Geomorphic hazards

Landslides and avalanches are the seventh biggest killer worldwide, ranking below virtually all other natural hazards (including windstorms/cyclones, wave surges, floods, extreme temperatures and earthquakes). Only volcanoes and forest fires have lower global death rates. Nevertheless, they are a widespread hazard, especially in mountainous areas of the world, which are subject to heavy rainfall.

Landslides

A 35-year study of Japan (1967–2002) showed that, during that time, landslides occurred every year, killing almost 3300 people. Landslides threaten some of the world’s most precious cultural sites, including Egypt’s Valley of the Kings and the Inca fortress of Machu Picchu in Peru.

Classification of the landslide hazard is complex and a number of different systems are used:

- **Type of movement** — the main movements are falls, slides and flows, but topples, lateral spreading and complex movements can be added to these.

- **Material of movement** — rock, earth and debris are the terms used to distinguish the materials involved in landslides. The distinction between earth and debris is made by comparing the coarse grain size fractions.

- **Activity** — the concept of activity is linked to state, distribution and style. ‘State’ describes information regarding the time in which the movement took place, ‘distribution’ describes where the landslide is moving, and ‘style’ indicates how it is moving.

- **Velocity of movement** — a velocity range is linked to different types of landslide.

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*Figure 62*  
The landslide hazard (usually a small-scale feature)
Landslides are caused by large volume combinations of rock, soil, ice, water and snow moving under the influence of gravity and, usually, water. Landslides are commonly composed of rock and soil, whereas the term avalanche refers to falls made up mainly of snow and ice (see p. 56).

Table 10 lists some of the worst landslides ranked by deaths.

Landslide distribution is controlled by a number of localised physical factors, including gradient and topography, land use, geology, permeability and climate. There are also some human-related factors that can promote the onset of landslides (Figure 64).
Bangladesh’s 2007 monsoon started with unusually heavy rain, intensified by a storm from the Bay of Bengal on 9–10 June. The heavy rain caused mudslides, which engulfed slums in the foothill areas of the large city of Chittagong on the coast in southeastern Bangladesh on 11 June 2007. The death toll was reported to be at least 128, including 59 children, and more than 150 people were injured.

Experts had warned of the increasing likelihood of landslides due to the Bangladesh government’s failure to curb illegal hill cutting in Chittagong. Hill cutting creates flat sites for the construction of new houses. Trees have also been cleared to build houses on the hill tops. This can block the natural rills or gullies that drain the landscape. Rainwater is then forced to enter the ground through cracks, which weakens the soil structure and promotes landslides.

**Avalanches**

Avalanches are a common phenomenon throughout mountainous areas of the world. Their distribution is becoming more widespread as human activity in these areas — mainly recreation and leisure tourism — increases. Specialist infrastructure to support such tourism is also increasing.

Avalanche distribution is relatively predictable because avalanches tend to recur in the same places.

There are three types of avalanche hazard:

- Powder snow avalanches can occur with little or no warning, at any time in the season, with speeds up to 300 km per hour and a force of up to 50 tonnes per square metre.
- Wet snow avalanches usually occur late in the season and are slower moving (8–25 km per hour). They typically carry a considerable weight of snow — up to 1 million tonnes.
- Slab avalanches are the most commonly occurring type and are often started by human error. With speeds of up to 150 km per hour, they cause death among skiers and snow-boarders.

The key causes of avalanches are:

- the weather — snowfall is an essential ingredient
- slope — more than 30° and less than 45° for starting an avalanche

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**Table 11**

The main causes of landslides in the UK

<table>
<thead>
<tr>
<th>Process/causal feature</th>
<th>Recorded number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weathering — loose material (regolith)</td>
<td>647</td>
</tr>
<tr>
<td>Natural erosion, e.g. by river or sea at base</td>
<td>1297</td>
</tr>
<tr>
<td>Artificial erosion, e.g. a railway cutting</td>
<td>276</td>
</tr>
<tr>
<td>Ground subsidence and removal of support</td>
<td>103</td>
</tr>
<tr>
<td>Deposition, e.g. of colliery waste on hillside</td>
<td>126</td>
</tr>
<tr>
<td>Seismic shocks and vibrations</td>
<td>73</td>
</tr>
<tr>
<td>Human-induced water regime change leading to surplus water lubricating soil</td>
<td>1203</td>
</tr>
</tbody>
</table>
changes in the snow pack. Air temperature changes can bring about partial melting of the snow pack or changes in snow crystal shapes and sizes. This influences the strength of the layers. There is often a delicate balance between the tensional forces keeping the snow anchored to the slope (adhesion and weight) and the forces trying to promote movement. When a combination of factors act together, rapid mass movements can occur.

For both landslides and avalanches, the impacts are significantly increased in areas with high population density in vulnerable locations. The controls over impacts of landslides and avalanches are shown in Table 12.

<table>
<thead>
<tr>
<th>Landslides</th>
<th>Avalanches</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land use is a dominant factor, especially where previously forested areas have been lost</td>
<td>Downward velocity depends on slope angle, density of the snow mass, the shearing resistance at the base of the side and the total length of the downward path</td>
</tr>
<tr>
<td>Water plays a major role in mudflow and debris flow formation and transport; heavy soils can lubricate basal planes, decreasing shear resistance</td>
<td>The number of fatalities will be temporally dependent, especially in tourist areas such as ski resorts</td>
</tr>
</tbody>
</table>
Managing the landslide and avalanche hazard

**Modify the event**

Measures taken to *prevent* landslides include:
- building restraining structures such as gabions and stone walls
- excavation and filling of slopes to level them
- improving groundwater drainage and diverting surface water away from gully areas
- erosion control such as rock armour, revetments and use of ‘gunite’ (a sprayed mixture of sand, cement and water)

Methods for the control of avalanches include:
- artificially triggering avalanches using explosive charges or shelling before the snow accumulates to dangerous levels (especially prior to the start of the tourist season)
- planting trees along known avalanche paths (deforestation has increased the incidence of avalanches in some places, e.g. Austria, in the last 200 years)
- snow fences to accumulate snow in areas not prone to landslide hazards

**Modify vulnerability**

Landslide vulnerability can be reduced by:
- diversion of roads and infrastructure from known active areas
- planning control to prevent development in landslide-prone areas
- evacuation warnings when a landslide is imminent (e.g. when heavy rain is forecast)
- banning logging on hillsides

Avalanche vulnerability reduction involves:
- avalanche zoning (e.g. in France, there is no construction in ‘red’ zones (high hazard), while ‘blue’ zones (moderate hazard) mean special building-construction codes, such as reinforced concrete and no windows on up-slope sides)
- use of warnings to restrict access to vulnerable slopes (both Europe and the USA have systems in place)
- educating skiers in risk assessment and likely occurrence of events

**Modify the loss**

Landslide insurance is possible in some parts of the world, although it is difficult to obtain in high-risk locations. Personal insurance is possible in the event of an avalanche incident.

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**Figure 67**

Landslide hazard and risk evaluation

*World Bank, 2006*
Computer models are becoming increasingly sophisticated, so that larger-scale risk maps can be produced. Figure 68 shows an example of a landslide risk map developed for Jamaica. Clearly, in areas of high risk, insurance is difficult to obtain, or is expensive for existing properties and businesses. Further development is therefore strictly controlled.

Summary

- Climate and weather conditions are crucial in determining the occurrence of both landslides and avalanches.
- Risk assessment, education and planning are decisive in terms of minimising impact. Post-disaster activity is a last resort.
- Current climate models for Europe and North America show increased winter temperatures leading to snowline rise. The same models predict increased heavy winter snowfall events at high altitudes in the collecting zones. Therefore, the risk of avalanche is increasing.
- Landslides may become more of a danger with increasing use of steep slopes for people to live on, combined with predicted higher-intensity rainfall patterns. Events such as debris flow, which occur infrequently, present particular problems since new migrants to an area often settle in hazardous areas, for example in shanty towns, and in favelas in Latin American cities, and are ignorant of the potential risk involved.

SOLUTIONS TO THE LANDSLIDE HAZARD

Technological solution to the landslide hazard in Hong Kong

Hong Kong is prone to landslides. In the 1960s and 1970s, management of the hazard was often reactive, that is, problems were sorted out after an event had occurred. But the late 1970s and 1980s saw a change from this approach to one that was more proactive — concentrating on landslide warning systems and prevention measures.

Systems were designed to give sufficient prior warning of an event so that the public and emergency services can be alerts. Warnings are based on groundwater levels
(using an automatic piezometer) and measured rainfall. If the rainfall exceeds 175 mm in 24 hours, a landslide warning may be issued.

Prevention measures include cutting and filling slopes, and building retaining walls. This follows a detailed survey of areas at risk and prioritisation of work schedules. Slopes that are identified as at risk have a full stability analysis carried out, including shear testing and installation of piezometers.

**Low-tech mitigation solutions to debris flows in Peru**

The foothills on the western side of the Andes of Peru and northern Chile lie along the coastal desert of the Atacama. Large quantities of weathered material can build up at the base of the slopes. High-intensity precipitation events can mobilise these sediments into debris flows, which occupy dry stream beds. Inhabitants of the area may even think the dry stream beds are inactive because the debris flow events have a relatively long return period in relation to the human life span. Mitigation approaches follow two main low-tech solutions.

**Terracing**

To mitigate the debris flow hazard in this area, terraces have been built within the stream bed to change its gradient. These slow the debris flow through a series of small reductions in slope angle. Community organisation has been important in delivering this low-cost solution. Local inhabitants have constructed 24 such breaks with an investment of less than US$30000. A similar approach has been adopted in California, where channels are built to divert flows as they approach settlements.

**Land-use zoning**

Land-use zoning to prevent the development of settlements in areas prone to debris events would reduce losses considerably. A lack of knowledge, and pressure on land, mean that such regulation is seldom introduced, despite the development of hazard maps at a local scale showing where the most stable slopes are and where there are high risks from debris flows and unstable hillsides.

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**Question**

(a) Why have people become increasingly vulnerable to hazards that result from mass movements on slopes?

(b) Research an example of a widely known landslide event, such as Aberfan in south Wales in 1966, and then assess the statement that ‘landslides are usually the result of both physical processes and human actions’.

**Guidance**

(a) People occupy and develop slopes, particularly in the crowded ‘primate’ cities associated with LEDCs. Landslides become more common, which increases vulnerability.

(b) Expect to write a ‘thumbnail portrait’ of your chosen event (location, date, number of deaths, damage caused). Then consider physical processes, which are likely to include rainfall problems, drainage issues, steepness of slope, structure and lithology, and the effect of human actions (basal steepening, overloading of upper part of slope, deforestation, and building in hazardous areas). Draw a summary diagram. Conclude by assessing whether you agree or disagree with the statement in the question.
Biohazards can be classified as follows:

- Communicable diseases of humans (viral, bacterial, protozoal or parasitic), which can lead to local and regional epidemics, and have the capacity to turn into worldwide pandemics — for example, the Black Death in the fourteenth century, or the worldwide influenza outbreaks in 1917 and 1960.
- Epidemic crop diseases such as blights — for example, potato blight in Ireland, 1845–47, resulted in a famine that led to the deaths of 1.5 million people and caused a further 1.5 million to emigrate.
- Epidemic diseases of domesticated animals (bacterial or viral) — for example, Newcastle disease of poultry and foot-and-mouth disease of cattle and sheep.
- Epidemic diseases of wildlife and plant resources — for example, fungal diseases affecting cocoa pods.
- Plant and animal infestations — invasions of exotic pest species, such as locusts, which invaded the sub-Saharan republics in 2004–05, or the rabbit and cane toad plagues in Australia.
- Biomass fires, where spontaneous combustion by lightning in forest/grassland areas leads to wildfires, especially in periods of extreme dryness or very low humidity.

This section provides in-depth case studies of wildfires and locusts.

Wildfires

Wildfires, commonly known as bushfires (Australia) or brush fires (North America), are a natural process in many ecosystems. They are frequently used in conservation areas such as wildernesses (in New South Wales) and remote national parks (Yellowstone) as a necessary and beneficial tool of ecosystem management (Figure 69). This is a controversial technique as it can also be a major cause of wildfire hazard.

Figure 69
The ecological cycle of burning

As the forest ages, food for wildlife is reduced; dense trees rob shorter plants of sunlight

Burnt plants provide extra minerals in the soil, promoting growth of other shrubs, and wildlife flourishes

Wildlife area regenerates itself naturally every 250 to 400 years
Wildfires can be classified as a biohazard because they can result from spontaneous combustion from lightning strikes. However, they are frequently induced either directly or indirectly by human actions (Table 13).

Fires are a major hazard if they occur in populated areas. They can cause widespread ecological destruction of rare animal species such as the lizards of Canford Heath in Dorset in the summer of 2006, or the orang-utans of Sarawak and Sabah in the Great El Niño forest fires of 1997–98. Large-scale fires can also be economically problematic.

Table 13 Principal causes of bushfires in Australia

<table>
<thead>
<tr>
<th>Cause</th>
<th>% of fires</th>
<th>Cause</th>
<th>% of fires</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industry, e.g. forestry mismanagement</td>
<td>0.3</td>
<td>Lightning</td>
<td>5.6</td>
</tr>
<tr>
<td>Sawmills</td>
<td>0.3</td>
<td>Transportation</td>
<td>8.1</td>
</tr>
<tr>
<td>Smokers</td>
<td>1.5</td>
<td>Arson</td>
<td>8.4</td>
</tr>
<tr>
<td>Campers</td>
<td>1.7</td>
<td>Miscellaneous, known</td>
<td>9.7</td>
</tr>
<tr>
<td>Power lines</td>
<td>1.8</td>
<td>Burning off, legal</td>
<td>12.3</td>
</tr>
<tr>
<td>Rubbish tips</td>
<td>3.2</td>
<td>Burning off, illegal land clearing</td>
<td>15.3</td>
</tr>
<tr>
<td>Domestic, children</td>
<td>4.3</td>
<td>Miscellaneous, unknown</td>
<td>27.5</td>
</tr>
</tbody>
</table>

Source: Average of data held by the NSW Department of Bushfires Services

The nature, intensity and rate of spread of a wildfire depends on the types of plants involved, the topography, the strength and direction of winds, as well as the relative humidity of the atmosphere. Some fires travel along the ground, others spread via the canopies of tree crowns. For this reason it is difficult to create a standard profile for wildfire (see Figure 1 on p. vii).

Wildfires are particularly associated with areas experiencing semi-arid climates where there is enough rainfall for vegetation to grow to provide fuel, yet with a dry season to promote ignition conditions (see Figure 70).

Wildfires are therefore concentrated in parts of Australia (NSW/Victoria), Canada (British Columbia), the USA (California/Mountain West and Florida), South Africa and southern Europe (in Mediterranean vegetation areas of Portugal, Greece, southern Spain and southern France). Traditionally, wildfires have not been associated with tropical rainforest areas because of the high humidity and all-year-round rainfall. However, burning for forest clearance and forest mismanagement by logging companies, combined with El Niño events leading to unusually dry conditions, have revised this.

Case study 17

INDONESIAN FOREST FIRES, 1997–98

The forest fires associated with the 1997–98 El Niño had the greatest impact in southeast Asia. They extended across the islands of Sumatra and Borneo (Sarawak) and generated a vast black cloud stretching over 300 km from west to east, engulfing several of the world’s major cities such as Kuala Lumpur, Jakarta and Singapore.
Over 300,000 hectares of forest, often of high ecological value, were affected, scorched beyond recovery (Figure 71).

The pollution from the fires produced a toxic haze. Around 60,000 people required hospital treatment for breathing difficulties.

The tourist industry suffered large losses for nearly 2 years. Tourist trips to places as far away as southern Thailand were cancelled. Some of the world’s busiest shipping lanes and international airports experienced transport chaos.

The widespread distribution and large scale of these forest fires is clearly very different from more localised fires. There were at least 15 major outbreaks.

**An increasing hazard**

Although wildfires are associated with rural areas and usually cause only a limited impact, the movement of people into rural areas in southeast Australia, California, Florida and South Africa has spread the risk from wildfires. As many areas are hit by droughts from global-warming-induced climate change — for example, the summer droughts in Europe in 2003, 2006 and 2007 — there is concern that wildfires could become an increasing hazard for many areas, with major economic consequences. Owing to the nature of the hazard, deaths are anticipated to remain low, although there are major impacts on the local environment and on property.
Forest fires are a hazard even in the UK, after periods of drought, especially for the ecology and environment — for example, the Canford Heath fires in 2005, and the recent North Yorkshire moors fires. Figure 73 shows the fire risk in May 2007 after an exceptionally dry period. With suggestions that climate change could make summers in southeast England similar to those in Spain, this may be a sign of things to come. Because of an unusually southern position of the jet stream, England had the wettest June and July ever in 2007 (see Case study 6, page 30), and it was the Mediterranean regions that experienced damaging forest fires, which killed 70 people in Greece.

‘We need to shift our attitude to fire more in line with Californians, southern Europeans and Australians.’ (Roger Ward, Natural England)

‘It only takes a spark to cause a devastating blaze from which moorland habitats and wildlife take years to recover.’ (Sean Prendergast, Peak District National Park)

Managing the wildfire hazard

Modify the event

In many countries, for example Australia, Greece and Spain, the main approach to fire management has been to extinguish all fires, especially in populated areas, or near to high-value timber reserves. Firefighters refer to the fire triangle — oxygen, fuel and a source of ignition being the apexes — when managing fires. With industrial fires, foam is used to exclude the oxygen supply. In a wildfire situation, however, oxygen is always abundant, so management to modify the event...
concentrates on reducing or eliminating the fuel supplies from the potential path of the fire by controlled burning. This practice is highly controversial. It is a high-risk, polluting, labour-intensive measure that has a damaging effect on local ecosystems.

In national parks in the USA, such as Yellowstone, the removal of litter and lower vegetation is routinely used to minimise the possibility of unintentional renewed ignition. Prescribed burning is a widely used strategy in remote areas of the Mountain West.

Wildfire is one of the few hazards where management — using a combination of ground and air firefighting — can actually control and ultimately prevent the hazard becoming a disaster. Helicopters and planes act as water bombers and slurry (fire retardant) bombers. Where the benefits clearly outweigh the costs of control — for example, conserving large areas of housing in ever-sprawling suburbs — extreme management measures are taken to extinguish usually smaller-scale wildfires.

**Modify vulnerability**

A combination of the technological fix and community preparedness is vital in the management of wildfires. The technological fix is essential in remote areas to warn of fires. Aircraft and satellites are used to carry out infrared remote sensing to check surface temperature and signs of eco-stress from desiccation. In many US forests there are lightning detection systems, and infrared sensors; weather monitors and video cameras scan the forests of Florida for early warning precursors of wildfires.

Community preparedness can lead to early warning (using fire towers). Citizens can be trained as an auxiliary firefighting force, to organise evacuation and coordinate emergency firefighting. The 2007 Californian fires produced a model response.

Public education concerning home safety in high-risk areas is essential. Supplies of fuel should be reduced, wood stores stacked correctly, and adequate water hose and ladders should be available. All green waste should be composted and shrubs pruned regularly. Householders are also reminded to remove dead leaves from gutters. Warning levels of fire risk are also a vital component: high risk puts communities on alert.
School education concentrates on ensuring young people understand the dangers of arson and casual cigarette use, and the need to adhere to barbecue laws when there are high-risk conditions.

Land-use planning is again important. Risk management identifies areas of high vulnerability, and planning legislation ensures houses are built in low-density clusters with at least 30 m of set-back from any forested area. New developments are designed with fire breaks and wide roads for access of firefighting equipment. Fire-resistant housing design is increasingly important in areas of risk.

**Modify the loss**

Insurance is a common approach in MEDCs but it is expensive and difficult to obtain in fire-prone areas. Aid is likely to apply at a national, regional or local level in areas of hardship or poverty where people have lost their houses and possessions.

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**Locust plagues**

The development of locust plagues is tied to locust breeding grounds in North Africa, the Sahel, the Arabian Peninsula and, periodically, parts of Asia, northwest India and Australia. Locusts are usually an unthreatening species. They breed rapidly and swarm only under favourable meteorological and environmental conditions:

- Rain promotes vegetation growth, which is necessary for locust development, and for the fat accumulation necessary for adult migration. It allows adults to mature and lay eggs, and speeds the development of eggs.
- Warmth promotes rapid development at all stages of the life cycle.
- Wind strength, direction and timing determine patterns of swarming and spread of locust plagues.

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**Question**

(a) In your view, which of the three strategies (modify the event, modify vulnerability, modify the loss) is most important in responding to wildfires?

(b) Is it true that wildfires are a quasi-natural hazard?

**Guidance**

(a) Modifying vulnerability is the key strategy for minimising the impacts associated with wildfires. There is a growing risk for increasing numbers of vulnerable people, and increasing potential for periods of drought induced by climate change — although, unlike many tectonic hazards, the event can be modified by controlled burn. Modifying the loss applies to people who can afford the cost of insurance, which is inevitably high in areas of high fire risk.

(b) Spontaneous combustion by lightning strikes accounts for less than 10% of all wildfires. While certain natural conditions promote fire risk, vulnerability is clearly linked to the amount of settlement in a fire risk area. As Table 13 on page 62 shows, there are many human activities that increase the chance of fire. Most outbreaks involve a combination of triggers. On this evidence, quasi-natural is a fair classification of the wildfire hazard.
Managing the locust hazard

Modify the event

Control is the main option. Possibilities include:

- preventing the plague by controlling the upsurge stage — by spraying pesticide on breeding grounds
- eliminating the plague by destroying all, or nearly all, the locusts — this is an impossible mission, even by air-to-air spraying (where planes spray swarms in the air); it also involves environmental risks
- attempt to protect crops and allow the plague to follow its natural course

Modify vulnerability

The goal is to eliminate poverty, debt and food insecurity so that people can cope with a plague.

Modify the loss

Insurance is rarely an option but aid can be vital as shown by Case study 18.
Warnings of locust plagues began to emerge in June 2003, after a very wet winter in northwest Africa. No vegetation escapes a hungry locust — a single swarm can eat the same amount of food in a day as the population of London will eat in a week. In spite of some efforts at pest control, strong northerly winds drove the locust swarms south to the Sahel, which also had a season of abundant rainfall (the first in years), causing the locusts to breed, especially in Niger and Mauritania (Figure 79). The Food and Agriculture Organization (FAO) issued numerous warnings of problems, but locusts bred while donors dithered. Subsistence farmers in these LDCs were completely helpless because of the size of the swarms and the lack of resources such as aeroplanes and fuel to spray pesticides on them.

The media gave little coverage to the crisis in west Africa — there were more exciting stories, such as the Iraq war. Agencies reported that appeals for food aid for west Africa raised nothing in many cases. It was not until October 2004 that war was declared on the locusts and the long-requested funds started to flow. Because FAO appeals fell on deaf ears, the infestation grew and spread, destroying millions of pounds worth of crops and pasture in the process. The costs of control escalated. However, by the end of 2004, a combination of control methods plus an unusually cold winter in the Atlas Mountains meant that the locust plague was under control. But that was by no means the end of the disaster, as millions of subsistence farmers struggled to survive a loss of crops and no pasture for dying livestock, thus contributing to widespread famine in 2005 (see Case study 9, p. 37).

Some of the world’s most vulnerable people live in the Sahel. Around 10 million people face problems of recurrent drought, political instability (Niger), chronic poverty,
national debt, poor health and now a lack of food security. The affected countries lack the resources to cope, and the regional cooperation required to fight transnational locust plagues proved difficult to generate. In the absence of recent experience of locust plagues, it is possible that international agencies underestimated the threat, especially the knock-on food crisis for nations ‘living on the edge’. But there is no doubt that donations were too little and came too late.

Lessons that can be learnt from this disaster include the need for:

- properly financed and managed early warnings — always a problem for chronic and infrequent disasters
- better data to model the impact, so that aid agencies understand the scope of the problem
- stronger information campaigns to use the media to raise emergency funding
- a policy of spray now or pay later — early action would have avoided a 100-fold escalation of control costs
- greater cooperation at a regional scale to create greater awareness of common threats such as locusts and drought that lead to famine — while it is difficult to tackle the causes, it is often possible to raise awareness, issue early warnings and coordinate the response to the resultant food security issues

Question
What factors led to the locust hazard developing into a major disaster for the people of the Sahel?

Guidance
Look at Case study 18 and make a note of the relevant factors — some are physical, most are human. Develop your answer along the following lines:

- the nature of the warning — failure to raise funding (late response)
- the nature of the hazard — perception, knock-on effects
- the nature of the location — LDCs, subsistence farmers, vulnerable people