Pearson Edexcel

INTERNATIONAL ADVANCED LEVEL

GEOGRAPHY

TOPIC GUIDE BOOKLET

Unit 1: Global Challenges

Topic 1: World at Risk

Pearson Edexcel International Advanced Subsidiary in Geography (XGE01)
Pearson Edexcel International Advanced Level in Geography (YGE01)
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Contents

Introduction

This booklet has been written to support teachers and learners teaching and studying the Pearson Edexcel International Advanced Subsidiary/Advanced in Geography qualification. This guide should be used alongside other published teaching and learning materials available on the Pearson Edexcel International Advanced Subsidiary/Advanced Level in Geography web page here.

Big Picture Overview:
Topic 1: World at Risk has six Enquiry Questions which must be covered, which focus on different aspects of hazard events, disasters and climate change. Enquiry Questions 1-3 focus on a range of tectonic and hydro-meteorological hazards, their causes and impacts on people. Enquiry Questions 4-6 explore the nature of past and contemporary climate change in terms of causes, impacts and management.

EQ1 Hazards and causes	EQ2 Hazard distribution	EQ3 Hazard trends and impacts
• Tectonic processes and hazards • Hydromet processes and hazards • Measuring risk	• Hazard risk distribution • Multiple hazard zones • Megadisasters	• Trends in hazards and disasters • Explaining trends • Impacts and management
EQ4 Past climate change	**EQ5 Global warming**	**EQ6 Global warming risks and management**
• Evidence for past climate • Causes of past climate change • Comparisons with global warming	• Evidence for and causes of global warming. • Future projections • Impacts of global warming	• Mitigation efforts • Adaptation strategies • Attitudes to global warming

Assessment:

Topic 1 is assessed as part of Paper 1. This is a 1 ½ hour exam. World at Risk is assessed:
• In Section A, Questions 1 and 2: a series of data stimulus and short-answer questions with a maximum mark of 6. These questions are compulsory.
• In Section B, Questions 5: a 10-mark data stimulus question plus a 20-mark essay question. This question is optional as candidates can choose to complete Question 5 instead (Going Global).

In addition, themes from World at Risk can be assessed as part of the content of Question 3, the 15-mark synoptic question in the Paper 3 Contested Planet examination.

1.3.1 Global hazards

Enquiry question: What are global hazards and what causes them?

Geophysical hazards
Plate tectonics is the fundamental cause of tectonic hazards. The earth's oceanic and continental plates are in constant motion (moving at between 20 mm and 60 mm per year) and this is responsible for tectonic hazards. The majority of earthquakes, volcanic eruptions and tsunami happen at plate boundaries where two tectonic plates meet (Figure 1.1):

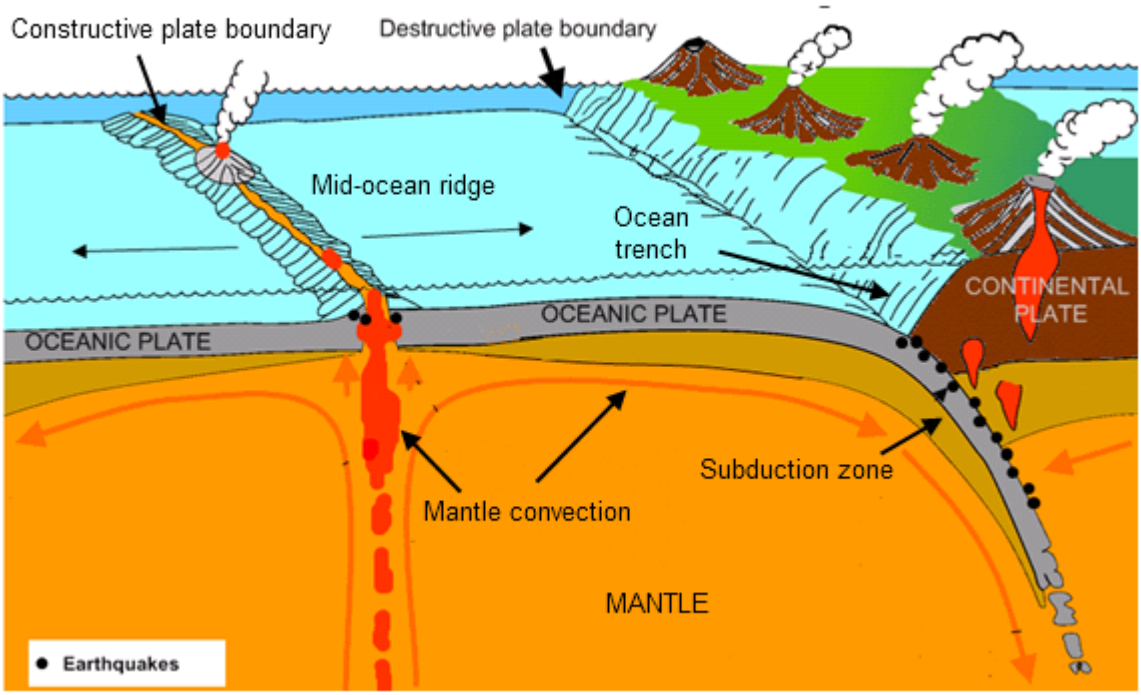

Figure 1.1 Constructive and destructive plate boundaries

Different types of plate tectonic setting generate different tectonic hazards, at different magnitudes. This means the risk of living close to a destructive plate margin subduction zone (Figure 1.2) are significantly higher than at a constructive plate margin:

	Earthquakes	Volcanic eruptions	Tsunami
Constructive plate boundaries	Low magnitude earthquakes generated by magma movement as plates pull apart.	Effusive eruptions, shield volcanoes. Basaltic magma and low hazard.	Not normally generated here.
Destructive plate boundaries	High magnitude earthquakes as subducting plate 'sticks'.	Violent, explosive andesitic eruptions; high hazard.	Most tsunami generated at these locations.
Conservative plate boundaries	High magnitude earthquakes along complex fault zones.	No volcanic activity.	Not normally generated here.
Other locations	Mid-plate earthquakes caused by re-activation of ancient faults. Continent-continent collision zones have high magnitude earthquakes e.g. Himalaya.	Mid-ocean plate hotspots e.g. Hawaii, Galapagos. Low hazard basaltic eruptions.	Volcanic tsunami generated by volcano collapse, usually at subduction zones.

Figure 1.2 Hazards at contrasting plate boundaries

Mass movements, including landslides and avalanches, are geophysical hazards, but they are complex ones. Landslide risk is a function of several factors including:

- *Topography and relief, as steep slopes increase risk.*
- *Weak, geologically young rocks, unstable soil, sediment as well as fractured and faulted rocks increase risk.*
- *Heavy rainfall and earthquake tremors can trigger landslides.*

In addition, human factors such as deforestation or construction on slopes can destabilize formerly stable slopes increasing risk.

Avalanches occur in specific locations:

- *mountain areas with high snowfall*
- *slopes between 30 and 45 degrees*

Avalanches can be triggered by weak snow layers, strong winds, rainfall and human activity. They can be triggered by earthquake tremors. Human factors such as deforestation can increase avalanche risk in specific locations.

Hydro-meteorological hazards

Tropical cyclones (also called hurricanes and typhoons) are a significant weather hazard in many parts of the world. These large, rotating storms cause widespread damage. They are a

short-term hazard because each tropical cyclone lasts for a few days to a few weeks, before dissipating.

Tropical cyclones occur in distinct seasons in different ocean basins:

	Ocean Basin	Season starts	Season ends	Average number of tropical cyclones per year	Name
Southern Hemisphere	North Atlantic	Jun 1st	Nov 30th	12	Hurricane
	Eastern Pacific	May 15th	Nov 30th	17	Hurricane
	Western Pacific	Jan 1st	Dec 31st	26	Typhoon
	North Indian	Jan 1st	Dec 31st	5	Tropical cyclone
Northern Hemisphere	South-West Indian	Jul 1st	Jun 30th	9	Tropical cyclone
	Australian region	Nov 1st	Apr 30th	11	Tropical cyclone
	Southern Pacific	Nov 1st	Apr 30th	7	Tropical cyclone

Figure 1.3 Tropical cyclone basins and seasons

Tropical cyclones form when:

- *Ocean water temperatures are at least 26.5 °C, extending to a depth of 50 metres.*
- *The air has high humidity.*
- *Rising (convecting) air cools quickly as it rises, releasing latent heat of condensation which powers the tropical cyclone.*
- *There is low vertical wind shear (change of wind direction with height) as wind shear disturbs cyclone formation.*
- *The Coriolis Effect is present to create the rotational movement of winds, which means tropical cyclones do not form within 0 and 5 degrees of the equator.*

The seasonal movement of the heat equator means that a water temperature of 26.5 °C is only present during the summer in each hemisphere.

Tropical cyclones bring a number of specific hazards when they make landfall:

- *very high rainfall, leading to flooding*
- *strong, destructive winds*
- *a storm surge leading to coastal flooding caused by the low air pressure with the tropical cyclone system.*

Flooding is a very widespread hydro-meteorological hazard that can affect almost all locations. Flooding can be caused by:

- *convectional storms and tropical storms leading to flash floods*
- *ice melt seasonal flooding in mountainous areas fed by glaciers*
- *frontal rainfall from mid-latitude depressions: rainfall totals can build up over days or weeks leading to extensive flooding that may last weeks.*

Drought is a longer-term hazard that tends to build up over several months or years. Drought is an abnormally low level of rainfall, leading to low water availability.

Drought is different from *aridity* which is a permanent state to low rainfall. Consequently, deserts do not suffer from drought; they are permanently arid. Meteorological droughts often lead to hydrological and agricultural drought when water supplies begin to run low:

Type of drought	Cause
Meteorological	Caused by lower than normal precipitation
Hydrological	Caused by depletion of water reserves: rivers, lakes and groundwater
Agricultural	Caused when soil water levels drop and crops begin to die

Figure 1.4 Types of drought

Drought is particularly dangerous when a large number of people depend on natural water sources for water (collecting water from rivers and lakes or simple wells) and on farming for income and food. In developed countries, sophisticated water supply systems and the small contribution farming reduces the impact of drought.

ENSO Cycles

Drought, flooding and even tropical cyclones can be affected by ENSO cycles in the Pacific Basin. ENSO cycles (El Nino Southern Oscillation) are periodic disturbances to the normal ocean and atmospheric circulation in the Pacific Ocean. ENSO consists of a cycle between:

- *normal conditions*
- *El Nino (warm episode) – a period when normal conditions are reversed e.g. dry areas are wet*
- *La Nina (cold episode) – a period of exaggerated or extreme normal conditions e.g. dry areas are exceptionally dry.*

El Nino events occur roughly every 5 years, but the strength of events is different and the timing cannot be predicted (Figure 1.5):

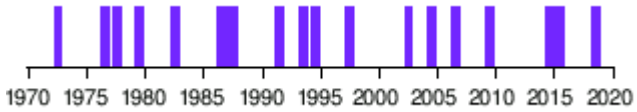

Figure 1.5 El Nino events between 1970 and 2018

The maps below (Figure 1.6) show how El Nino changes the normal situation in the Pacific Basin.

Normally:

- An anti-clockwise ocean current circulation brings cold water up the west coast of South America (the Peru Current), meaning the waters off Chile and Peru are cold.
- This cools the air above the ocean, leading to persistent high air pressure, few clouds and very low rainfall.
- The ocean circulation moves water west with the trade winds, across the Pacific Ocean along the equator.
- As the water moves west, it warms up significantly.
- The now warm ocean waters north of Australia and around SE Asia heat the air above the ocean, leading to convection and high levels of rainfall.

El Nino

- The trade winds weaken, and the normal westward moving ocean currents weaken or even reverse, to flow east towards South America.
- This creates an area of unusually warm water west of South America.
- The normally high air pressure over western South America is replaced by low air pressure, rainfall and the risk of floods (Peru, Chile, Mexico).
- In Asia, normally low air pressure is replaced by higher pressure and lower rainfall than normal.
- In some years, this leads to drought conditions and a higher risk of forest fires.

The impact of an El Nino can ripple out around the world affecting weather patterns as far afield as Europe and Africa. El Nino events usually lead to fewer hurricanes in the Atlantic Basin.

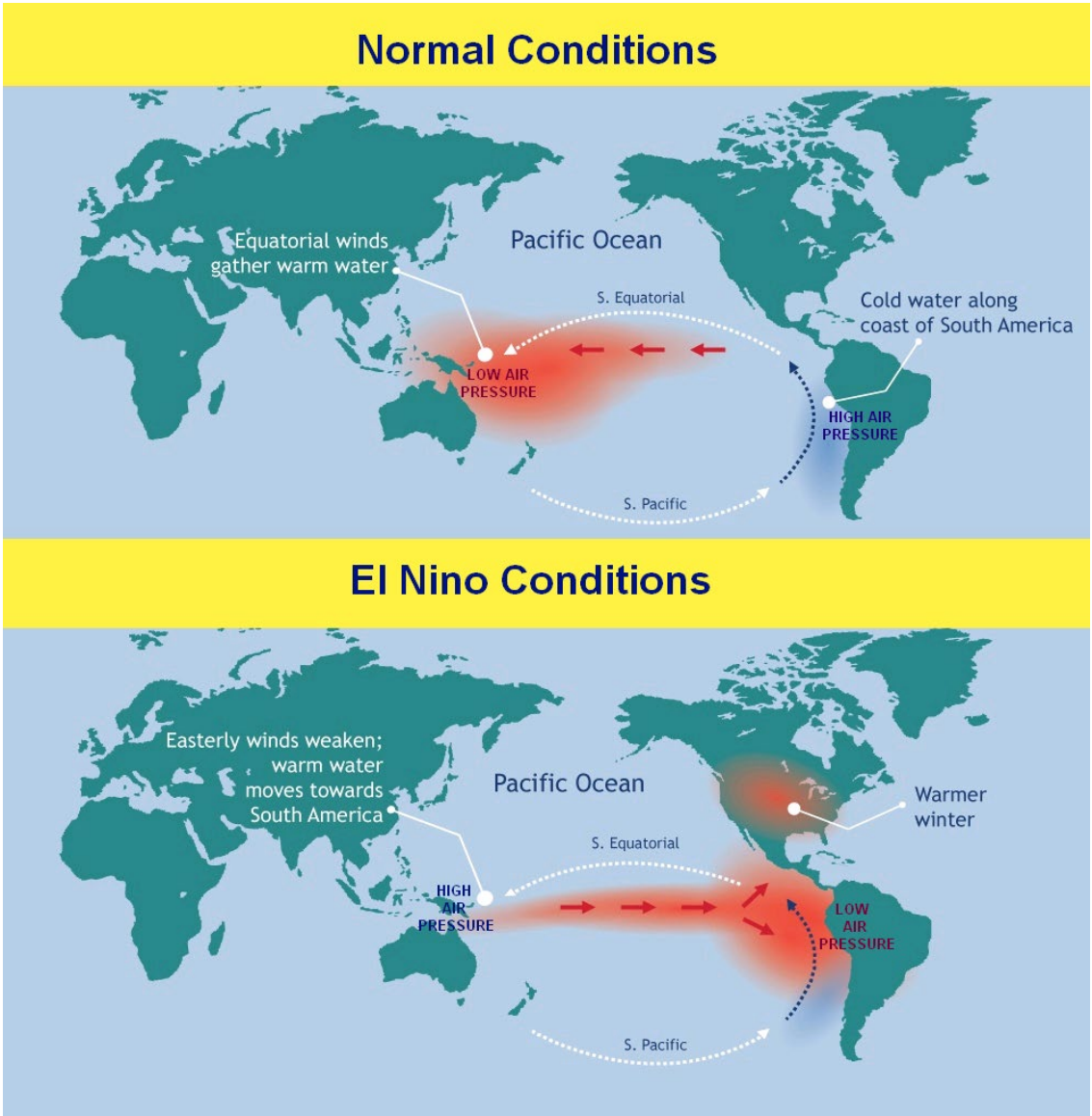

Figure 1.6 El Nino versus normal conditions in the Pacific Ocean [1]

[1] Adapted from: https://spudman.com/news/el-nino-dry-pacific-northwest/

Hazards versus disasters

Natural hazards are '*events with the potential to harm people and /or their property*'. A natural disaster is the realisation of the hazard so that harm has occurred. There is no universal definition of 'natural disaster' but often definitions include thresholds such as:

- *10 or more people are killed, or*
- *100 more more people are affected, or*
- *a state of emergency is declared / international assistance is asked for.*

These thresholds mean that some hazards might be thought of as 'events' rather than disasters because their impact is small and limited.

The Degg Disaster Model (Figure 1.7) is useful. It shows that a natural disaster occurs when a vulnerable population is affected by a natural hazard:

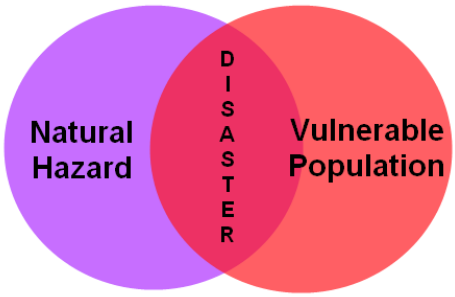

Figure 1.7 The Degg Disaster Model

The Degg Model implies that if a population is ***not*** vulnerable, then it might be able to cope with the impacts of the natural hazard so that a disaster is avoided.

Very generally, the larger the magnitude of the natural hazard, the more likely it is that a disaster will occur. However, people in developing countries (low incomes, low quality housing, limited education, limited emergency services) could be much more vulnerable than people in the developed world to the same magnitude (Figure 1.8) of natural hazard.

Measuring natural hazard magnitude		
Earthquakes	***Moment Magnitude Scale (MMS)***	Measures earthquake energy release using a log-scale. Magnitudes over 6.5 MMS are usually significant; the largest recorded was about 9.5 MMS.
Volcanic Eruptions	***Volcanic Explosivity Index (VEI)***	Uses a 0-8 scale to rate eruption size based on ash cloud height, volume of material erupted and eruption style. VEI numbers of 5 and above are large eruptions.
Tsunami	***Run-up Height (metres)***	The maximum height water reaches on land, above normal sea-level.
Floods	***Discharge (cubic metres) and Return Period***	Discharge is the volume of water in a river measured in cubic metres per second (cumecs). The Return Period is measured in years: how often a flood of a particular discharge can be expected on average.
Tropical Cyclones	***Saffir-Simpson Scale***	A five-point scale (1-5) that combines wind speed with storm surge height to provide an indication of intensity.

Figure 1.8 Measuring hazard magnitude

The disaster risk equation is a non-numerical equation that helps our understanding of disasters. It is expressed as:

$$R = \frac{H \times V}{C}$$

Where:

- R = Risk (the level of risk)
- H = Hazard magnitude
- V = Vulnerability
- C = Capacity to Cope

The two examples below serve to illustrate how the disaster risk equation works:

$R = \frac{H \times V}{C}$	$R = \frac{H \times V}{C}$
Note that the magnitude of the hazard, 'H' is the same in both cases.	
In this example, the risk of harm is large because the population is vulnerable and has a low capacity to cope.	In this example, the risk of harm is small because the population has low vulnerability and has a high capacity to cope.
High vulnerability? • Poverty • Poorly built, slum housing • Food insecurity and poor water supplies • Poor governance • High risk locations • Young and old people who can't easily help themselves	**High capacity to cope?** • Population educated and aware of risks • Well planned, well built homes • Trained and equipped emergency services • Response has been planned in advance • Government able to provide relief effort

Figure 1.7 The disaster risk equation

Disaster profiles (below, Figure 1.9) can also be used to understand contrasting natural hazard impacts. Hazard profiles estimate 6 different characteristics of natural hazards to produce a visual profile. This shows that some natural hazards affect larger areas than others (areal extent); some have a higher speed of onset and the degree of spatial predictability varies:

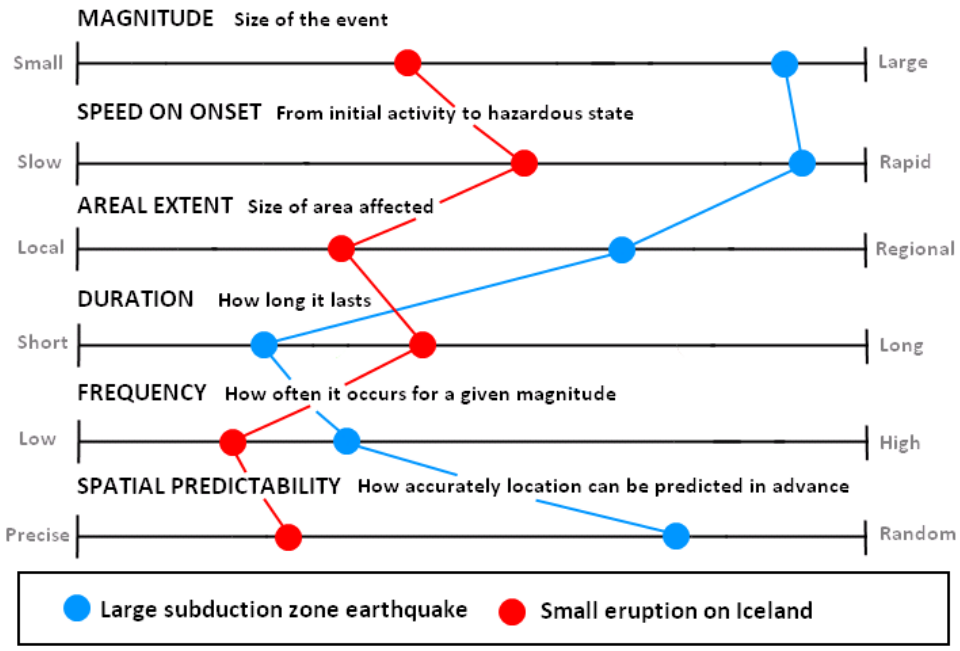

Figure 1.9 Disaster profiles

1.3.1 Questions to think about	1 Which natural hazards are caused by tectonic processes and which by hydro-meteorological processes? 2 Explain the changes caused by ENSO cycles and how this affects the distribution of weather hazards. 3 Why is drought a complex hazard which is different to flooding or tropical cyclones? 4 Explain how the magnitude and or intensity of natural hazards is measured. 5 How can the disaster risk equation help our understanding of natural disasters?

1.3.2 Global hazard distribution

Enquiry question: Which areas are affected by geophysical and hydro-meteorological hazards and disasters?

Geographical distribution

Most geophysical hazards occur at plate boundaries, as shown in the map below:

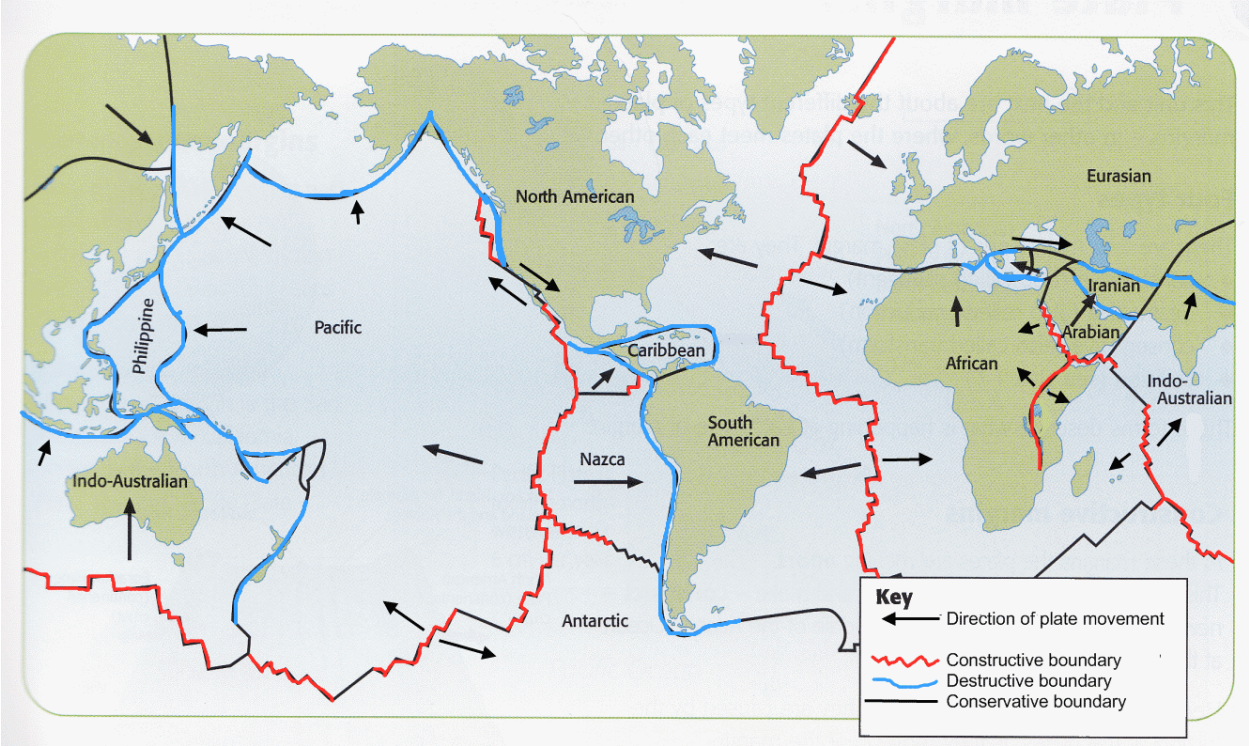

Figure 2.1 Global plate boundaries map

A very high proportion of **tectonic hazards** occur around the Pacific Ring of Fire, which is the arc of destructive plate boundaries (blue on Figure 2.1) encircling the Pacific Ocean. Here, oceanic plates are subducted under continental plates / other oceanic plates leading to a large number of earthquakes and volcanic eruptions:

- *Around 450 active volcanoes are found in the Ring of Fire, about 75% of the world total.*
- *80% of the world's large (MMS 7.0+) earthquakes occur here.*
- *Tsunami are more common in the Pacific Ocean than any other ocean*.

There are other high-risk locations, including:

- *the Caribbean, where earthquakes and eruptions occur*
- *the earthquake zones running from southern Italy east through Turkey, Armenia and northern Iran*
- *the Himalaya, which is a continent-continent collision zone with frequent, large earthquakes*
- *the central African Rift Valley, a continent-continent constructive plate margin, which has dangerous volcanic eruptions, e.g. Mount Nyiragongo.*

Landslide risk is high in most mountainous regions. However, it is especially high in geologically young mountains formed recently by crustal compression and volcanic activity. This means the Himalaya, Andes and many volcanic islands are at high risk of landslides as well as being at risk from volcanic activity and earthquakes.

Flooding is a natural phenomenon. Almost all rivers flood from time to time in response to periods of unusually high river discharge. The floodplain of a river is a natural physical feature that temporarily accommodates this higher than usual discharge. When flooding becomes hazardous to people, it is often because:

- *People have chosen to live on floodplains, which inevitably flood from time to time.*
- *Actions such as deforestation have increased flood risk, by altering catchment processes: decreasing interception, infiltration and throughflow but increasing surface runoff.*
- *Urbanisation has reduced infiltration by increasing impermeable surfaces (roofs, roads, car parks).*
- *Rivers have been made navigable, and channelized - which decreases their capacity.*

Drought risk is generally highest in areas that are:

- *Already semi-arid, so water availability is low.*
- *Rainfall is very seasonal so small variations from normal seasonal rains can quickly become problematic.*
- *Water use is rising due to increases in population, farming, industrial and domestic water use – so the supply-demand equation is changing.*

Drought risk is highest in the seasonal tropics, such as the Sahel in Africa, NE Brazil, western USA and northern Mexico, and central South Asia.

Tropical cyclones have a very distinct geographical distribution:

- *spatially they occur from about 5° North / South of the Equator, with most forming between 10° and 30° North / South*
- *temporally they occur in distinct seasons North / South of the equator, caused by the seasonal movement of the heat equator.*

This means some locations are at very high risk, such as the Philippines, whereas other locations have no risk at all. The map below (Figure 2.2) shows 150 years of tropical cyclone tracks. This illustrates that the western Pacific and Atlantic Basins are the most likely places for tropical cyclones to form.

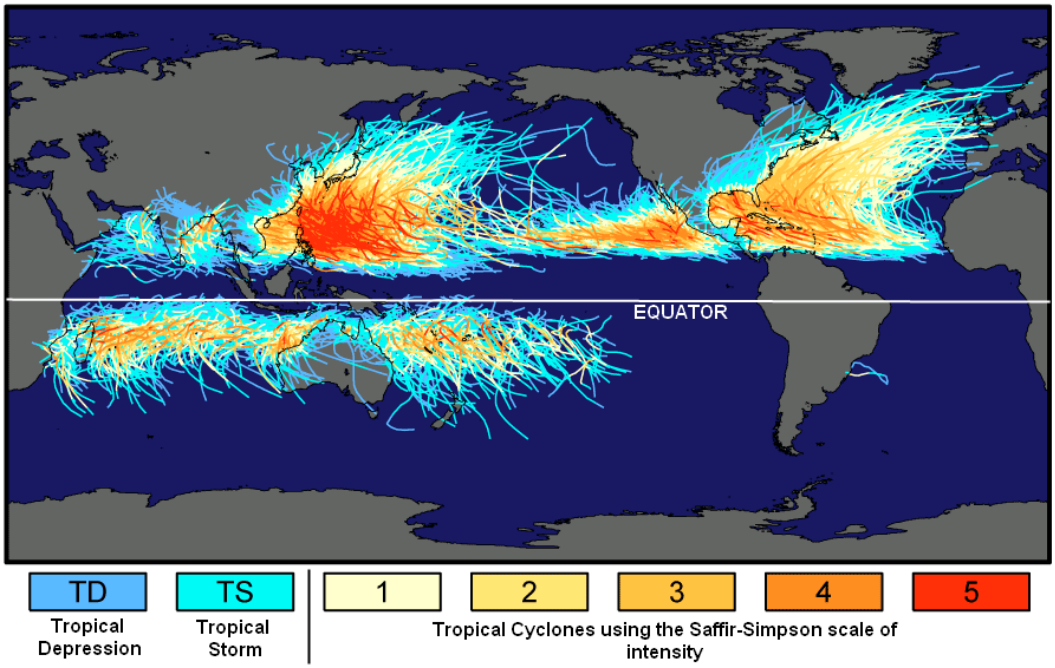

Figure 2.2 Tropical cyclone tracks over the last 150 years [2]

Human factors

Physical geography explains why some locations are at risk from natural hazards, but human factors (Figure 2.3) are important in explaining why risk of disaster is high in some places but not others:

Level of Development	Population density
Developing countries and low-income groups in emerging countries are at higher risk because of: • *poorly built housing* • *low incomes, limited financial safety-net in the event of disaster* • *lack of social security, and no insurance* • *lack of education and health care.*	*Areas with high population densities, especially in cities, can be badly hit by hazards especially if:* • *poorly built housing is densely packed, restricting post-disaster access.* • *large numbers of vulnerable people are in one place, e.g. children.* • *locations are physically risky, e.g. steep slopes, low-lying.*
Accessibility	**Governance**
Isolated, inaccessible areas can increase vulnerability because: • *access routes such as roads can be cut.* • *rescue workers and emergency aid are delayed by logistical difficulties.* • *bad weather (snow, torrential rain) in mountains can delay rescue.*	• *Governance refers to how well places are run, by civil society (police, administrative organizations responsible for health, water, planning and education).* • *Poor governance often goes hand in hand with corruption and lack of democracy.* • *Poor governance means preparation is poor and response is usually inadequate.*

[2] Adapted from: https://earthobservatory.nasa.gov/images/7079/historic-tropical-cyclone-tracks

Figure 2.3 Factors affecting risk

The table below (Figure 2.4) shows the 2018 scores for World Bank Worldwide Governance Indicators where higher scores indicate better governance. Countries with low scores for government effectiveness, regulatory quality and accountability are likely to be much less well able to both prepare for and respond to a natural disaster:

World Bank Worldwide Governance Indicators 2018	**Japan**	**Philippines**	**Indonesia**	**Bangladesh**	**Haiti**
Control of Corruption	**1.4**	-0.5	-0.6	-0.9	**-1.3**
Government Effectiveness	**1.7**	0.0	0.2	-0.8	**-1.9**
Political Stability	**1.1**	**-1.1**	-0.5	**-1.0**	-0.6
Regulatory Quality	**1.3**	0.0	-0.1	-0.8	**-1.2**
Rule of Law	**1.5**	-0.5	-0.3	-0.6	**-1.0**
Voice and Accountability	**1.0**	0.0	0.2	-0.7	-0.8

Figure 2.4 WB WGI indicators

Explore more at:
https://datacatalog.worldbank.org/dataset/worldwide-governance-indicators

Multiple hazard zones

Some locations can be described as multiple hazard zones (or hazard hotspots) because their physical geography means they are at risk from more than one hazard type. Based on the 2017 *World Risk Index* from the United Nations University, these countries all have a 'very high chance' of disasters:

Risk Rank (out of 172)	**Country**
150	Chile
151	Haiti
152	Jamaica
154	Vietnam
155	Japan
162	Papua New Guinea
164	Costa Rica
167	Bangladesh
168	Guatemala
169	Philippines

- The countries listed include developed, emerging and developing countries.
- Most are in tectonically active areas, with a few exceptions (Vietnam, Bangladesh).
- Almost all are in places that can get tropical cyclones (Chile is an exception).
- Flooding is a risk in all of the countries shown, and landslides are common in most. Some are at risk from tsunami.

Figure 2.5 Selected high risk countries[3]

[3] Data is from the United Nations University 2017 World Risk Report:
https://i.unu.edu/media/ehs.unu.edu/news/4070/11895.pdf

Both California and the Philippines are multiple hazard zones:

California	Philippines
• Southern California is located on a conservative plate margin, the San Andreas transform fault zone – so is at risk from large, shallow earthquakes. • Complex geology, faulting and mountainous areas means landslide risk is high in the Coast Range Mountains. • Northern California is part of the Cascadia Subduction zone which brings a risk of earthquakes, tsunamis and volcanic eruptions (Lassen Peak, Mount Shasta). • Flooding is a risk, especially in the Central Valley east of San Francisco. • California also suffers from drought, for instance between 2011 and 2017; drought also brings a very high risk of wildfires.	• The Philippines is arguably the most 'at risk' major country on earth. • On average, it is hit by 3 typhoons per year, and these can be very intense. • Flood risk is high, and landslides are a frequent major hazard during typhoons and sometimes can be triggered by earthquakes. • There are several major subduction zones which bring the risk of major earthquakes and tsunami. • There are over 20 active volcanoes including Mount Mayon and Mount Pinatubo. • The Philippines can be impacted by ENSO events due to its location in the western Pacific.

Figure 2.6 Hazard hotspots

In the Philippines, the annual economic costs of natural disasters are around US$ 4 billion, 1.5% of annual GDP. This is a significant cost, and money that could be spent on health or education rather than annual rebuilding and recovery.
About 25% of people in 2018 worked in agriculture in the Philippines. Natural hazards can directly impact the livelihoods of farmers, destroying crops, food supply and sources of income.
In California, there are significant costs in terms of planning and management, met by State and Federal Government as well as costs incurred through insurance against natural disasters. Farming can be hit badly by drought, and water shortages.

Mega-disasters

Mega-disasters are those where the scale of the impacts is much greater than would normally be expected. There is no universal definition of a 'mega-disaster'.
The magnitude of the event may be similar to that of a 'normal' disaster but the impacts are much more widespread. They could be:

- ***regional*** *i.e. more than one country is affected*
- ***global*** *– having consequences for the entire world.*

In some cases, the death toll from mega-disasters may not be large but their economic consequences are especially severe.
Three of the deadliest earthquakes of the last 20 years cannot be described as mega-disasters because they only affected one area, in one country:

- *Kashmir, Pakistan 2005 – approx. 100,000 deaths*
- *Sichuan, China, 2008 – 87,000 deaths*
- *Haiti, 2010 – approx. 160,000 deaths*

The **2004 Asian Tsunami** in the Indian Ocean was Sweden's biggest ever natural disaster by death toll. 543 Swedish citizens died holidaying in Thailand. Not since 1709 have so many Swedes died in a single incident in one day. The tsunami killed people in 14 countries (Figure 2.7) as well as tourists from numerous other countries, giving it a global profile like no other event in recent history:

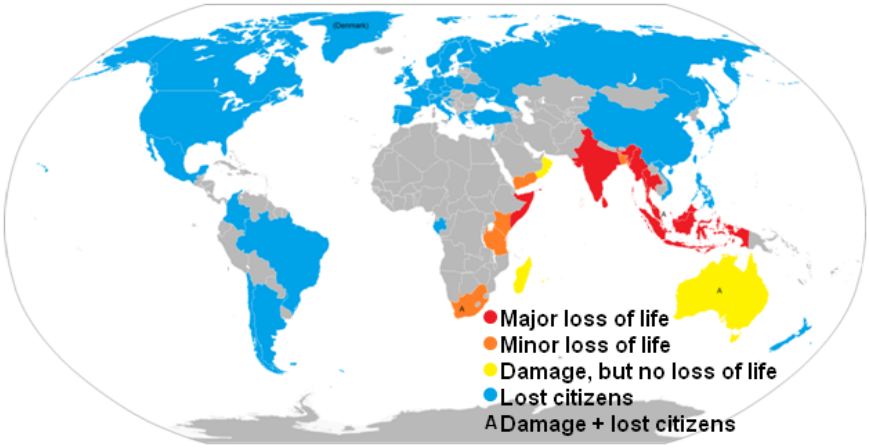

Figure 2.7 The global impact of the 2004 Asian Tsunami

The losses in some countries were very large (death tolls in pink):

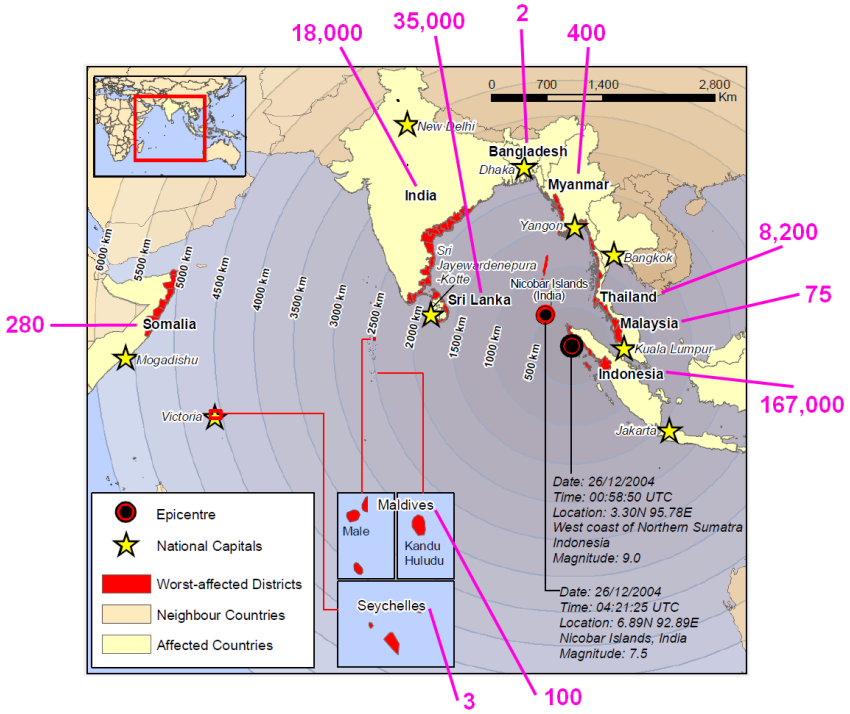

Figure 2.8 Deaths from the 2004 Asian tsunami[4]

In terms of global impact:

1 – Over $14 billion was pledged in aid to help the countries affected.

2 – The event caused a renewed interest in tsunami – and how to manage them.

[4] Adapted from a map produced by Relief Web in 2004: https://reliefweb.int/maps

3 – A tsunami warming system was put in place in the Indian Ocean.

2010 Eruption of Eyjafjallajokull on Iceland

Eyjafjallajokull erupted as a VEI 4 volcano in March 2010. At first, it was a relatively minor eruption. On the 14th of April, a more violent explosive phase of eruption started. The volcano erupted ash with a high silica content and a series of vents exploded this ash up to 8km into the atmosphere. Cold melt-water from the ice above the erupting volcano chilled lava below causing it to fragment into glass-like particles, which were then erupted into the ash cloud. The combination of ash and glass fragments were hazardous to aircraft:

- *Ash can get into jet engines, melt and gum them up – leading to failure.*
- *Abrasive volcanic glass particles can fog aircraft windscreens.*

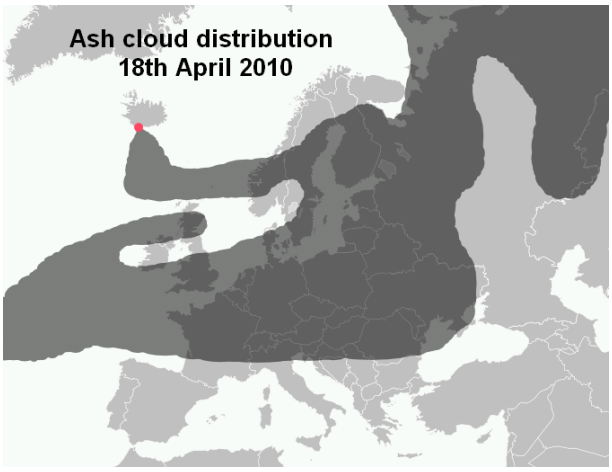

Figure 2.9 The Eyjafjallajokull ash cloud in 2010

The ash cloud was moved by the North Atlantic jet-stream down over Europe so it became a major hazard to air traffic, especially on trans-Atlantic routes. This led to airspace being closed in many countries. Losses were as follows:

- *£130 million per day from the airline industry and £1.1 billion was lost overall.*
- *Airports lost a further £80 million.*
- *107,000 flights were cancelled.*
- *About 10 million people were affected.*

This event shows how, in a heavily interconnected world, a tectonic hazard can cause major economic disruption. The eruption caused no deaths.

2011 Japanese (Sendai) tsunami

This event caused perhaps the most significant global impacts ever. In terms of Japan, the economic losses amounted to some $360 billion – the largest economic loss from a natural disaster ever (similar in size to the entire annual GDP of Norway).

However, there were wider impacts:

- *The explosions at the Fukushima nuclear reactors, damaged fatally by the tsunami, led to world-wide fears over the safety of nuclear power. In 2011, Germany decided to shut permanently its 17 nuclear reactors (17% of Germany's electricity generation) by 2022. Eight reactors were immediately shut in 2011.*
- *There were major impacts on the global supply chain of components parts for goods. One destroyed factory made 60% of the entire world's supply of car engine air flow sensors. Another factory supplied all of the brakes for new Toyota cars, forcing Toyota to shut all its factories for 2 weeks, at a loss of over $300 million.*

Regional drought

In some cases, widespread drought might be classed as a mega-disaster because of:

- *the number of people affected, which can run into millions*
- *more than one country being affected*
- *refugees crossing international borders to escape drought and famine, leading to indirect impacts in neighbouring countries.*

Major droughts in the Sahel in 1984-1985 and in 2010 led to refugee crises. The 2010 event affected Sudan, Chad, Niger and Mali as well as some neighbouring countries. Around 10 million people were affected by food shortages. While drought conditions triggered the event, there were many contributing, underlying causes including conflict in Sudan, deforestation, poor farming management and poverty.

1.3.2 Questions to think about	1 Use a large A3 outline world map to show the distribution of tropical cyclones, earthquakes and drought. 2 Explain how human factors make some places more vulnerable to the impacts of natural disasters than other places. 3 Explain the difference between a natural hazard and a natural disaster. 4 Use examples to explain the difference between a mega-disaster and a 'normal' disaster. 5 Use examples to explain why some locations are considered to be multiple hazard zones.

1.3.3 Global hazard trends

Enquiry question: What are the global trends in hazard occurrence and disaster impacts?

Trends

When considering trends, it is very important to distinguish between:

- *hazard events (natural hazards) – which are caused by physical processes*
- *natural disasters – which are the realization of the hazard, when harm has occurred to people and / or their property.*

It is important to recognize that the data used to determine trends is problematic, especially data from before 1970:

- *Before widespread use of satellites, some tropical cyclones were not recorded especially in the southern hemisphere.*
- *Prior to widespread use of telephones, mobiles and the internet disasters that occurred in distant and isolated places may not have been recorded – or not recorded in any detail.*
- *Data on ocean and air temperatures was 'patchy' in terms of global coverage until relatively recently.*

Trends in the occurrence of **floods** are difficult to determine accurately. The number of flood events is likely to be relatively stable over time but could increase as a result of global warming especially if there are more intense rainfall events. Both deforestation and urbanization lead to an increase in flood events in places that previously only rarely experienced flooding. The number of people *affected* by flooding is rising but this is caused more by increasing numbers of people living is high-risk locations i.e. floodplains, urban areas and areas that have experienced deforestation.

There is some evidence that the intensity of tropical cyclones in increasing. The graph below (Figure 3.1) shows the Power Dissipation Index (PDI) for Atlantic hurricanes 1950-2015. PDI is one way of measuring the tropical cyclone intensity.

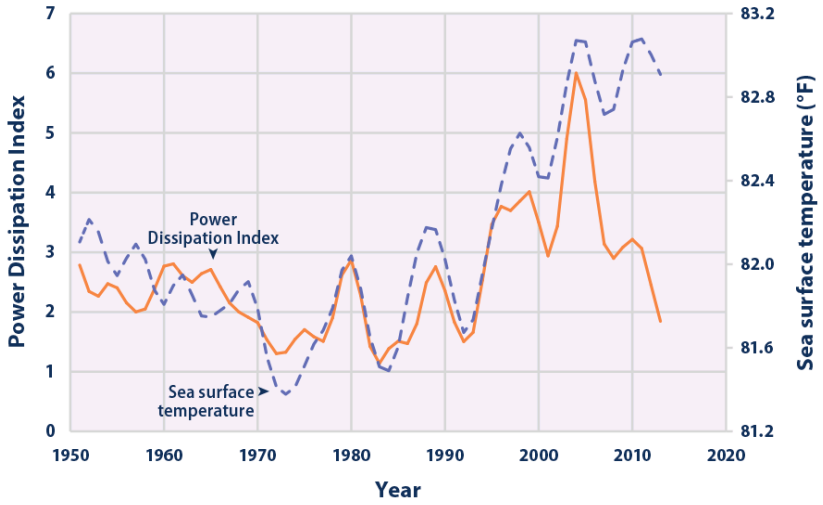

Figure 3.1 PDI for Atlantic hurricanes 1950-2015[5]

The graph above suggests that:

- *There is a high degree of variability in the intensity of tropical cyclones.*
- *There is some limited evidence of an increase in cyclone intensity since the 1990s.*

There is less evidence of an increase in the *number* of tropical cyclones. Trends in tropical cyclones, and drought are naturally very variable and are influenced by natural phenomena such as ENSO events and ocean circulation systems, such as the Atlantic Multi Decadal Oscillation (AMD). In order to determine if hydro-meteorological hazards are increasing in number and / or intensity, data from many decades will need to be analysed. A warmer world caused by global warming could lead to warmer oceans and therefore more powerful tropical cyclones.

Explore more at:
https://www.epa.gov/climate-indicators

Disaster trends

The graph below (Figure 3.2) shows the number of reported natural disasters from 1970 to 2018:

- *The number of disasters increased steadily from 1970 until the late 1990s, then stablised at 300-400 disasters per year from 2000 until 2010.*
- *Since 2010, there has been a downward trend in disaster numbers.*
- *Floods and tropical cyclones (which include other storms) account for the majority of disasters; earthquakes and extreme temperature and drought are also significant.*
- *Volcanic activity makes up a very small proportion of disaster numbers.*
- *Most of the recent downward trend in numbers is accounted for by fewer flood disasters.*

[5] From the United States Environmental Protection Agency:
https://www.epa.gov/climate-indicators/climate-change-indicators-tropical-cyclone-activity

The data in Figure 3.2 could suggest that for at least some hazards, such as floods, successful management means that fewer hazards are turning into disasters.

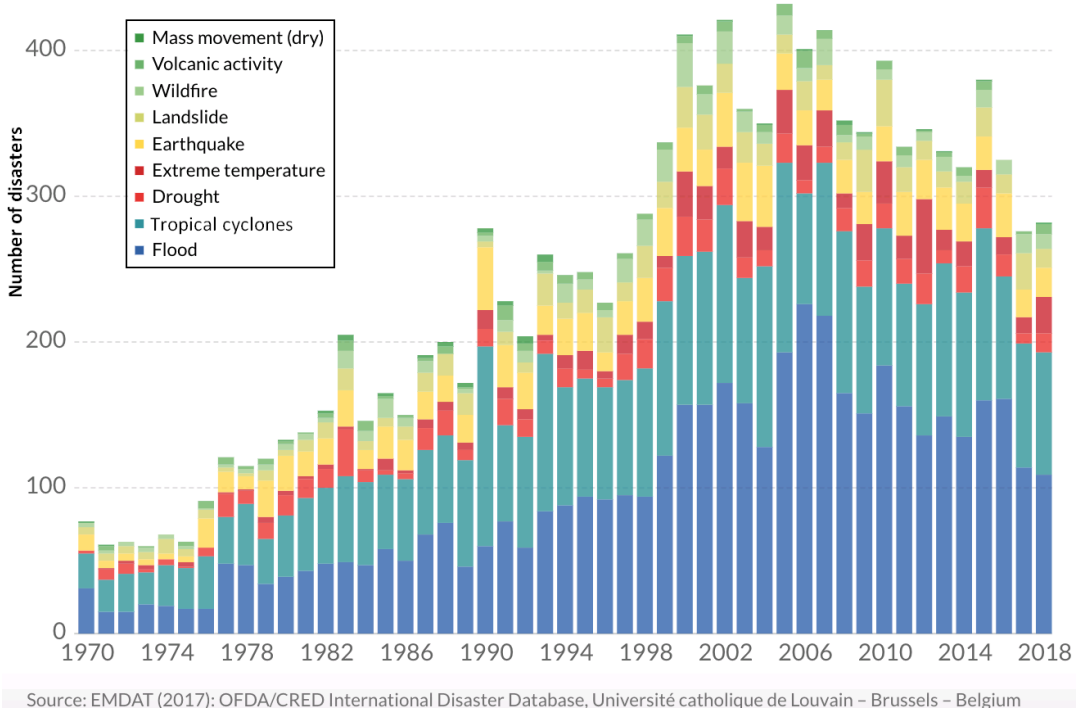

Figure 3.2 Disaster number trends [6]

Economic losses from natural disasters continue to rise. In the early 1990s, global losses averaged around US$75 billion per year. This had risen to about US$ 150 billion by the 2015-2020 period.

Economic losses are very 'spiky' because some very costly disasters have a major impact on the overall trend:

Cost in 2017/2018 US$	***Disaster***	***Year***
411	Tōhoku earthquake & tsunami	2011
330	Kobe earthquake	1995
176	Sichuan earthquake	2008
165	Hurricane Katrina	2005
130	Hurricane Harvey	2017

Figure 3.4 The top 5 natural disasters by economic losses

Rapidly rising wealth in emerging countries (especially in Asia) and continued increases in average wealth in developed countries accounts for the increase in economic losses.

The number of people affected by natural disasters also continues to rise:

- *In the early 1990s, about 200 million were affected worldwide each year.*
- *By the period 2015-2020, this had risen to around 300 million.*

[6] From EM-DAT, the International Disasters Database at the Centre for Research on the Epidemiology of Disasters – CRED at the University of Louvain.

Deaths from natural disasters have fallen:

- *In the early 1990s, average annual deaths were around 30,000.*
- *This increased to peak in the period 2000-2005 at about 70,000.*
- *Average annual deaths have since declined to around 40,000 per year.*

Population increase, urbanization and increasing population densities in coastal and other locations means that more people than ever are at risk of being affected by disasters. However, falling death tolls suggest management may be improving so risk of dying is falling. It should be noted that a small number of very costly disasters (Figure 3.5) in terms of death tolls account for a high proportion of total deaths so death tolls are very variable year on year:

Year	Death toll	Disasters with the highest death tolls since the year 2000
2004	227,898	Indian Ocean earthquake and tsunami
2010	160,000	Haiti earthquake
2008	138,373	Cyclone Nargis
2008	87,587	Sichuan earthquake
2005	87,351	Kashmir earthquake
2003	70,000	European heat wave
2001	20,085	Gujarat earthquake
2011	15,897	Tōhoku earthquake and tsunami
2007	15,000	Cyclone Sidr

Figure 3.5 Disasters with the highest death tolls since the year 2000

Prediction and monitoring

One of the most effective ways of reducing the impacts of natural disasters is the ability to predict them. For a prediction to be useful, it needs to lead to timely evacuation so needs to accurately:

- *predict the area that will be affected*
- *predict the timing, so that evacuation is done quickly enough.*

This ability to predict in time and space is important. Earthquakes cannot be predicted. Areas that are at risk are known, such as destructive plate margins, but when and where earthquakes will strike is never known in advance. This is not true of some other natural hazards (Figure 3.6):

Volcanic eruptions	*Scientific monitoring equipment can be used to predict many eruptions but the scientists and equipment are costly so not all volcanoes are monitored:* • *Tiltmeters are used to measure slope angle on the volcano sides and indicate when magma is filling the volcano from below.* • *Seismometers measure the earth tremors caused by magma movement.* • *Gas spectrometers measure the chemistry of gas emissions, changes to which can indicate eruptions.*
Tsunami	*The sub-sea earthquakes that trigger tsunami cannot be predicted, but seismometers can quickly pinpoint earthquake locations and issue warnings to coastal locations:* • *Sea-floor pressure sensors and floating buoys can detect the passage of tsunami.* • *Satellite, mobile and internet communications can alert at risk coastal locations.* • *Multi-media warnings can be used to provide evacuations alerts.*
Tropical cyclones	*Satellites can track tropical cyclones and computer models are used to predict their paths, with some accuracy.* • *Warnings can be given to at risk coastal locations.* • *Evacuation – either further inland or to shelters – can happen based on warnings.*

Figure 3.6 Prediction

It is important to recognize that prediction, warning and evacuation can save lives – but it does not prevent damage to property so may not mitigate economic losses very much.

Hazard Response has many different facets which partly depend on the nature of the hazard. If prediction and warning are possible then evacuation can take place.

- *In the USA, evacuation routes for hurricanes are sign-posted on highways and interstates, and evacuation centres are public buildings such as schools and sports centres inland away from the hurricane path.*
- *In developing countries, such as Bangladesh, cyclone shelters are usually found in at-risk locations. These concrete, elevated shelters allow communities to ride-out the cyclone without evacuating a long distance.*
- *Volcanic eruption risk is such that people need to evacuate some distance from a volcano, beyond the area at risk from lava flows, pyroclastic flows, volcanic mudflows (lahars) and major ash-fall.*
- *Tsunami evacuation routes lead to high ground inland, which is safe from rising waters. In some coastal locations, elevated concrete tsunami platforms are built as safe places for those that cannot quickly get inland.*

In some cases, levees (raised flood embankments), pumping stations and sea defences are built to prevent storm surges flooding areas inland. However, these are costly to build and maintain and are not common in developing and emerging countries away from major cities.

Tsunami defences consist of high concrete sea-walls, rip-rap and concrete tetrapods and sluice gates that automatically close the entrances to rivers when tsunami warnings are given. Tsunami defences are very expensive and are rare outside Japan.

Land-use zoning is a valuable tool for reducing the number of people at risk:

- *Areas at high risk of ground liquefaction during earthquakes can be zoned to prevent housing development.*
- *In tsunami risk areas, it is common for a 200-500m wide coastal strip to be zoned against urban development.*
- *Areas at high risk from volcanic mudflows and other volcanic hazards can be zoned as 'red-zones' where housing is banned.*

Land-use zoning is effective, but only if it is enforced by planners, monitored and policed, i.e. building in the highest risk areas is effectively prevented.

Hazard resistant design is effective against earthquakes as buildings can be made earthquake proof or 'aseismic', as shown in Figure 3.7.

Although costly, a simpler method can be used on residential buildings to reduce the possibility of collapse during intense ground-shaking.

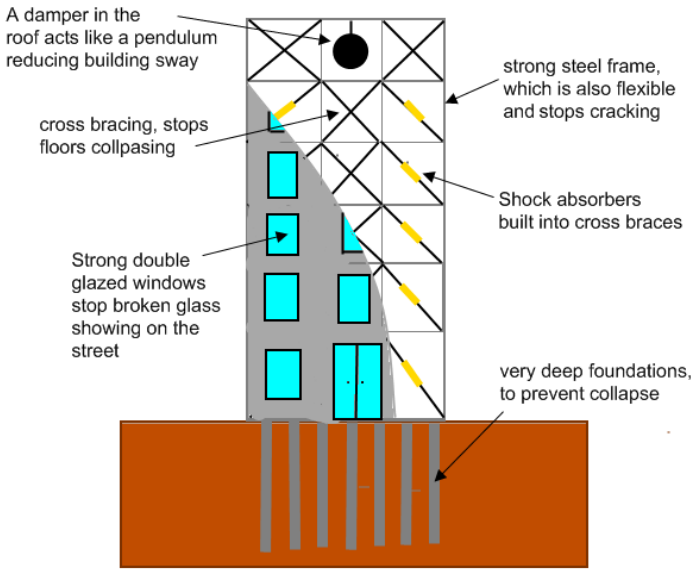

Figure 3.7 Earthquake proof construction

In developing and emerging countries – even in poorer rural areas, houses can be made earthquake resistant using simple guidelines. Shown below is part of some guidance issued by the Pakistan ERRA for the rebuilding of houses after the 2005 Kashmir earthquake. This basic advice, in visual form for people who are not literate, helps people build lower risk homes:

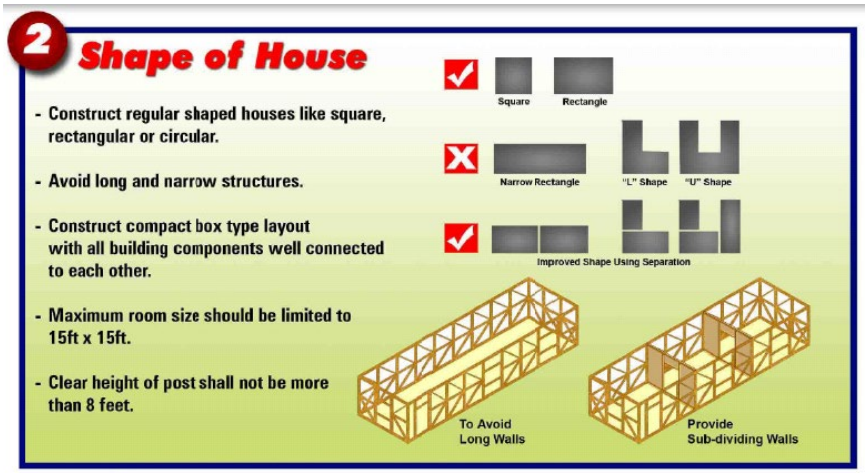

Figure 3.8 Advice from Pakistan's ERRA[7]

Explore more at:
http://www.erra.pk/sectors/housing.asp

Aid can be very important in terms of disaster response:

- *In developed and emerging countries, government-run emergency services or 'first responders' provide most of the immediate response in terms of rescue and basic relief (food, shelter, medical treatment, water).*
- *This may be supplemented by NGOs such as the Red Cross and other local charities.*
- *Many countries have rescue and recovery teams which can be flown out to help.*
- *In some developing countries, lack of local resources means an international aid response is needed.*
  This could involve funding from developed world governments, sending military assistance to help the rescue and aid effort (helicopters, medical teams), and sending emergency aid in the form of food supplies, tents, medical equipment and water supply systems),
- *International NGOs such as the Red Cross, Red Crescent, MSF, Oxfam and others often provide aid.*
- *The United Nations has capacity to send aid in the form of supplies, funding and technical help.*

Aid also includes longer-term support for recovery and rebuilding, including psychological help for people traumatized by the disaster and its impacts.

[7] From http://www.erra.pk/sectors/housing.asp

1.3.3 Questions to think about	1 How have physical and human factors affected trends in the occurrence of natural hazards? 2 How should a 'disaster' be defined? 3 Suggest reasons why the death toll from natural disasters worldwide is falling. 4 Which natural hazards can be and which ones cannot be predicted? 5 Use examples to explain what is meant by 'hazard response'.

1.3.4 Climate change

Enquiry question: How and why has climate changed in the past and how significant is recent global warming?

Past climate change

The Quaternary Period is the last 2.6 million years of geological time, it is divided into the Pleistocene epoch (2.6 million years ago to 12,000 years ago) and the Holocene epoch (12,000 years ago to the present day).

Quaternary climate has been characterized by:

- *repeated warm-cold cycles lasting around 100,000 years*
- *about 20 such cycles*
- *during cold periods, ice sheets that grew to cover much of the northern hemisphere*
- *sea-levels that varied enormously during these warm-cold cycles.*

Cold periods are referred to as glacial periods, and warm periods as interglacial periods:

- *The current Holocene epoch is a warm interglacial.*
- *The Last Glacial Period (called the Devensian in the UK, Wisconsian in North America and Wurm in Europe) lasted from 115,000 years ago to 12,000 years ago.*
- *A warmer interglacial period (the Eemian or Ipswichian) preceded the LGP 130,000-115,000 years ago.*

Evidence for the variable Quaternary climate on long-term timescales is very good (Figure 4.1):

Tree Rings (dendrochronology)	Ice Cores	Ocean Sediment Cores
Tree rings provide a climate record back to about 14,000 years ago in some locations.	Ice cores provide a record back 130,000 years on Greenland and 800,000 years on Antarctica.	The ocean sediment core record extends back to several million years.
The thickness of annual growth rings in trees varies due to annual weather conditions (warmer = wide rings, cooler = narrow rings). Sequence of rings can be matched up to produce a record of climate change.	Ice builds up on ice sheets as annual snowfall is slowly buried and compressed. Layers contain tiny air bubbles which preserve the chemistry of the atmosphere from the time of ice formation. Crucially, the concentration of trapped Carbon Dioxide (CO_2) can be used as a climate proxy.	Sediment cores from the ocean floor contain tiny shells (tests) of plankton, which contain a ratio of oxygen-18 (^{18}O) to oxygen-16 (^{16}O) isotopes. This ratio can be used as a proxy for past ice volume, and therefore past global sea-level.
• Trees are not found in all locations. • The record does not extend back very far. • It is an indirect record of past climate. • Other factors, not related to climate, could affect tree growth.	• Scientists assume a close link between past climate and level of carbon dioxide. • Atmospheric gases can diffuse through ice, during ice formation, leading to contamination.	• There is some debate over what sediment cores indicate best – past temperature or ice volume. • Ocean sediments are prone to mixing and disturbance. • Evidence for past climate in indirect.

Figure 4.1 Evidence for long-term climate change

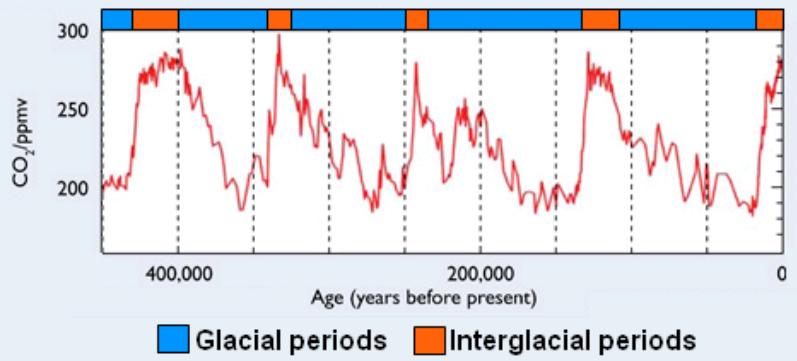

Figure 4.2 Carbon dioxide record from an ice core[8]

The graph above (Figure 4.2) shows the CO_2 record from part of the EPICA Dome C ice core on Antarctica. This indicates carbon dioxide concentrations measured from air bubbles in ice in parts per million volume (ppmv). A pattern of warm-cold-warm roughly every 100,000 years is clearly shown.

Medium-term climate change

Evidence for medium-term climate change during the Holocene suggests smaller climate fluctuations over the last 12,000 years. Evidence comes in the form of:

Pollen Records (palynology)	Historical Sources	Art
Pollen grains, from trees and other plants, are often preserved in peat-bogs, marshes and lake sediments. They can be extracted from sediment cores and change in plant species over time can indicate changing climate.	Information about weather and climate has been recorded in diaries, journals and even the dates of harvests. Dates of the first frost, flowering of plants in spring and when rivers froze were often written down.	Paintings of weather events such as 'Frost Fairs' on London's River Thames are common, and the paintings of Pieter Bruegel 1525-1569 record snowy scenes in modern day Netherlands.
• Changes to plant species in an area could be the result of human activity, e.g. the onset of farming. • Results are only applicable to local areas.	• Records are usually not continuous and evidence a few decades of change. • The proxy records only indirectly indicate climate in most cases.	• It is likely that 'extremes' were recorded, leading to bias. • The artistic record is very patchy and incomplete.

Figure 4.3 Evidence for medium-term climate change

Global temperatures were of the order of 8-10°C colder during glacial periods compared to interglacial periods during the Pleistocene. In the Holocene, the temperature variations were much smaller, as the graph below (Figure 4.4) shows:

- *The Medieval Warm Period (MWP) from 950-1250 AD was about 0.5 ℃ warmer that the Holocene mean.*

[8] From **European Project for Ice Coring in Antarctica (EPICA).**

- *The Little Ice Age (LIA) 1550-1850 was around 0.8 ℃ colder than the Holocene mean.*
- *During the Roman period temperatures were warm but during the 'Dark Ages' they were cooler.*

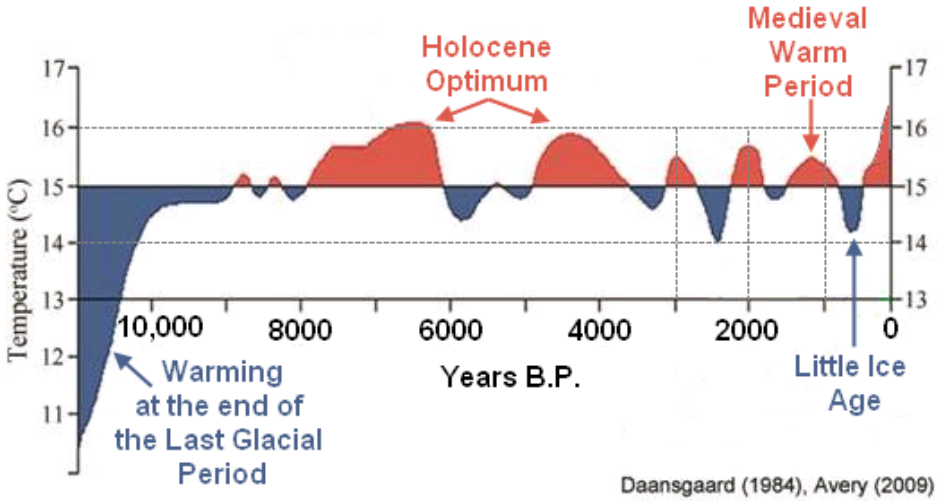

Figure 4.4 Holocene climate change [9]

Milankovitch cycles

There are several causes of natural climate change. Long-term interglacial- glacial cycles are usually attributed to Milankovitch Cycles (Figure 4.5). These are natural changes to Earths' orbit around the sun that occur on three timescales:

Orbital eccentricity	Axial tilt	Precession
100,000-year cycle	**41,000-year cycle**	**26,000-year cycle**
Earth's orbit changes from circular, to elliptical and back again.	Earth's axis tilts from 22° to 24.5° and back again.	Earth's axis 'wobbles' (traces a circular path) because it is not stable.
A more elliptical orbit increases the temperature differences between seasons on Earth, and the length of seasons.	Higher tilt increase differences between winter and summer. Alters the areas of land/ocean receiving the most solar heating.	This alters the timing of seasons, and the difference between the same season in each hemisphere.

Figure 4.5 Milankovitch Cycles

The overall impact of the three Milankovitch Cycles on the amount and timing of solar insolation Earth receives from the sun is relatively small, but small changes can be amplified by feedback mechanisms, which lead to larger changes in the climate system, for instance:

- *Slightly longer, colder northern hemisphere winters increase snow cover on land and sea-ice on the oceans: this snow and ice has a high albedo, reflecting solar insolation back into space; this leads to further cooling, more snow cover and so on – the small cooling is amplified by ice-albedo feedback.*

[9] Adapted from Greenland Ice Core Studies, by W Dansgaard, 1985.

- *A slight warming effect could be amplified if permafrost melting increased, and there was more decay of organic matter in peat bogs; this could release stored carbon as carbon dioxide and methane, leading to a stronger natural greenhouse effect that leads to more warming.*

Solar output and volcanic emissions

Medium-term natural climate changes, such as the LIA and MWP, have different causes. Milankovitch cycles were operating during the LIA and MWP but climate changed for a few 100 years only – much shorter than Milankovitch Cylces, suggesting some other cause.
One possibility is volcanic eruptions. Major volcanic eruptions at 6 or above on the VEI scale have the potential to affect climate:

- *Large volumes of gas are erupted, particularly sulphur dioxide (SO_2), which has a cooling effect as it blocks incoming solar radiation.*
- *Ash and volcanic dust erupted high into the atmosphere and, spread by upper atmosphere winds into the stratosphere, can also block incoming solar radiation.*
- *The net effect is too cool Earth's climate by 0.3-1℃.*
- *The last eruption that cooled the Earth was Mount Pinatubo in 1991.*
- *However, the effects of most eruptions are short-lived: the cooling lasts for a few months to a few years.*
- *It is possible that longer periods of more active or less active global volcanic activity could alter climate.*

Some scientists have suggested that the eruption of Toba in modern day Indonesia 75,000 years ago could have led to a 1000-year cooling period. Toba was a supervolcano erupting at VEI8 level. There is an ongoing debate about the exact impact Toba had on Earth's climate.
Sunspots (Figure 4.6) are often suggested as the cause of the LIA and MWP.

- *Sunspots are dark spots on the surface of the sun caused by magnetic disturbances.*
- *They appear, often in pairs, then decay away.*
- *The sun has an 11-year cycle of solar activity with the number of sunspots going from minimum to maximum and back to minimum over 11 years (see graph below).*
- *There are longer cycles of increased overall sunspot activity – and even periods of decades with almost no sunspots at all.*
- *During periods of intense sunspot activity, more solar energy is emitted from the sun and Earth receives more energy so is warmer.*

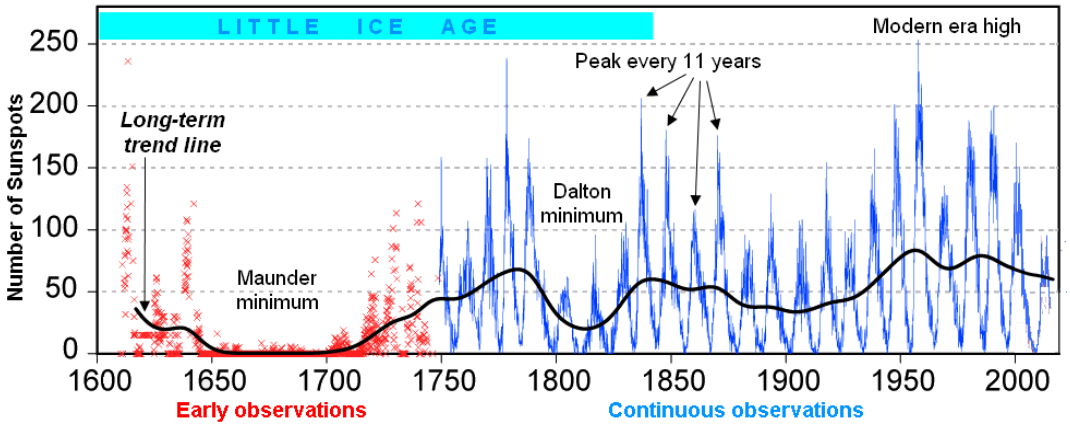

Figure 4.6 The sunspot record since 1600[10]

Longer-term context

The overwhelming majority of scientists agree that recent global warming is real and is caused by human activity. However, it is important to consider how warming over the last 100 or so years is different to climate change in the past:

- *The cause is human pollution (greenhouse gases), not natural cycles or gases emitted by natural processes - such as volcanoes.*
- *Since the second half of the 19th century, carbon dioxide levels in the atmosphere have risen by about 40% - from 280 to 410 ppm of CO_2. This is much faster than any changes measured in ice cores.*
- *Temperatures have increased by about 1 ℃ since 1900, which is at a speed and scale faster than evidence for past climate change suggests. Most of the warming has happened since 1960.*
- *19 of the 20 hottest years between 1880 and 2018 have happened since 2001, suggesting the pace of warming has increased recently.*

However, there are questions about the accuracy and reliability of climate data and its interpretation:

Instrumental record	Proxy data
Since 1850, there has been a reasonably accurate 'instrumental record' of global temperatures and other data collected using scientific measuring equipment of known accuracy. However, 150 years worth of data is not very long.	Prior to 1850, almost all data is 'proxy data': it does not directly measure climate but rather requires careful interpretation to indicate climate. This includes well-known, often quoted data such as that from ice cores.
Geographical coverage	**Length of record**
Climate data collection stations are much more numerous in the northern hemisphere than the southern and large parts of the interiors of Africa and South America have limited coverage.	Climate data has been collected in North America, Europe, Japan and India for 100+ years. Many climate data collection sites in Africa, China, Arabia and South America only have a record going back between 30 and 70 years.

[10] Adapted from https://commons.wikimedia.org/wiki/File:Sunspot_Numbers.png

Figure 4.7 Data accuracy and reliability

1.3.4 Questions to think about	1 What evidence is used to reconstruct past climate from the Quaternary period? 2 Evaluate the reliability of evidence used to reconstruct climate in the past, both long-term and medium term. 3 Explain how Milankovitch Cycles are thought to cause climate change. 4 Suggest why data on climate, even from the last 200 years, may not always be reliable. 5 Explain what is meant by a climate 'feedback mechanism'.

1.3.5 The causes and impacts of global warming

Enquiry question: How significant are the current and future impacts of global warming in contrasting locations?

Atmospheric composition

Levels of CO_2 have been measured continually on Hawaii since 1958-59 and the graph showing rising CO_2 concentrations is called the Keeling Curve (Figure 5.1)

Importantly, this graph is not a straight line. The rate of increase in CO_2 concentrations is accelerating. In the 1960s, levels were rising at 0.85 ppm per year but by the 2010s they were rising at 2.42 ppm per year (numbers above graph). Carbon Dioxide levels in 2018 are:

- *28% higher than in 1959*
- *45% higher than in 1850.*

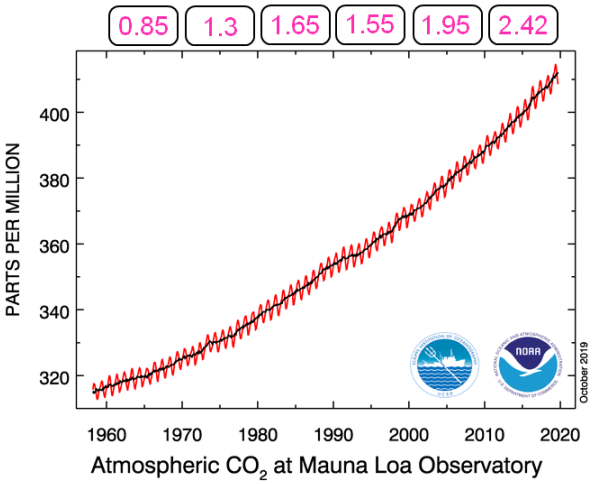

Figure 5.1 The Keeling Curve[11]

[11] Adapted from https://www.noaa.gov/

Levels of other greenhouse gases have also increased:

- *Methane (CH_4) levels were 1630 parts per billion (ppb) in 1980 rising to 1870 ppb by 2018.*
- *Nitrous Oxide levels increased from 315 ppb in 2000 to 330 ppb by 2018.*

All of these gases are greenhouse gases and so contribute to the enhanced greenhouse effect (EGE). Molecules of different greenhouse gases have different Global Warming Potential (GWP).
This is a measure of how much outgoing longwave radiation each molecule reflects back to earth plus how long the gas remains in the atmosphere. Figure 5.2 illustrates the 20 year GWP for different greenhouse gases.

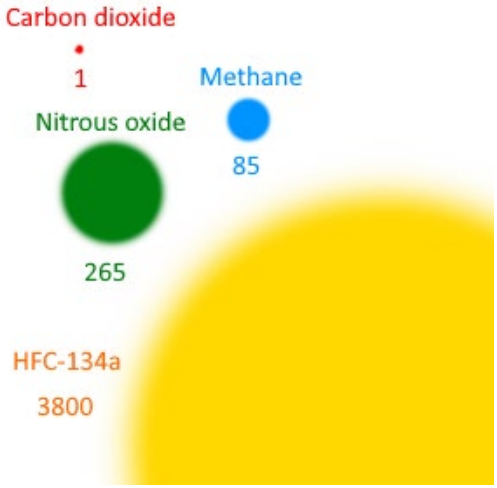

Figure 5.2

Sources of emissions

The sources of greenhouse gas pollution are many and varied:

Carbon dioxide	• *burning fossils fuels (coal, oil, gas) in power stations, as fuel for transport (petrol, diesel, aviation fuel, fuel oil) and in industry* • *deforestation*
Methane	• *farming, either from cattle or paddy-field rice farming* • *landfill sites* • *leaks in natural gas pipeline networks*
Nitrous oxide	• *coal-fired power stations* • *cars, trucks and aircraft* • *use of fertilisers on fields*
HFCs	• *gases used as refrigerants (fridges, freezers, air-con) and propellants (aerosol cans)*

Figure 5.3 Sources of greenhouse gas emissions from human activity

The pie chart (Figure 5.4) shows greenhouse gas emissions by economic sector (globally) and shows how a wide variety of human activities contribute to emissions.

In developing countries, agriculture usually forms a larger share of total emissions, whereas in emerging countries industry is a greater contributor. Developed countries have a large share of transport and electricity generation sectors.

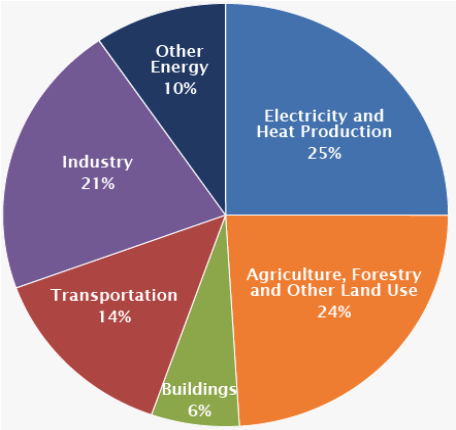

Figure 5.4[12]

Although global GHG emissions are rising, this is not the case in all countries. The graph below shows five countries' GHG emissions since 1990:

- *India's emissions have increased dramatically.*
- *Turkey's emissions have roughly doubled.*
- *Australia's emissions are basically stable.*
- *Emissions in the UK and Germany have fallen significantly.*

In many emerging countries that are urbanizing and industrializing, emissions are rising whereas in most developed countries they are stable or falling (Figure 5.5).

[12] From the USA Environmental Protection Agency https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data

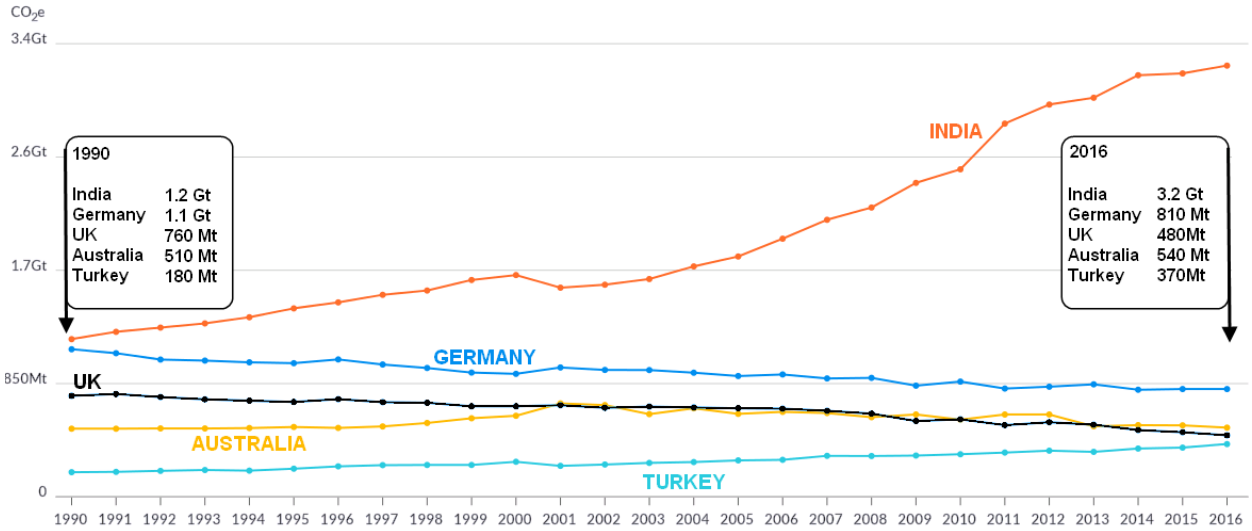

Figure 5.5 Carbon dioxide equivalent (all greenhouse gases) emissions 1990-2016[13]

Explore more at:
https://www.climatewatchdata.org/ghg-emissions

27.5%	**China**
14.8%	**USA**
9.3%	**EU-28**
6.4%	**India**
4.9%	**Russia**
2.9%	**Japan**
2.3%	**Brazil**
1.6%	**Indonesia**
1.6%	**Canada**
1.6%	**Mexico**
= 73% of global emissions	

As can be seen in the 2017 data on the left, a very small number of countries account for almost three quarters of global greenhouse gas emissions.

It would be tempting to 'blame' China, the USA and EU countries for global warming. However, data on absolute emissions totals only tell part of the story.

Relative emissions per person could be viewed as a more useful way of considering greenhouse emissions. These are total emissions for a country divided by number of people in the country.

[13] Adapted from Climate Watch: https://www.climatewatchdata.org/ghg-emissions

The table below shows examples of per capita CO_2 emissions:

Country	CO_2 emissions per person 2017-18 (tonnes)	Total annual CO_2 emissions 2017-18 (millions of tonnes)
UAE	22.4	202
Australia	16.8	402
USA	16.1	5,107
UK	5.6	379
China	8.0	10,877
India	1.9	2,454
Ghana	0.7	19
Ethiopia	0.2	15

Figure 5.6 Relative and absolute emissions [14]

Figure 5.6 is interesting because it shows that:

- *developing countries (Ghana, Ethiopia) make almost no contribution to global warming as both per person and total emissions are tiny. Ethiopia is not a small country, with a population of 112 million in 2019 it is the world's 12th most populous country.*
- *while India's total emissions are large, its per person emissions are small – so the average Indian is not contributing much to global warming.*
- *China's total emissions are the largest of all, and its per person emissions are high – higher than the average person in the UK, a much richer country by per capita income.*
- *people in the UAE and Australia have very high emissions per person, but total emissions are quite small because overall population is quite small.*

Future climate projections

It is the task of the IPCC (Intergovernmental Panel on Climate Change) to report on the science behind global warming and make projections about future temperatures and sea level. The IPCC is part of the United Nations. It produces Assessment Reports every 5-6 years. The last of these was AR5 in 2014.

The IPCC produced "Special Report 1.5°C", 2018 (*SR15*), which stated:

"Human activities are estimated to have caused approximately 1.0°C of global warming above pre-industrial levels, with a likely range of 0.8°C to 1.2°C. Global warming is likely to reach 1.5°C between 2030 and 2052 if it continues to increase at the current rate."

Figure 5.7 shows the different projections for future temperature that IPCC AR5 report outlined. For each of the 4 coloured projections, there is a centre line and an error bar. For instance: for the worst-case scenario (**red**), the most likely temperature increase by 2100 is +4.2°C, but temperatures could be in the range of +3.4 to + 4.9°C.

[14] From https://www.climatewatchdata.org/

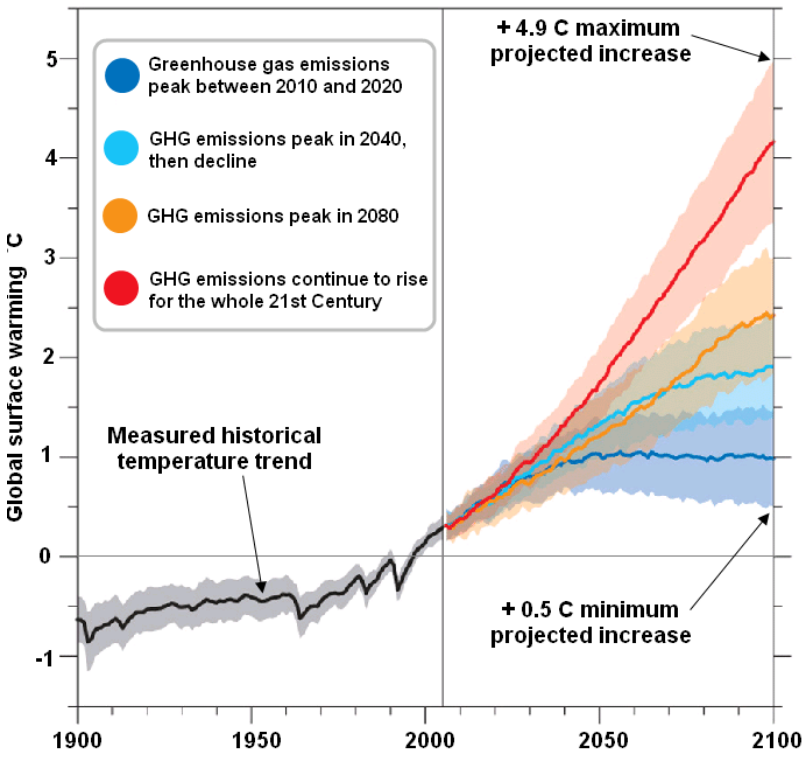

Figure 5.7 IPCC projections from AR5, 2014[15]

The very wide range of future temperature projections is a result of uncertainty in terms of:

- *what the total population of the world will be in 2100*
- *what the average income of people will be, which strongly influences resource consumption and therefore emissions*
- *levels of economic growth in the future, which could influence resource consumption*
- *the extent to which people will shift away from fossil fuels towards renewable resources and try to reduce pollution, waste and emissions in other ways – or simply continue to use resources as they do today ('business as usual').*

Future mitigation efforts are a major unknown quantity. IPCC AR5 projected sea level would rise 29-82 cm by 2100. Since AR5 was published in 2014, some scientists have suggested sea level rise of 100cm by 2100 is more likely than AR5 suggested.

As well as there being socio-economic uncertainties which make projecting future temperatures and sea-level very challenging, there are also physical systems uncertainties. It is possible that the global climate could reach a tipping point.

A tipping point is a threshold that, once passed, causes major change in a system and return to the previous state is not possible (Figure 5.8).

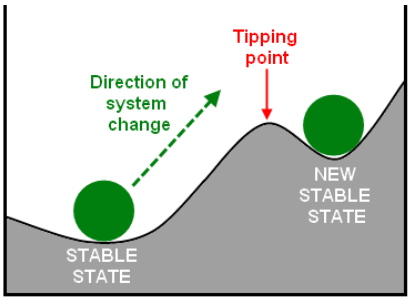

Figure 5.8

[15] Adapted from the IPCC Fifth Assessment Report.

Climate feedback

There are several possible feedback mechanisms that could cause change to the climate system that could not be reversed even if humans stopped all greenhouse emissions:

Feedback mechanisms leading to a tipping point		
Ice albedo feedback	**Ocean carbon sinks**	**Forest 'die back'**
Warming leads to reduced Arctic ice cover, replacing high albedo reflective snow/ice with low albedo rock/soil and ocean. Darker surfaces absorb more heat, leading to more warming and more ice/snow cover loss. In addition, melting permafrost in the Arctic releases CO_2 and methane, further enhancing the greenhouse effect (so-called 'runaway warming').	Oceans have so far absorbed about 90% of the excess heat generated by global warming, and up to 40% of all CO_2 pollution. As oceans warm, their ability to absorb more CO_2 declines – so more will end up in the atmosphere. Oceans are also becoming more acidic due to CO_2 absorption, threatening species like coral which sequester carbon.	Higher temperatures, lower rainfall and increased number of droughts and forest fires leads to widespread death of tropical forests. This turns forests from carbon sinks to carbon sources, increasing CO_2 concentrations and leading to a more powerful greenhouse effect.

Figure 5.9 Possible climate tipping points

Sea level

Sea level rise is a major threat to some locations. Global sea levels are rising at 3.2mm per year. Sea-levels are rising for two reasons:

- ***Thermal expansion:*** *as the oceans warm due to absorbing the excess heat caused by the enhanced greenhouse effect, the water expands in volume.*
- ***Ice melt on land****: ice sheets on land (especially Greenland) and glaciers in mountain areas are melting, adding water to the oceans.*

Melting of floating sea-ice does not contribute to rising sea levels. There is considerable uncertainty about how far global sea level will rise by 2100. The consensus is somewhere between 40 and 100cm, but some researchers have suggested up to 200cm. Much depends on the rate of melting of Greenland and Antarctica, as well as the degree of warming which affects the rate of thermal expansion. There are many locations which are vulnerable to rising sea levels, including:

- *low lying land, already close to sea level which could flood permanently – such as parts of the East of England, the Florida coastline in the USA, Venice in Italy and Alexandria in Egypt*
- *many small island states such as the Maldives, Vanuatu and Tuvalu*
- *some countries – notably Bangladesh and the Netherlands – which have much of their land at or even below sea level*
- *some cities such as London, Jakarta and Osaka*
- *some locations which are actually sinking (subsiding) at the same time as sea level is rising, e.g. the Mississippi Delta in the USA, Bangkok in Thailand and South East England.*

Of particular concern are large, low-lying deltas at the mouths of major rivers. These areas of fertile land are often heavily cultivated and critical to food security. As they are flooded by saltwater, food production will be reduced. The Nile Delta in Egypt is at risk.

In Asia, there are a number of mega-deltas that are at risk. These have very high population densities and, in some cases, include major cities:

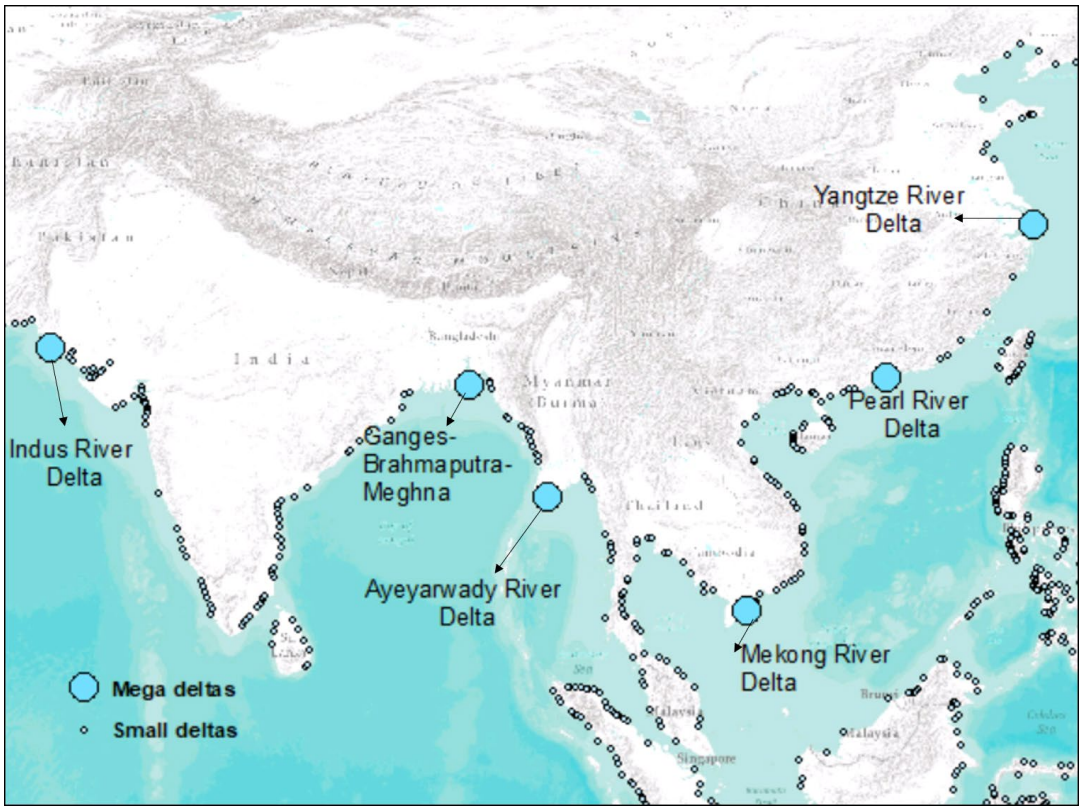

Figure 5.10 Asian megadeltas[16]

Shifting climate belts

A possible consequence of global warming could be a shift in climate belts. Many parts of the world depend on rain-fed farming for crops.

This includes much of Africa and large parts of South Asia. Seasonal rains brought by annual monsoons and wet seasons provide the water needed to grow crops.

Many subsistence farmers and commercial farmers depend on these rains for their food and income. Changes to seasonal rains could be caused by global warming as Figure 5.11 shows:

[16] From: https://www.sei.org/perspectives/deltas-face-the-brunt-of-unsustainable-development-and-climate-impacts-we-must-move-beyond-concrete-to-shore-them-up/

- *Movement of the ITCZ brings seasonal rains to areas of Africa.*
- *North and south of the equatorial belt (tropical rainforest) are areas of savanna grassland and semi-arid lands that depend on seasonal rains.*
- *These areas are used for crops and cattle.*
- *The movement of the heat equator and ITCZ rainfall north and south brings seasonal rains to these areas.*
- *Any shift in climate belts caused by less northward/southward ITCZ movement and lower/more unreliable rains could make farming less viable or force farmers to change the way they farm.*
- *There is evidence that the climate of the Sahel has become much more variable since the year 2000 with high rainfall years being followed by several years of drought conditions.*

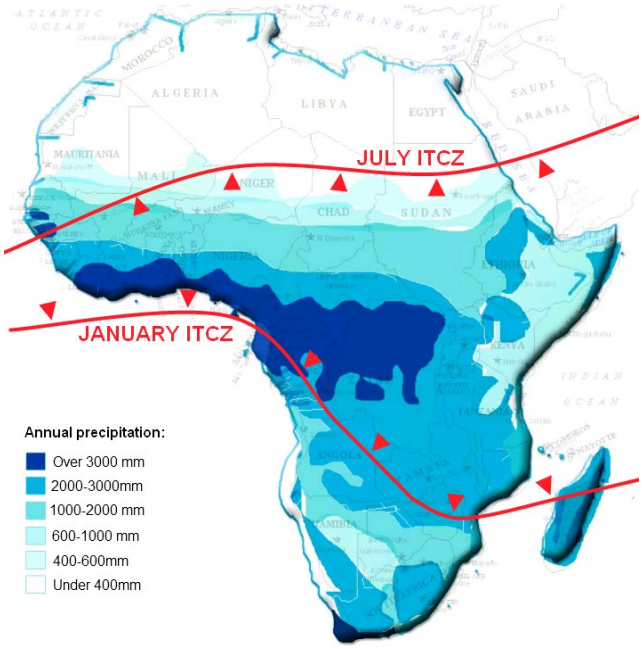

Figure 5.11 Map of annual precipitation in Africa and the position of the Intertropical Convergence Zone (ITCZ) in January and June.[17]

1.3.5 Questions to think about	1 What are the major greenhouse gases? 2 Explain the difference between absolute and per capita greenhouse gas emissions. 3 Describe the range of current projections for global sea level and temperature to the year 2100. 4 Explain why there is so much uncertainty about future sea level and temperature projections. 5 Which places are most at risk from sea level rise?

[17] From: http://mapofafricanew.blogspot.com/2017/06/precipitation-map-of-africa.html

1.3.6 Managing global climate risk

Enquiry question: How significant are the current and future impacts of global warming in contrasting locations?

Mitigation

It is widely accepted that action is needed to mitigate carbon emissions by reducing total emissions. Some countries have reduced their emissions and the UK is a good example. Carbon dioxide emissions in 2018 were 38% lower than in 1990, despite the UK growing by close to 10 million people over the same period:

- *The UK has reduced its use of coal in power stations from 67% in 1990 to less than 5% in 2018.*
- *The switch to natural gas and renewable electricity from wind turbines and biofuels has reduced emissions.*
- *Since 2005, the amount of electricity used in homes and by industry has actually fallen, largely because modern home appliances and industrial processes have become more efficient, e.g. LED lighting replacing incandescent lightbulbs.*
- *In 1990, the average UK car had a fuel efficiency of 33 miles per gallon; this had risen to 41 miles per gallon by 2016.*

Many developed countries have shifted energy production away from fossil fuels and towards solar power, wind power, biofuels and other renewable sources. This is a key way to mitigate emissions.

In the EU in 2017, 46 % of all household waste was recycled, up from 30% in 2004. This means that fewer new resources are needed and this reduces the carbon emissions associated with making new glass, paper, cardboard and aluminum.

Many countries have introduced some form of carbon tax, which makes it more expensive to use fossil fuels and should reduce their use:

UK **Vehicle Excise Duty (VED) or 'car tax'**	**Singapore** **Carbon Pricing Act**
• UK car tax ranges from £0 to £2000 when a new car is bought, depending on the CO_2 emissions per kilometre driven. • This is basically a tax on pollution and carbon emissions. It incentivizes buying low emission cars, including electric cars.	• The Carbon Pricing Act was passed on 20th March 2018. • It will tax large emitters at S$5 per tonne of greenhouse gas emissions for now, with a review in 2023. • Eventually, it will increase between S$10 and S$15 per tonne of emissions by 2030.

Figure 6.1

Because not all countries have acted to reduce emissions, there have been global efforts to reduce emissions. However, this is very challenging:

- *Some countries rely heavily on fossil fuels in terms of their economy and exports (Russia, Australia, UAE) and have been reluctant to agree to reductions in fossil fuel use.*
- *Some countries argue that emission reductions will hurt industry and cost jobs (USA) so they have not agreed to emission reductions.*
- *Some emerging countries believe they should be allowed to develop economically, as developed countries have done, before they are required to cut carbon emissions.*
- *There are costs, for instance in shutting down coal-fired power stations and building wind turbines and other energy generation facilities to replace them.*

Montreal Protocol	*1987*	• *Developed countries only* • *Agreement to phase out, then ban, CFC gases* • *CFCs were damaging the ozone layer and are a powerful greenhouse gas*	***Highly successful***
Kyoto Protocol	*1997 to 2012*	• *Developed countries only* • *Set emission reduction targets* • *USA, Russia, Canada and Australia did not fully take part* • *Countries that signed up did reduce emissions but as emerging countries were not included, global emissions increased*	***Limited success***
Paris Agreement	*2015*	• *All countries* • *Widespread agreement that warming should be kept below 1.5℃* • *Countries made emission reduction pledges, but not on the scale needed to meet the 1.5℃ target* • *The USA may withdraw in 2020*	***Shows some hopeful signs***

Figure 6.2 Global agreements on emissions

Since the 2015 Paris Agreement, progress has been patchy. Climate Action Tracker tracks the progress of 32 countries. Most are not on target at all (Figure 6.3). This includes many 'big' emitters that need to take action if overall emissions are to stabilise or reduce:

Explore more:
https://climateactiontracker.org/publications/warming-projections-global-update-dec-2018/

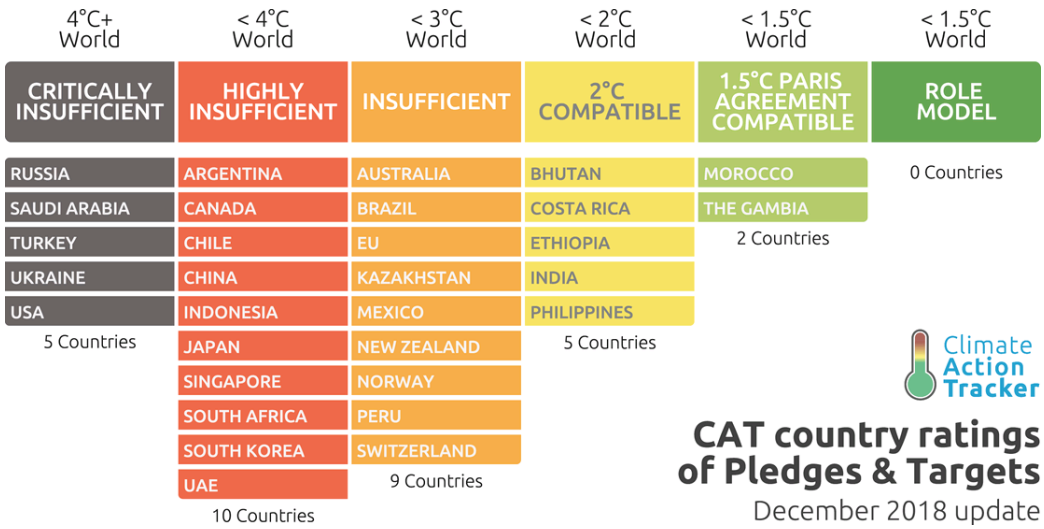

Figure 6.3 Climate Action Tracker for selected countries[18]

Adaptation

Adaptation involves accepting that global warming will happen and will have negative impacts, but attempting to manage these impacts by coping with or reducing them.

Under an adaptation scenario, sea levels would rise by 50cm, 100cm or even more by 2100 and people would have adapt to cope. Rising sea levels mean that:

- *some low-lying coastal areas will flood permanently*
- *coastal areas that occasionally flood during very high tides will flood more often*
- *some coastal areas will be at greater risk from tropical cyclone storm surges*
- *places that are below sea level (26% of the Netherlands) will become ever harder to protect.*

Engineering can prevent this by building sea defences:

- *Between 1954 and 1997, the Netherlands spent about 10 billion Euro (at 2012 prices) on the Delta Works project to prevent coastal flooding in the country.*
- *This included sea walls, flood barriers and storm surge barriers.*
- *The Netherlands expects to spend 1 billion Euro every year between now and 2100 strengthening its coastal defences.*

With a per capita income of US$53,000 in 2018, the Netherlands is the 12th wealthiest country in the world on a per person basis. Bangladesh is 145th in terms of wealth per person at US$1750. That country cannot afford to protect its coastline from sea level rise. Estimates have suggested that it would cost US$50-100 billion to defend Bangladesh's entire coastline from sea level rise, which is not affordable.

[18] From: https://climateactiontracker.org/publications/warming-projections-global-update-dec-2018/

Farmers may have to adapt to changing climate by:

IRRIGATION *Artificially watering crops to offset lower/more variable rain. This requires investment in equipment as well as a water supply, e.g. groundwater.*	**CROP CHANGES** *Switching from traditional crops to ones that grow in a changed climate: it requires new farming skills, new equipment and the development of new markets.*
DROUGHT-RESISTANT CROPS *Genetic Modification (GM) could produce new seed varieties that are drought-resistant, or resist being flooded by sea water – but these are expensive to develop and buy.*	**FARMING YEAR** *Farmers may have to alter when they plant crops and when they harvest. This has economic as well as social and cultural implications.*

Figure 6.4 Farming adaptations

Farmers in developed and emerging countries can probably afford to adapt. They are likely to be supported by their governments to make the changes. In developing countries, subsistence farmers and small commercial producers of coffee, tea and cocoa may not be able to afford these adaptations.

Attitudes and opportunities

Attitudes to global warming vary between countries. The results of a 2018 Pew Global Research survey are shown in Figure 6.5:

- *Climate change is perceived as a major threat in some countries such as Greece, France and Spain.*
- *However, in the US, Poland and Russia, far fewer people perceive it as a major threat.*
- *These results do not neatly divide into 'rich and poor' – for instance, 71% of people in Kenya state major threat but only 41% in Nigeria.*
  Reasons for the differences are complex.
- *Some climates might be vulnerable, e.g. a rising risk of tropical cyclones in the Philippines, but perhaps some cold places (Russia) view the threat as less.*
- *Particular industries might be threatened, e.g. Kenyan coffee farmers, whereas in other places fossil fuel exports (Australia) mean economic self-interest is seen as more important than climate change.*
- *Within countries, subsistence farmers might have very different attitudes to people in cities, people living at the coast or big businesses.*

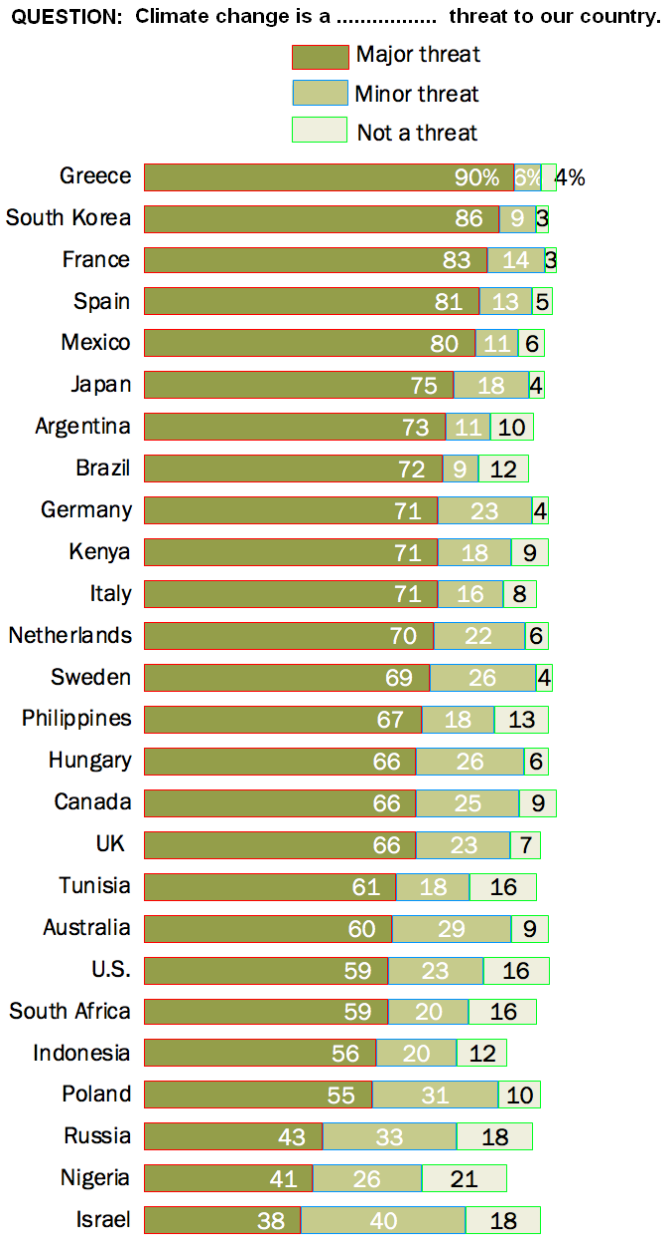

Figure 6.5 Attitudes to climate change

Explore more at:
https://www.pewresearch.org/fact-tank/2019/04/18/a-look-at-how-people-around-the-world-view-climate-change/
https://climatecommunication.yale.edu/wp-content/uploads/2019/06/Climate_Change_American_Mind_April_2019c.pdf

There are some locations were global warming might be viewed as an opportunity rather than a threat.

• *In the high-latitude Arctic of Canada and Greenland, shrinking ice sheets could open up areas once covered by ice to mining, oil and gas drilling and other exploitation.* • *As Arctic sea-ice shrinks, areas of ocean open up to fishing.*
• *Greenland, Iceland, Alaska, Svalbard, Northern Norway and Finland could experience an increase in tourism in a warmer world.* • *Their very shorts summers could become longer and more visitor-friendly.*
• *Farming could expand northwards in some parts of Canada, Russia and Scandinavia.* • *There could be opportunities for higher value crops in some places – such as grapes for winemaking in the southern UK.*

Figure 6.6 Opportunities from global warming?

The overwhelming majority of climate scientists (most surveys suggest 97%+) believe humans are causing Earth's climate to change. That of course means that there is still a very small minority who believe otherwise.

About 40%[19] of Americans ***do not*** believe that humans are causing global warming. Around half (50%) of Americans view global warming as a future threat – in contrast to most Europeans who see it as a present-day threat.

Importantly, some world leaders are not overly concerned about environmental issues or global warming. In 2019, these included President Donald Trump of the USA, Prime Minister Scott Morrison in Australia and President Jair Bolsonaro in Brazil. These leaders may not be all-out 'climate change deniers' but their policies tend to prioritize economic development over climate change mitigation.

1.3.6 Questions to think about	1 Explain the difference between mitigation and adaptation as a response to global warming. 2 Explain what is meant by the term 'carbon tax'. 3 Why is getting a global agreement on emissions reduction so difficult? 4 Explain why adaptation may be challenging for some people in developing countries. 5 To what extent could global warming bring opportunities for some places?

[19] Data quoted is from the Pew Research Centre https://www.pewresearch.org/