterfall near Marysville

b

Figure 1: Regeneration of fern and eucalypt forest at Steavenson Falls near Marysville, Victoria. Photo taken May 2017, facing north. Note the trunks of trees burned as a result of the Black Saturday bushfires on the slope above the falls. (Photo: Micah Wilkins)

Figure 7.20 shows the difference between a weak example and a better example of a figure presentation of a photograph. In Figure 7.20 (a) there is no border and the caption is uninformative, whereas in Figure 7.20 (b) the border enhances the appearance of the photograph and the caption is informative and sourced.

Figures should only be included in order to illustrate a point that you wish to make. You may have collected data that in the end you decided was not relevant to your topic. Do not include this just because you have it. Each figure should act as a necessary jigsaw piece to help you respond to your initial fieldwork question and hypothesis.

Analysis of processed data and information

This section is often referred to as the 'discussion' and it is where you will show your understanding of the data you have collected. You will identify key features, describe patterns, draw relationships between key features and patterns, relate back to the research question and discuss whether or not your data and information has supported the hypothesis. You will need to break the discussion up into some key themes and to place the results from the primary data in the context of the secondary sources. It is here that cross-referencing is particularly important.

Conclusion

Your conclusion should identify the extent to which the analysis has answered the research question and responded to the hypothesis. It is an important opportunity to reflect on the findings and to indicate where improvements could be made or where future research could be directed.

Evaluation of the techniques used

This is where you provide an overall assessment of the relative effectiveness of the way the fieldwork has been conducted by discussing the limitations and weaknesses or difficulties on the day. You might consider whether the questions you asked in interviews might have been clearer or more appropriate to obtain the information you needed. Often there will also be residual questions you had not considered before the trip and will occur to you during and after the field trip. These should be included here. This evaluation leads naturally to a short, final section which outlines some suggestions for future research. Ultimately, your fieldwork should raise more questions to be explored by you and other researchers.

Referencing

This includes a bibliography with correct and consistent referencing as well as an acknowledgement of sources of information and people. Be consistent in your approach to referencing and use a valid citation guide such as APA, Harvard or Chicago.

FIELDWORK EXAMPLES

CASE STUDY Hydro-meteorological hazards and disasters

Fieldwork – Investigate the risks and impacts of bushfire on a community in a *region* affected by bushfires

From this brief example of a case study on a particular bushfire, many potential research questions might be identified, as well as potential hypotheses, each requiring data from some type of fieldwork that might form the basis of a well-planned and well-conducted student fieldwork report.

Bushfires (or wildfires) are a natural part of the Australian *environment*. The eucalypt forests of the southern parts of the Australian continent, particularly in the south-east mainland and in Tasmania, have evolved to withstand regular burning by bushfires caused by lightning strikes. Many plant species require burning in order to regenerate. Under natural conditions, for example, seeds from a mountain ash (*Eucalyptus regnans*) falling to the ground following fire will germinate in the ash bed and begin the *process* of regrowth. However, bushfires can be highly destructive socially, *environmentally* and economically.

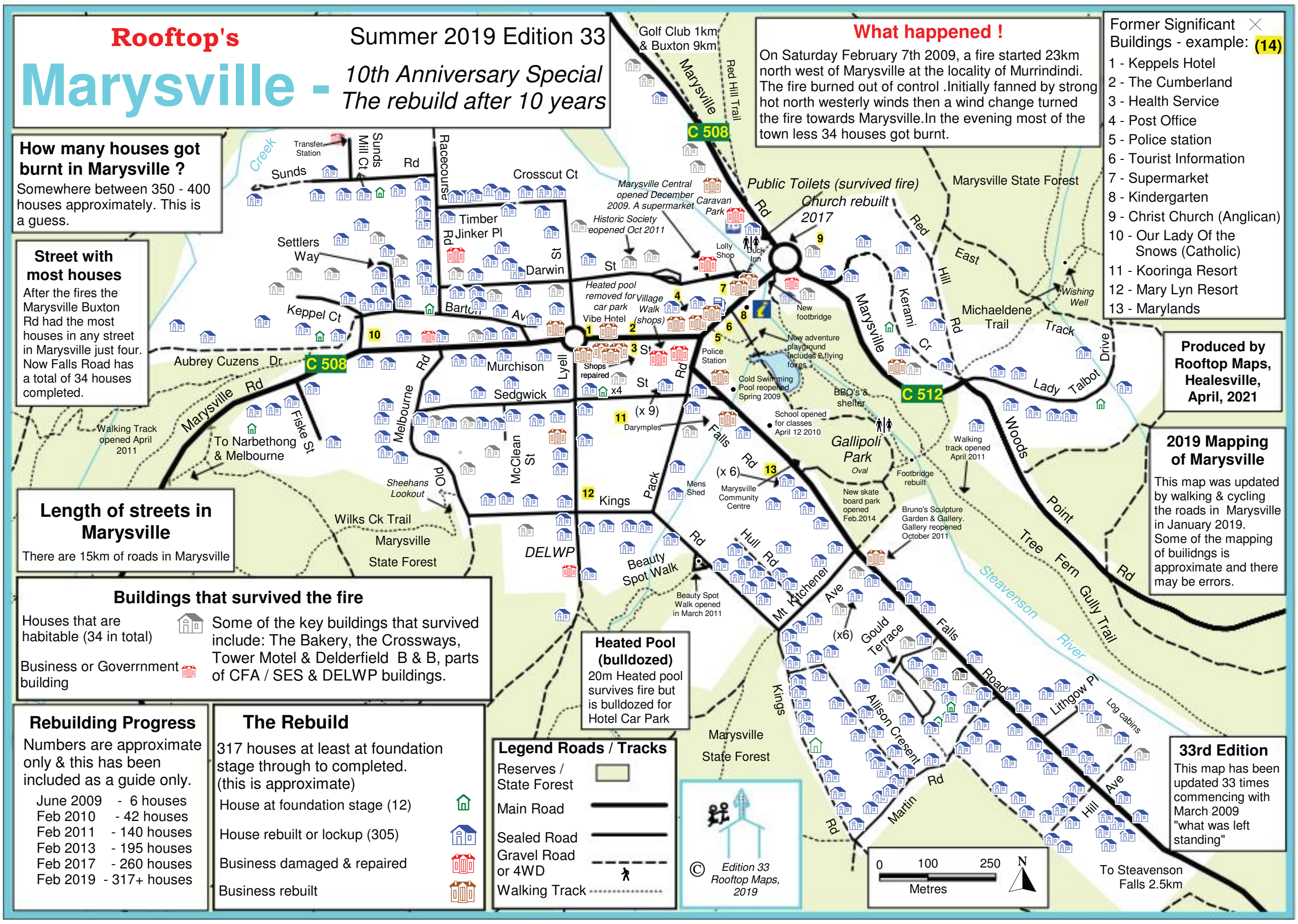
On an individual *scale*, the personal trauma associated with the experience of escaping a fire can be lifelong without appropriate support. When deaths or injury occur, families and whole communities grieve.

On a local *scale*, communities can take decades to recover financially from loss of revenue after a fire, including the cost of recovery operations. *Environmentally*, there can be permanent loss of species, accelerated erosion, *changes* to the water-holding capacity of soils, and increased vulnerability to exotic plant and animal species. Government institutions such as schools and public amenities can also be seriously affected. The *sustainability* of human and natural communities may be seriously affected by hazard events such as major bushfires.

Figure 7.21 shows the rebuild in Marysville 10 years after the Black Saturday bushfires. The bushfires decimated the town: there were 35 fatalities and 95 per cent of the town was destroyed (only 14 of 400 buildings survived). Although significant repairing and rebuilding has occurred in Marysville the recovery *process* is still ongoing. In the most recent census the population was 394, significantly less than the 519 it was in the 2006 census.

Climatic evidence suggests that with hotter, drier summers, fire intensity and fire frequency will increase. How can communities in forested *regions* be expected to respond to the likelihood of increased fire risk expected in future?

Figure 7.21 A town map of Marysville, showing what has been rebuilt in the 10 years since the Black Saturday bushfires, February 2019



Rooftop's
Marysville -
Summer 2019 Edition 33
10th Anniversary Special
The rebuild after 10 years

What happened !
On Saturday February 7th 2009, a fire started 23km north west of Marysville at the locality of Murrindindi. The fire burned out of control .Initially fanned by strong hot north westerly winds then a wind change turned the fire towards Marysville.In the evening most of the town less 34 houses got burnt.

Former Significant Buildings - example: (14)
1 - Keppels Hotel
2 - The Cumberland
3 - Health Service
4 - Post Office
5 - Police station
6 - Tourist Information
7 - Supermarket
8 - Kindergarten
9 - Christ Church (Anglican)
10 - Our Lady Of the Snows (Catholic)
11 - Kooringa Resort
12 - Mary Lyn Resort
13 - Marylands

How many houses got burnt in Marysville ?
Somewhere between 350 - 400 houses approximately. This is a guess.

Street with most houses
After the fires the Marysville Buxton Rd had the most houses in any street in Marysville just four. Now Falls Road has a total of 34 houses completed.

Length of streets in Marysville
There are 15km of roads in Marysville

Buildings that survived the fire
Houses that are habitable (34 in total) ⌂
Business or Goverrnment building ⌂
Some of the key buildings that survived include: The Bakery, the Crossways, Tower Motel & Delderfield B & B, parts of CFA / SES & DELWP buildings.

Rebuilding Progress
Numbers are approximate only & this has been included as a guide only.
June 2009 - 6 houses
Feb 2010 - 42 houses
Feb 2011 - 140 houses
Feb 2013 - 195 houses
Feb 2017 - 260 houses
Feb 2019 - 317+ houses

The Rebuild
317 houses at least at foundation stage through to completed.
(this is approximate)
House at foundation stage (12) ⌂
House rebuilt or lockup (305) ⌂
Business damaged & repaired ⌂
Business rebuilt ⌂

Heated Pool (bulldozed)
20m Heated pool survives fire but is bulldozed for Hotel Car Park

Legend Roads / Tracks
Reserves / State Forest ▨
Main Road ━━
Sealed Road ──
Gravel Road or 4WD - - -
Walking Track ┈┈

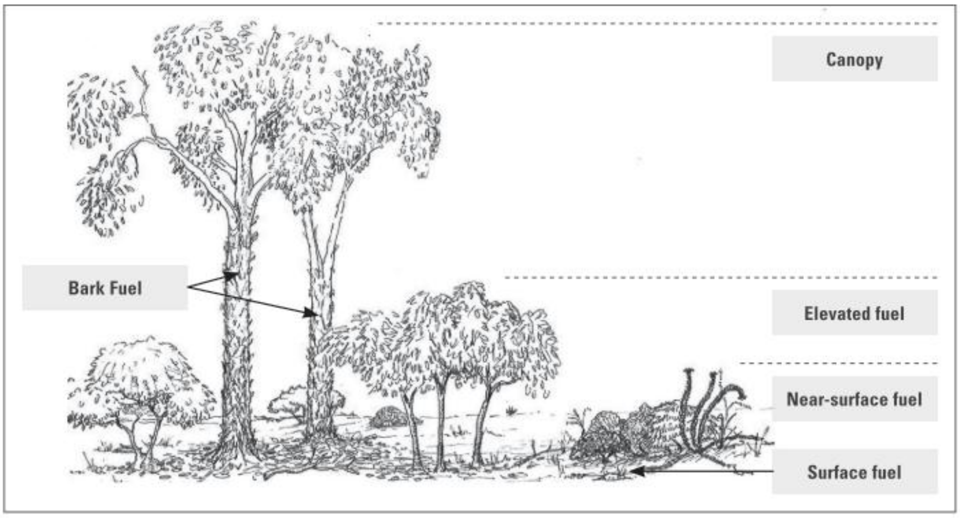
Produced by Rooftop Maps, Healesville, April, 2021

2019 Mapping of Marysville
This map was updated by walking & cycling the roads in Marysville in January 2019. Some of the mapping of builidngs is approximate and there may be errors.

33rd Edition
This map has been updated 33 times commencing with March 2009 "what was left standing"

© Edition 33 Rooftop Maps, 2019

Figure 7.22 Fuel layers and bark, overall fuel hazard assessment guide, 2010



SUGGESTED ACTIVITIES

Some activities to get you started.

1. Locate a site that has, or is at risk of being, affected by a bushfire event in your local *environment*. As a class, formulate a hypothesis that you would like to investigate.
2. Discuss the type of information that you could collect in the field and the different methods by which you could safely collect this data. Justify your choice of data collection method.
3. What are some of the ethical considerations you would need to make when collecting data in a *region* that has been affected by a bushfire or other hazard event?
4. Use Figure 7.21 to describe the *changes* that have occurred in Marysville since the Black Saturday bushfires. In your answer consider what was left standing, what has been repaired and what has been rebuilt. Hypothesise what further *changes* might occur in the future and what factors might contribute to the *changes*.
5. As can be seen in Figure 7.22, fuel in forests, woodlands and shrublands can be divided into four layers, each based on its position in the vegetation profile. Complete a sketch of a heavily vegetated area in or near your school. Annotate your sketch to clearly show the four 'fuel layers' that contribute to the overall fuel hazard assessment of a site.
6. Using an appropriate fuel hazard assessment guide (like the Department of Environment, Land, Water and Planning (DELWP) *Overall fuel hazard assessment guide* (2010) found on the Forest Fire Management (FFM) website), find a suitable *place* to complete the following in your school or local area:
   a. Assess the fire hazard risk of the bark on several dominant trees.
   b. Make an assessment of the elevated fire fuel hazard in the vicinity of these trees.
   c. Make an assessment of the near-surface fire fuel hazard around the same *places*.
   d. Calculate the surface fuel load of the site.

Rikki Weber

Geoscientist / Hazard Modeller

I studied Geography in Years 7 and 8 in high school, and then again in first year and third year at university. My work is focussed on tsunami hazards in Indonesia. I run computer simulations of theoretical tsunami events to study the properties and effects of the tsunami on land (for example, wave height, velocity and distance). I then use the outputs of the simulation to produce inundation maps that predict how far inland a tsunami would penetrate on a particular coastline. These maps are useful for evacuation planning, land use planning and community education.

I use commercial and open-source Geospatial Information System (GIS) software on a daily basis to compile input data (for example, bathymetry and topography) for my tsunami simulations. When creating my maps from the output data I also use population data and political boundary data to look at the possible impacts on a coastal population. My work uses a good combination of physical and social geography skills.


CAREER PROFILE

Maps are an important aspect of our work and used on a daily basis – so everyone needs to know how to make and interpret maps. The geosciences use a lot of information from geography, from map making, to understanding topography and geomorphology to looking at the impacts on populations. So there are many avenues to be involved, using cartography skills, more physical geography knowledge and also social geography such as demography skills.

CASE STUDY Biological hazards and disasters

Fieldwork – The *distribution* of introduced species and the impact they have on the local *environment*

Conducting fieldwork to investigate biological hazards can include examining the *distribution* and management of introduced species. Introduced plants have been estimated to comprise 30 per cent of Victoria's flora species. Weeds can broadly be grouped as *environmental* weeds or agricultural weeds, according to the systems they affect. Many weeds may be both. Some weeds have been declared noxious under the *Catchment and Land Protection Act 1994.*

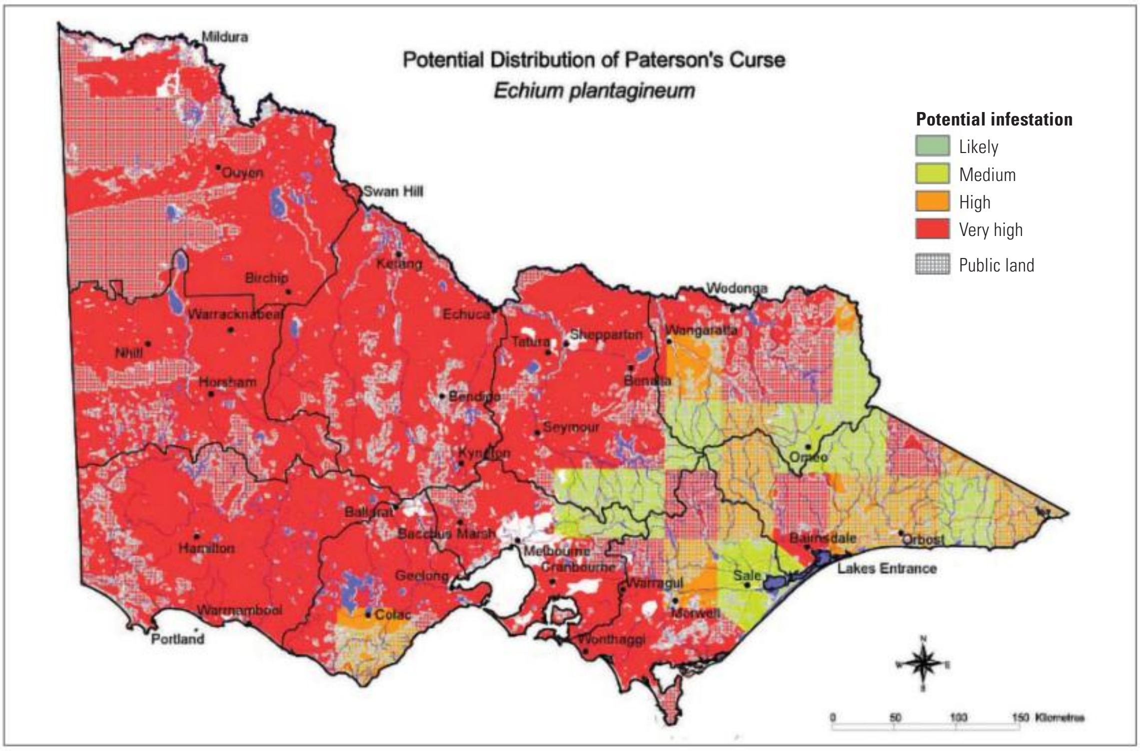
An example of an introduced species is 'Paterson's curse' (*Echium plantagineum L.*, usually known as Salvation Jane, Figure 7.23). Native to *regions* around the western Mediterranean, it was naturalised in Australia between 1850 and 1900 and is now classified as a 'noxious weed'.

Paterson's curse infestations are found in numerous locations around the state, but particularly in the north-central and north-eastern *regions* (see Figure 7.24).

In Australia, it has become a common weed of degraded pastures, roadsides and neglected areas. Paterson's curse can invade areas of natural vegetation, such as shrubland, lowland grassland and grassy woodland, particularly where there is frequent disturbance, and can suppress smaller plants. It reduces pasture productivity by competing for light, moisture and nutrients with desired commercial species and is poisonous to grazing animals.

This is just one example of an invasive species that you could focus on as part of your fieldwork. Other species could include blackberries, thistles, rabbits, cats and foxes.

▼ **Figure 7.23**
Paterson's curse



◀ **Figure 7.24**
Potential *distribution* of Paterson's curse

SUGGESTED ACTIVITIES

Some activities to get you started.

1. Locate a site in your *region* which has an issue with an introduced species. As a class formulate one or more hypotheses that you would like to investigate. List the data that you could collect and how it might be collected and recorded. Consider both primary and secondary data collection.
2. Using GIS mapping software, prepare a base map of your survey area. A base map needs to show the key geographic characteristics of your survey area such as topography and key natural and human features.
3. What do you observe about the various types of plants found in your study area? Can any be classified as weeds? If so, identify these and classify them as *environmental*, agricultural or noxious weeds. There are a number of free, online applications (apps) that can be downloaded to assist you with this task.
4. Plan how you will collect information about major vegetation types including weeds in the study area.
5. Hypothesise which factors may have a *spatial association* with this *distribution*, for example slope, soil type, soil moisture, proximity to housing, road access, and so on.
6. Create additional layers on the GIS map you previously used to map at least two of these factors.

▶ CASE STUDY Technological hazards and disasters

Fieldwork – Investigate to what extent and how light commercial vehicles (LCV) and truck *movements* are a problem in the local *environment*

In the past 10 years, the amount of freight *moving* around Victoria has increased by more than 30 per cent. By 2025 the number of kilometres travelled by road freight is predicted to rise a further 70 per cent.

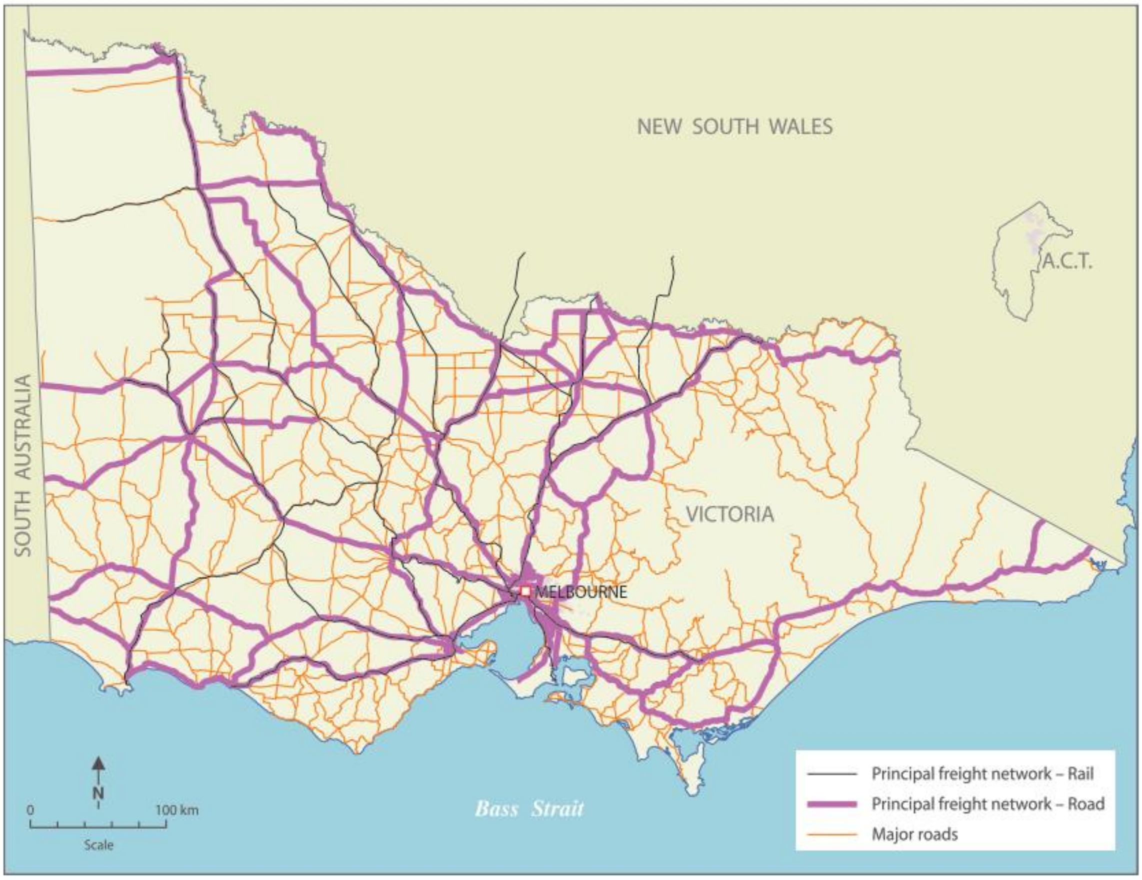
At the Port of Melbourne, which is the biggest in Australia, its current volume of two million containers a year is projected to quadruple to eight million by 2035. The vast majority of the containers are *moved* around on trucks with LCVs being used to transport some of the content of the containers. The map in Figure 7.25 shows Victoria's principal road and rail freight network, which originate in Melbourne's CBD and the Port of Melbourne and are *distributed* radially in the western and northern *regions* of Victoria.

The increase in freight is reflected in the increase in vehicle registrations for LCVs and trucks, with LCVs involving the biggest percentage *change* which can be seen in Figure 7.26. One of the major driving factors for this is the rise in e-commerce (online shopping). As more people buy products online, for example through Amazon, eBay or even the local supermarket, more vehicles are needed to deliver the goods quickly, safely and efficiently.

The increase in vehicle numbers can contribute to increased travel times and traffic accidents as well as an increase in noise and particulate (i.e. diesel fume) and toxic air pollution. Furthermore, it can also lead to a decrease in the liveability of a *region* as air quality is reduced, noise pollution increases, and the 'walkability' of a local area is negatively impacted.

Locate a suitable site in either your local *environment* or, if possible, plan a fieldtrip to the suburbs of Melbourne that act as thoroughfares for freight *moving* away from

▼ **Figure 7.25** Victoria's road and rail freight network



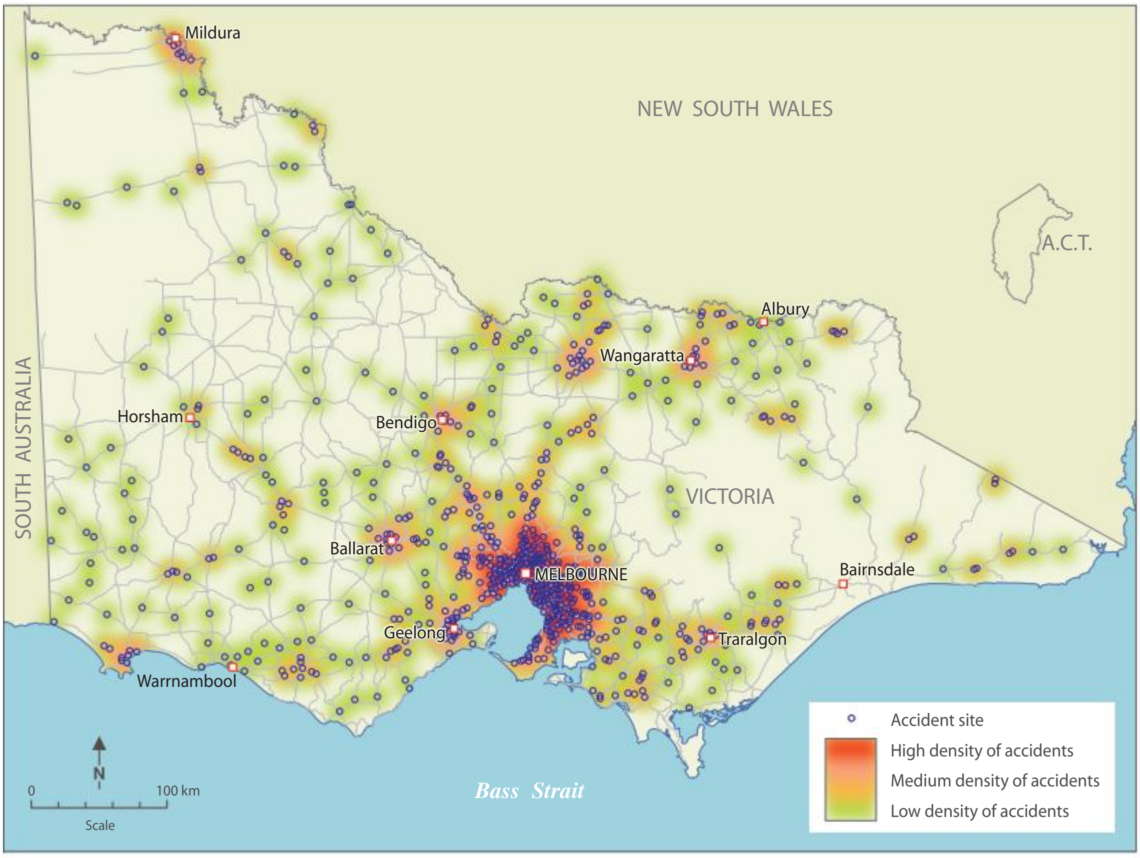
▼ **Figure 7.26** Vehicle registrations for years 2007, 2012, 2017 and 2020

	2007	2012	2017	2020	Percentage *change*
LCVs	490,513	580,727	675,606	753,341	+54
Rigid Trucks	93,131	104,781	114,500	129,653	+39
Articulated Trucks	22,254	25,265	27,472	30,010	+35
Total	605,898	710,773	817,578	913,004	+51

the Port of Melbourne. As an example, the Napier Street Bridge in Footscray in Melbourne's inner-west, is often the scene of accidents as trucks carrying shipping containers attempt to squeeze under the 4.0 metre bridge (Figure 7.27). Despite significant investment in a warning and safety system, there are still over 20 accidents at the Napier Street Bridge per year.

When investigating secondary data sources about your site, look for data relevant to your topic. For example, the map in Figure 7.28 details the number of accidents involving trucks and heavy vehicles causing injuries and fatalities in Victoria from 2015 to 2018. This type of information will help you when investigating whether the LCV and truck *movements* are a problem in the local *environment*.

▲ **Figure 7.27** Truck collision with Napier Street Bridge, Footscray, in October 2019



◀ **Figure 7.28** Number of accidents involving trucks and heavy vehicles causing injuries and fatalities in Victoria from 2015 to 2018

▶ SUGGESTED ACTIVITIES

Some activities to get you started.

1. As a class, formulate a hypothesis that you would like to investigate using this case study. Discuss the type of information that you could collect in the field and the different methods by which you could safely collect this data. Also consider secondary data that may be available, for example from the local council, VicRoads etc.
2. Define a case study area and produce a labelled sketch map. Ideally this should be a busy area with mixed industrial and retail use. Local council-supplied maps or a street directory may be useful for a base map.
3. Identify the land uses of the *region*. This could be done by completing a street walk of the study area and recording data, or, using secondary information such as a street directory map or Google Earth. A land use map, using a GIS mapping platform, can be constructed with the information.
4. Decide where data will be collected and how the information will be recorded. For example, a basic map could be produced to show where pairs or groups of students could stand to observe and count vehicles for a specific time period. One student could count while the other records the types of vehicles. Ideally, this should be repeated at different times of the day, morning and afternoon peaks as well as during the middle of the day.
5. Photographs could be taken to show different types of vehicles, congestion, and specific issues with that location such as air pollution from vehicle exhaust. Don't forget to record the location as well as time and date of the photograph.
6. Design a questionnaire to survey residents about the hazards of LCVs and trucks in the study area.

Glossary

accelerated erosion: *the process* by which the rate of removal of soil or rock is increased by natural causes or human actions

air pollution: a physical, chemical or biological *change* to the atmosphere usually resulting from either natural *processes* or human actions involving the emission of gas or particles into the air

ameliorate: improve, usually by reducing the harm caused by an impact or removing the impact altogether

anthropogenic: caused or produced by people

aquifer: an underground rock layer that is permeable and able to hold water

archipelago: a group of islands

ash plume: an ash cloud erupted from a volcano and comprising rock fragments from the crater rim and pulverised particles of solidified lava

aspect of a slope: the compass direction the slope faces

atmospheric or meteorological hazards: threats to humans and the *environment* from natural weather and climatic *processes*, including storms, drought and flood

avalanche: the sudden downhill *movement* of snow

bacteria: single-celled microorganisms that usually live in the ground or water, but may live inside or on the skin of other organisms, including humans

biodiversity: the range of animals and plants in a particular area or a living system such as an ecological community

biological hazards: threats from life-forms including infectious diseases, water-borne diseases, plant and animal invasions

carcinogenic: a substance that, by causing cell mutations, could trigger the development of cancer

climate: the average, predictable, weather at a location at the Earth's surface over a relatively long time period. The Earth's climate zones (tropical, temperate, polar, etc.) and the climates of *regions* within them are relatively fixed because they are mainly determined by slowly-*changing* natural geographical influences. These include the curvature of the Earth, the seasonal cycle of the tilt of the Earth's axis, latitude, and general topography (elevation, aspect, position relative to oceans or mountain ranges, etc.). Traditionally, then, it was assumed that the climate of particular locations was highly stable and *changed* little over millennia or many centuries.

climate *change*: variations in the global patterns of climate in the long term

compound disaster: when one disaster, such as a cyclone, creates another disaster such as flooding from the rain associated with the cyclone

Coriolis effect: the deflection of air on both sides of the Equator due to the rotation of the Earth

cyclone: an area of low atmospheric pressure with air spiralling into the centre in a clockwise direction in the southern hemisphere, and an anticlockwise direction in the northern hemisphere

DDT (dichlorodiphenyltrichloroethane): a toxic, persistent, chemical compound used as insecticide

deforestation: the clearing or destruction of a large area of forest by natural or human causes

disaster: a hazard event causing significant damage to property and or loss of life and requiring considerable rebuilding, usually with outside assistance

earthquake: a violent shaking of the ground sometimes creating great destruction caused by the sudden release of energy in the Earth's crust typically forcing rocks to break under the strain and in some cases surface fault-lines to form

eddy: a circular *movement* of air or water

emissions: matter or energy that has been released or emitted. Examples are gasses, smoke and radio transmissions

epicentre: the point on the Earth's surface directly above the start or focus of an earthquake

epidemic: an infectious disease that spreads rapidly and widely among the population in a *region*

epidemiology: the study of the patterns, causes and effects of health and disease conditions in defined populations

erratic flood regime: intermittent, unpredictable floods with extreme dry periods between each flood

fault lines: fractures in the ground that have occurred because of earthquake activity; they can form locally and vary greatly in size, and may or may not be located along tectonic plate margins. They can form the steep sides of faulted mountain ranges and bays, and can direct the flow of rivers.

fire regime: the fire intensity, frequency and seasonality of fire in a particular *region*

floodplain: mostly flat to gently-sloping land alongside a river that is inundated with water during floods. Floodwaters may carry fine silt or alluvium which is deposited over the land.

focus: the location under the Earth's surface where the earthquake begins. The ground ruptures at this spot. It is from this point that seismic waves radiate outwards in all directions.

fossil fuels: dead organic matter that has decomposed and *changed* its chemical composition over millions of years. Oil, natural gas and coal are fossil fuels.

fracking: a *process* by which liquid is injected at high pressure into underground rock which forces open cracks and fissures to assist the extraction of oil and gas

fuel rod: a long metal tube filled with radioactive uranium pellets. The tubes are stacked in bundles of about 200 and inserted into nuclear reactors as fuel to provide the heat energy to create steam from water to drive electricity-generating turbines. Once they are depleted, the fuel rods remain highly radioactive and have to be cooled and stored safely – usually for long periods of time.

Geographic Information Systems (GIS): a computer-based system used to collate, analyse, produce and present digital data in a spatial form. It includes, but is much more than, a highly-sophisticated way of quickly, cheaply and accurately conducting research into *spatial associations*, and of mapping.

geological or geophysical hazards: the threat from natural *processes* such as volcanic activity and earthquakes that release enormous amounts of energy stored in the Earth's crust or even deeper in the mantle. Their location may be *spatially associated* with tectonic activity along plate boundaries, or may occur in more geologically-stable *regions*.

geospatial technology: a range of integrated systems and their components (GNSS, GPS, GIS, etc) that use digital geographical data to collect, analyse, compare and display information; also known as spatial technology

geothermal energy: natural forms of energy generated from radioactive decay deep in the Earth's core and stored in the Earth's crust; usually harnessed as heat to warm water or create steam

Global Navigation Satellite System (GNSS): systems of multiple satellites providing global coverage that transmit position and time data to Earth-bound GNSS receivers for use in navigation and the analysis of geographic data. The GNSS's individual networks include Galileo, BeiDou, NAVSTAR, and GLONASS.

Global Positioning System (GPS): a computer-based system that allows accurate positioning (usually in latitude and longitude) of a receiver anywhere on, or near, the surface of the Earth. It uses a range of satellite-based receivers for triangulation of electronic signals transmitted from a GPS-unit. It does this by automatically calculating the time differences that the signal reaches the two or more different satellites of known location and returning that information to the receiver. Initially developed with high accuracy, great privacy and stability for military operations in the 1970s, it has been expanded to civilian applications for governments, businesses and private citizens. Cost, accuracy, and ease of use have all dramatically improved. It can be used for many applications wherever precise knowledge of real-time geographical location is valuable including navigation, mapping, environmental monitoring and management, remotely-operating mobile machinery, and inventory-tracking.

global warming: increases in global temperatures over a long period of time. Refers to natural warming or the current *process* of human-induced warming from the enhanced greenhouse effect

green wedge: rural or natural landscapes separating corridors of urban development

greenhouse gases: water vapour, carbon dioxide, methane, nitrous oxide, ozone and halocarbons are found in the Earth's atmosphere and absorb longwave radiation which is radiated from the Earth's surface, warming the atmosphere

groundwater: the water beneath the surface of the ground that has seeped down (i.e. percolated) and is stored in, or moves through, porous rock layers and sands

hazard event: the realisation of a hazard such as a bushfire

hazardous waste: any waste that can be harmful to the *environment* or human health. The waste can be in liquid, solid or gaseous form.

hazards: situations with a potential to cause harm to people and or the *environment*, such as a bushfire, flood, cyclone, or volcanic eruption

Human Development Index (HDI): a composite index used by the United Nations measuring average achievement in three basic dimensions of human development – life expectancy, education and income

hydrocarbons: organic compounds of hydrogen and carbon; the main components of petroleum and natural gas

impermeable rock: a rock layer that does not allow water to flow through

impervious surface: a surface which does not allow penetration of water or other substances

incised: a deeply-eroded landscape feature such as a glacial- or river-valley; or at a smaller *scale* such minor features as rills formed when bare soil begins to erode

indoor residual spraying (IRS): the application of insecticide to the inside of houses. This kills mosquitoes (and other insects) when they come in contact with treated surfaces, preventing disease transmission.

industrialisation: a *process* by which an economy *changes* the nature of its major industries. The shift is typically from being largely dependent on agriculture or other primary industries (where natural resources are extracted or nurtured) to one based on adding greater economic value such as the manufacture of goods (secondary industry where materials are more highly processed) or the provision of services (tertiary industries such as the provision of entertainment, finance or information).

infiltration: the *process* in the water cycle whereby water on the surface enters and flows through the soil or other porous materials

infrastructure: the basic, essential structures and services required for an organisation, *region* or country to function efficiently; for example, roads, rail, docks, water and power networks

insecticide-treated nets (ITNs): a net (usually a bed net), typically designed to stop mosquitoes, which has been treated with a residual insecticide which kills or repels mosquitoes. A long-lasting insecticide-treated net (LLITN) remains effective for multiple years.

inundation: when an area of land is covered by water during a flood

invasive alien species: plants or animals whose spread outside their natural *distribution* is a threat to valued *environmental*, agricultural or other social resources due to the damage caused

lahar: fast-moving mudflows which are a result of volcanic ash and mud mixed with water or melting snow

landfall: the event when and where a storm moves from being over water to entering the land via the coast

landslide: the sudden mass *movement* of rock, debris or earth down a slope

levee: a naturally-occurring ridge or artificially-created wall, typically atop the banks, which regulates water levels and prevents the overflow of a river

liquefaction: occurs when soil and unconsolidated rock such as sand and gravel acts as a liquid because of shaking during an earthquake event

low pressure system: a *region* where the atmospheric pressure at sea level is temporarily lower than its surroundings; usually associated with rising columns of air and therefore unstable (cool and potentially wet) weather. These are the opposite conditions to a high pressure system where air is typically descending causing relatively stable and fine weather.

megadisaster: result from deaths exceeding 100,000 people occurring with a single event

megafire: a massive wildfire covering above 400,000 hectares in size and leading to considerable destruction to life and property

mitigation: strategies used to reduce the likelihood or impact of a hazard event

monsoon: a very large-*scale* wind system formed by large differences in heating of some parts of the Earth's surface especially over the sub-tropics; it reverses direction with the seasonal tilt in the Earth's axis, thereby influencing the weather patterns for a large *region*. It usually produces a distinctive wet and dry season that profoundly shapes biological and human activity in monsoonal *regions*.

pandemic: the spread of an infectious disease through human populations across a very large *region* and typically at a global *scale*

particulate matters (PM): any fine particles in the air which include dust, smoke, soot and liquid droplets; they are classified according to size, with $PM_{2.5}$ being particles of 2.5 microns

photochemical smog: a type of secondary air pollution produced by the action of sunlight on hydrocarbons, nitrogen oxides and other primary pollutants; typically forms in temporary atmospheric inversion layers above cities or industrial areas in warm climates

plantation: a type of large-*scale* commercial farming, typically found in tropical *regions*. Often tree crops are grown, for example, rubber, coffee, palm oil. Can also refer to forest plantations used in forestry operations, or increasingly in carbon-sequestration for climate *change* amelioration (these can also occur outside tropical *regions*).

Plate tectonics: the slow geological *process* that causes the *movement* of the large rocky plates floating on the Earth's crust upon which the continents are located

pollarding: involves cutting or pruning trees back nearly to the trunk, so as to create a denser network of branches. The regrown branches can be used *sustainably* over long periods for fuel or animal feed.

population density: the number of people living in a given area, for example per square kilometre

precipitation: liquid or solid water (such as rain, hail and snow) that because of gravity falls from the atmosphere once water vapour there is condensed and the resultant water droplets are sufficiently large

premature deaths: are deaths that occur before a person reaches an age to which they would, if reasonably healthy, be expected to live (e.g. age 75). Many of these deaths, either from natural causes such as disease or human actions such as smoking or accidents, are considered preventable.

pyroclastic flow: a fast-moving, and potentially destructive, current of hot gas and rock (collectively known as tephra), which reaches speeds moving away from a volcano of up to 700 kilometres per hour. The gas can reach temperatures of about 1000°C.

qualitative description: a description based on an analysis of the observed qualities of a research subject – such an assessment may be subjective and vary according to an individual researcher's and subject's experience, attitudes or opinions. Qualitative data is useful in understanding why people behave in particular ways.

remote sensing: involves data-gathering distant from the human observer including in remote, inaccessible or inhospitable *regions* or in areas too large for affordable ground-based investigation; the production of images gathered from aerial photographs, satellites, radar, laser scanners (LiDAR) or drones. Increasingly, but not exclusively, the data is presented in a digital form that can be analysed by computer e.g. in data layers for mapping or to investigate *spatial association*.

residual risk: the remaining risk after efforts to eliminate and manage risks have been made

Richter Scale: a base-10 logarithmic *scale* which defines magnitude as the logarithm of the ratio of the amplitude of the seismic waves to an arbitrary, minor amplitude. The Richter Scale is used to rate the amount of energy an earthquake releases.

risk: the likelihood of a hazard event occurring. Risk is often expressed as a statistical probability for a particular time period, and is independent of the threat of what happens (i.e. the hazard) when the event actually occurs.

run-off: water that flows over the surface of the land

saturated: when soil contains as much water or moisture as it can absorb so that any additional rainfall runs off the surface

sea level rise: the increase in the average height of the sea's surface between high tide and low tide relative to the land. Occurs when increasing temperatures cause an increasing proportion of the Earth's ice to melt and by thermal expansion of the oceans' surface water.

seismicity: the occurrence, frequency and *distribution* of earthquakes in a *region*

seismograph: an instrument that records earthquake activity, and measures its intensity using the Richter scale

seismologist: an Earth scientist who specialises in geophysics and studies the nature, causes and consequences of the *movement* of seismic energy waves

shale: a soft sedimentary rock formed from compressed mud and clay; it can easily be split into flat plate-like pieces

shifting agriculture: a cyclical form of traditional farming where a small plot of land is cleared and farmed for a short time, then abandoned when soil fertility there is depleted and the yield of crops or livestock declines. As long as there is sufficient land available, the cultivator can repeat the cycle by moving on to another, more fertile, plot, and eventually return to an earlier used plot when its fertility is naturally restored.

sial: the material of the continental crust, made up of silica and alumina

sima: the material of the oceanic crust, made up of silica and magnesia

sinkhole: a hole in the ground caused by some form of collapse of the surface layer into a cavity below that was formed by erosion or drainage of water; often formed in water-soluble, easily-eroded, bedrock such as limestone

snow-pack: a mass of accumulated snow on the ground that is compressed and hardened by its own weight

solid biomass: a source of energy derived from living materials such as wood, sawdust, crop waste or other plants. Commonly used as a cooking fuel as wood or converted to charcoal.

solid fuel: solid (as opposed to liquid oil or gas) fuel that can be used as an energy source. These include biofuels such as wood or charcoal, or mineral fuels formed from once-living organisms such as peat or coal (and their processed forms such as briquettes).

spatial technology: *see* geospatial technology

storm: extreme disturbance in the atmospheric conditions producing thunder, strong winds, heavy rain and or hail and snow

Sub-Saharan Africa: according to the UN, it consists of all African countries that are fully or partially located south of the Sahara Desert

subsidence: the gradual caving in or sinking of a land surface. This is often caused by the *unsustainable* removal or extraction of groundwater – either locally or at a greater *distance*.

technological hazards: also referred to as anthropogenic hazards; triggered or caused by humans playing a significant role in their development, such as oil spills, air pollution

temperature inversions: normally, air temperatures in the lower atmosphere decline at a regular rate with altitude. Sometimes, however, this normal pattern is temporarily 'inverted' when a thin layer of stable air (where the rate of loss of temperature is much less) forms a few hundred metres high above the surface. The inversion layer acts like a lid preventing the cold surface air blanketing the Earth below it from rising normally, especially in confined spaces like valleys. Therefore any pollutants and fog below the inversion are trapped until sunlight warms it enough for the air to expand and disperse. The inversion usually only lasts a day or so, but more dangerously can last weeks producing major air pollution hazards.

thermal expansion: an increase in the volume of matter due to an increase in its temperature causing its molecules to take up a larger space

thermohaline: an oceanic *process* involving the joint effect of temperature and salinity on the *movement* of water

topography: the arrangement of the physical features which shape the landscape including the underlying landforms and any land cover on the Earth's surface

trade winds: reliable and predictable easterly winds generated by intense solar heating of tropical and subtropical ocean *regions*; historically used by sailing vessels for navigation and trade

trans-boundary: phenomena such as patterns, *processes* or events that cross a boundary or border. Trans-boundary pollution originates in one *place* or *region* e.g. a country or state and crosses the border via wind or water creating a larger *environmental* impact elsewhere. Management is made difficult especially when the cause and effect is separated by political or other borders.

transect: a strip or area on land or at sea in which measurements are taken at regular intervals to record *distributions*, e.g. the number of plants, animals or pollutants; may also refer to a topographic profile e.g. an imaginary line from the coast to the mountains, or across a valley

tsunami: a giant wave formed by the sudden release of energy following an oceanic volcanic eruption or an earthquake; the wave may travel huge *distances* before significantly increasing in height only when the energy reaches shallow coastal *regions*

urban–forest fringe: the zone of transition from the city and its suburbs to a forested area

urban sprawl: the uncontrolled expansion of urban areas; usually results in the loss of access to urban infrastructure and a declining quality of life in the outer-suburbs

urbanisation: occurs whenever there is an increase in the proportion of the population living in urban rather than rural areas

vector: an organism that does not cause disease itself but which spreads infection by acting directly as host e.g. to a virus or indirectly by hosting a different carrier e.g. bacteria-infected fleas living on rats

virus: a small infectious microorganism that reproduces only inside the living cells of other organisms

viscosity: describes the resistance to flow of a fluid; lava that is thick and is highly viscous is typically high in silica

volcanic eruption: occurs when molten rock, ash and steam pour out of, or is erupted more explosively, through a vent or crater in the Earth's crust

Walker Circulation: the atmospheric circulation from east to west above the tropical Pacific which forms as warm air rises above warmer ocean *regions* and descends over cooler *regions*; periodic shifts (oscillations) in the strength and location of the Walker Circulation, due to the underlying ocean currents, influence the temperature and rainfall patterns that we associate with La Niña and El Niño events. These can bring droughts or floods to different *regions* of the Pacific.

water table: the level below which the rock and soil layers are fully saturated with water

weather: the atmospheric conditions at the Earth's surface over a relatively short period of time of hours and days

weed: a pest plant that has a potentially negative impact on economic, social or natural *environments*

wildfire: a fire that is burning uncontrollably in a natural landscape, or that originates in a natural landscape; also known as a bushfire

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More information can be found here: https://earthdata.nasa.gov/earth-observation-data/near-real-time/ citation#ed-firms-citation; **6.15a** and **6.15b**/Earth Observatory/Joshua Stevens using MODIS data from LANCE/EOSDIS Rapid Response; **6.16a** and **6.16b**/Earth Observatory/Joshua Stevens using modified Copernicus Sentinel 5P data processed by the European Space Agency; **6.18a** and **6.18b**/Earth Observatory/Joshua Stevens using Landsat data from the U.S. Geological Survey, GEOS-5 data from the Global Modeling and Assimilation Office at NASA GSFC, and MODIS data from NASA EOSDIS/LANCE and GIBS/Worldview; • National Oceanic and Atmospheric Administration (NOAA): figures **1.18** (image GNSS); **3.18**; **3.19**; • Newspix: figures **3.39**/David Crosling; **6.10**/Mark Smith; • Nextstrain: figure **5.19**/with rendering in Leaflet, Mapbox, with data from OpenStreetMap; • NSW Rural Fire Service (RFS): figure **1.5** (source); • Our World in Data (Licensed under CC BY 4.0): figures **2.7** (source) and **2.8a** (source)/EM-DAT (2020) OFDA/CRED International Disaster Database; **4.28**; **5.25**/Eurostat, OECD and individual national statistics agencies; **5.26**/Johns Hopkins University CSSE COVID-19 Data; **6.7**/World Bank; • Ray Pask: figures **2.1c**; **2.4**; **2.10**; **2.12**; **2.20**; **2.21**; **2.26**; **2.27**; **2.30**; **2.31**; • RBM Partnership To End Malaria: figure **5.11**; • Reuters: figures **3.36b**/Adi Kurniawan; **6.33**; • Rezatec ©: figure **1.18** (image remote sensing); • Rooftops Maps © figure: **7.21**; • Sage Publications: figure **7.17**/*Qualitative Data Analysis: An Expanded Sourcebook*, 1994 • ScienceDirect: figure **4.23**/*Journal of Safety Science and Resilience*, 2020; • Sentinel Hub (Licensed under CC BY 4.0) (modified Copernicus imagery): figures **3.35a**; **3.35b**; • Shutterstock.com: figures **2.1a**/Zacarias Pereira da Mata; **2.1b**/Marcin Balcerzak; **2.1d**/Odua Images; **2.2a**/ kajornyot of wildlife photography; **2.2b**/Free Wind 2014; **2.2c**/meunierd; **2.13**/suronin; **2.18**/Johann Helgason; **2.22**/Tatiana Gaisch; **2.24**/wadstock; **2.25**/Chumash Maxim; **2.32**/Jonathon Street; **3.6**/Wead; **3.41**/salajean; **4.20**/Taras Vyshnya; **4.29**/ChameleonsEye; **4.36**/Mirek Nowaczyk; **5.5**/ Kletr; **5.7**/Sam Dcruz; **5.17**/Lightspring; **6.3a**/Nickolay Khoroshkov; **6.3b**/ ssuaphotos; **6.3c**/Mikhail Starodubov; **6.8**/Ajay Bhaskar; **6.14**/Shuang Li; • South Asian Association of Regional Cooperation (SAARC): figure **2.15** (source); • Springer Nature: figure **5.16**/Florian Girond et al, *Malaria Journal*, 2017; • State of New South Wales © Department of Primary Industries: figure **5.32**/Jan Carey; • State of Victoria © Agriculture Victoria: figures **5.30**; **5.33**; **7.24**; • State of Victoria © DataVic: figure **7.28** (source); • State of Victoria © Department of Economic Development, Jobs, Transport and Resources (DEDJTR): figures **7.5**; **7.25** (source); • State of Victoria © Department of Environment, Land, Water and Planning (DELWP) (Licensed under CC BY 4.0): figure **4.18**; • State of Victoria © West Gate Tunnel Project: figure **6.11** (source); • Statista (Licensed under CC BY-ND 4.0): figure **6.9**/data from World Air Quality Index (WAQI); • susDrain: figure **1.3**; • Swiss Seismological Service: figure **6.23** (source); • United Nations Conference on Trade and Development (UNCTAD): figure **5.23**/*Global Trade Update,* October 2020; • United Nations Office for the Coordination of Humanitarian Affairs (OCHA)/ReliefWeb: figures **1.4** (source); **1.8** (source); **1.10** (source); • USAID: figure **5.10**; • US Geological Survey (USGS): figures **1.15** (source); **2.3** (source); **3.2** (source); **3.3** (source); **3.5** (source); **3.12**; **3.14** (source); **3.23** (source); **3.28** (source); **3.30** (source); **3.33** (source); **3.34** (source); **3.40**/Tom Casadevall; **6.24** (source); **6.25** (source); **6.26** (source); • US Government Accountability Office (USGAO): figure **1.18** (image GIS); • US National Park Service (NPS): figure **6.4**; • Micah Wilkins: figures **7.1**; **7.2**; **7.16**; **7.20**; **7.23**; • World Health Organization (WHO): figures **1.13**; **5.2** (source); **5.6** (source); **5.12** (source); **5.14** (source); **5.15** (source); **5.21** (source); **5.22** (source); **5.27**; **6.6**/Urban Ambient Air Pollution Database; • www.howstuffworks.com: figure **3.17** (source).

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VCE GEOGRAPHY SERIES

3rd Edition

UNIT 1

Hazards and Disasters

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Developed and published for the VCE Geography Study Design 2022–2025, *Hazards and Disasters* is a comprehensive course book that provides topical case studies helping students to understand and apply geographical concepts, key knowledge and skills.

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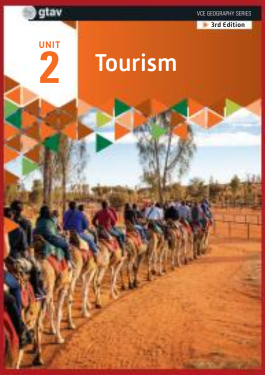

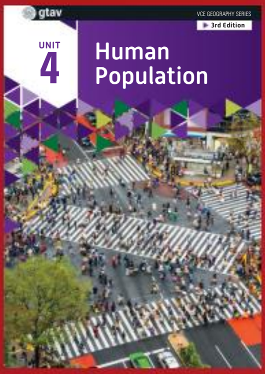

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