Geo Factsheet

April 2005 Number 182

Acid Rain : yesterday's problem?

Introduction

This Geo Factsheet examines the acid rain problem. This atmospheric pollution issue first came to prominence in the 1960s, when forest damage and acidified lakes were observed in northern Europe, Canada and the USA. Action to tackle to the problem was taken in the late 1970s and 1980s. To some extent, the problem fell from the public gaze as ozone depletion, and more recently, global warming became major environmental issues. So, is it 'problem solved' for acid rain or simply that other environmental issues take centre stage? This Geo Factsheet will review the causes and impacts of acid rain, and assess its current environmental impact. Case studies of the UK and China are used to illustrate the causes, issues and solutions surrounding the acid rain issue.

What is acid rain?

'Acid Rain' is a general term used to describe the ways in which acids fall out of the atmosphere. Acid deposition is a more accurate term, as acids can be deposited 'dry' as particulate matter and gas, or 'wet' as any form of precipitation (rain, mist, snow). *Fig. 1* summarises the processes and atmospheric chemistry of wet and dry deposition for the USA.

'Natural' precipitation is slightly acidic. This is due to atmospheric carbon dioxide dissolved in water droplets. This produces weak carbonic acid, with a pH of about 5.6. Precipitation with a pH below 5.0 is usually considered to be 'acid rain'. Importantly, the pH scale is logarithmic, so that pH 5.0 is 10 times more acidic than pH 6.0. In areas suffering the impacts of acid deposition, precipitation is often pH 4-4.5.

Why is acid deposition a threat?

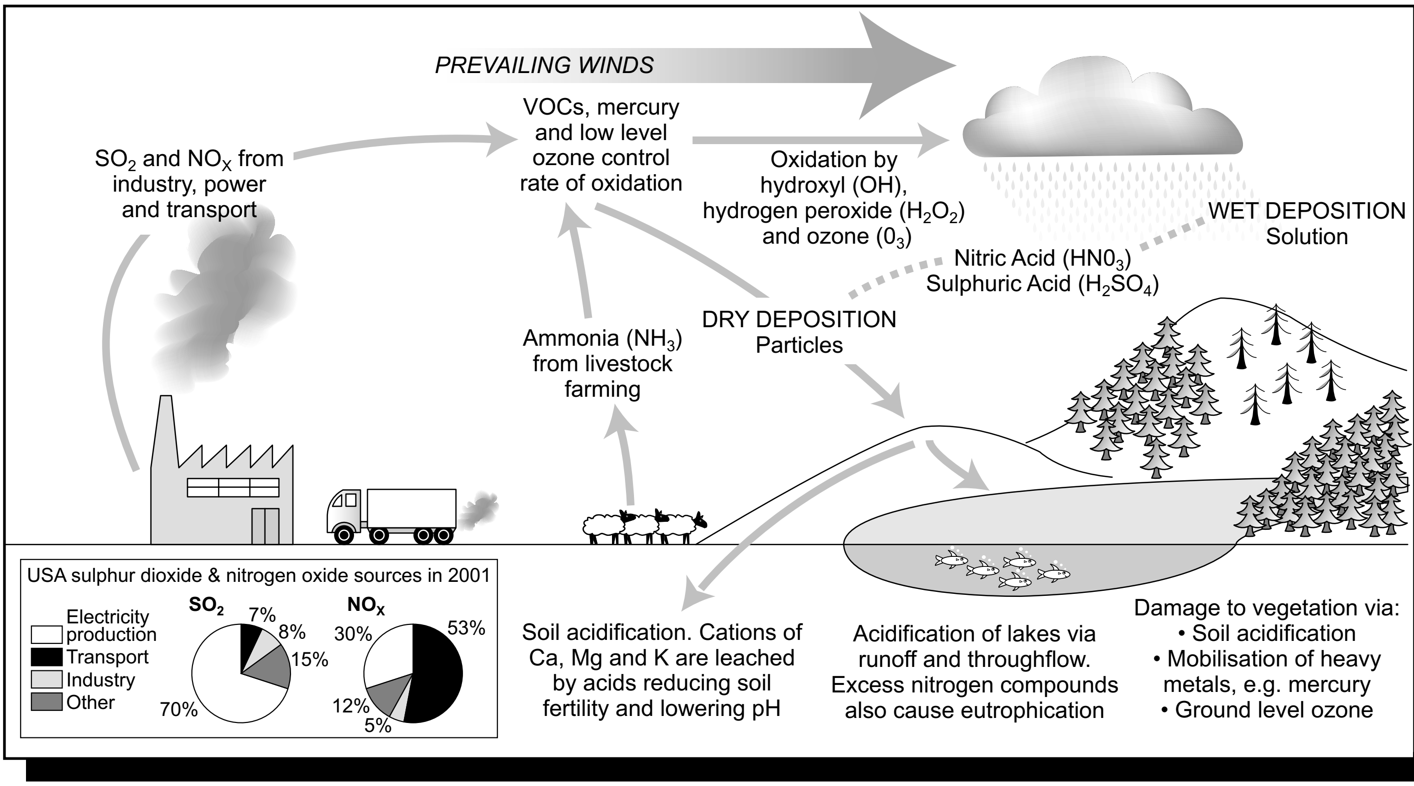
Acid deposition generates a range of environmental threats, both to ecosystems and humans. Nitrogen oxides and sulphur dioxide have direct impacts, additionally nitrogen oxides and volatile organic compounds (VOCs) can react to increase levels of harmful ground level ozone. The threats are summarised in *Fig. 2.*

Fig. 2 Summary of acid rain threats.

Lakes	*Acidification of lake water killing fish and disrupting food webs.*
Soil fertility	*Direct acidification reduces nutrient levels and fertility; mobilisation of heavy metals such as mercury.*
Species diversity	*Vulnerable terrestrial and aquatic species lose their habitats. Eutrophication due to nitrogen excess.*
Forest damage	*Reduction in foliage and canopy density, as tree health declines.*
Human health	*Effects on airways and lung function.*
Cultural heritage	*Increased acid weathering of buildings, especially limestone masonry.*

Exam Hint: Practice drawing a simplified, annotated version of Fig. 1. You may find this quicker and easier to repeat in an exam. Explaining complex processes such as acid deposition can eat up a lot of writing time in exams.

Fig. 1 Acid deposition processes



Case Study 1: The United Kingdom

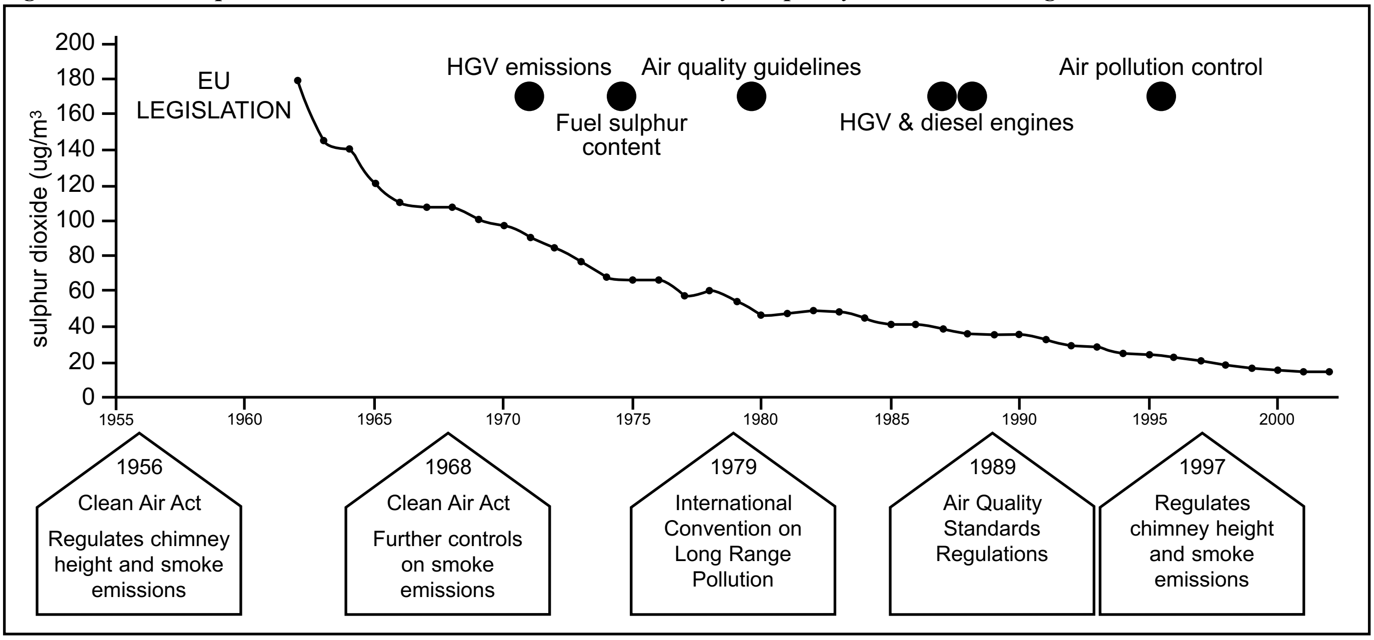
The UK has significantly reduced its air pollution since the 1950s. Pressure to clean up the air initially arose from a series of 'black smokers', major smog events in London in the 1950s. The response to these events was the 1956 Clean Air Act, which increased the height of large factory and power station chimneys (to disperse pollution from urban areas) and restricted emissions of smoke. This legislation had the effect of beginning to reduce sulphur dioxide concentrations, a trend which has continued to the present day. Fig. 3 shows the trend in mean annual sulphur dioxide concentrations from 1962-2002, linked to the key UK and European Union legislation on air quality and emissions in this period.

Total quantities of pollutants have declined significantly in the last 35 years in the UK as Fig. 4 shows:

Fig 4: Change in UK emissions 1970-1999

Pollutant & source	% change 1970 - 1999
Total sulphur dioxide	-82
Sulphur dioxide from power stations	-73
Nitrogen oxides from road transport	-9
Total nitrogen oxides	-30

Fig. 3 UK mean sulphur dioxide concentration 1962-2002 and key air quality and emissions legislation.



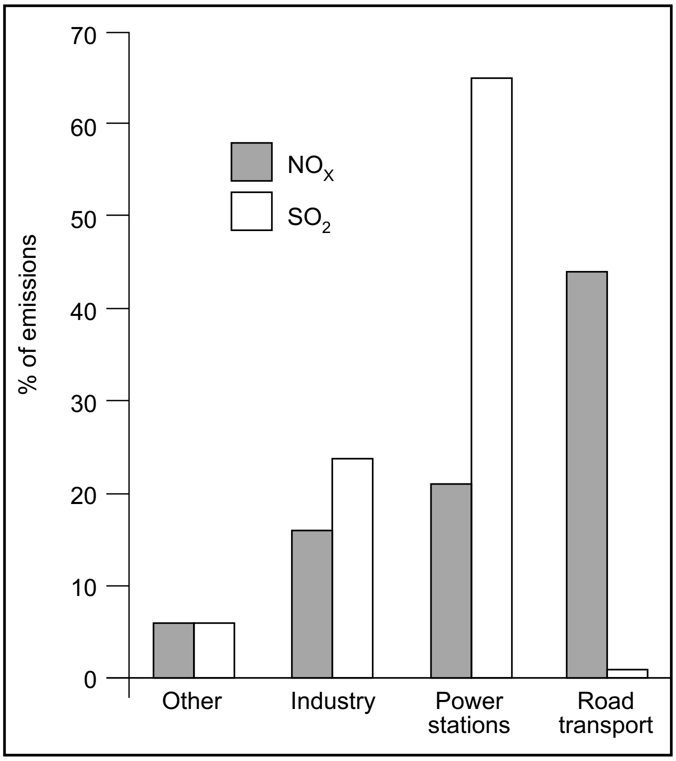
Legislation is only one factor which has contributed to lowering UK emissions of the pollutants that contribute to acid deposition. Changes in the UK economy have led to significant reductions:

- *Deindustrialisation - the shrinkage and closure of polluting heavy industry.*
- *A switch from coal burning power stations to cleaner gas burning ones.*
- *New technologies, such as flue gas desulphurisation which removes sulphur dioxide from power coal burning power station emissions.*

As Fig. 5 shows, sulphur dioxide emissions have declined much faster than nitrogen oxides emissions. This is down to our increasing use of road and air transport, the main source of NO_x emissions at 44% of total UK NO_x emissions.

The UK has 'cleaned up its act' and this has decreased sulphur deposition over the UK by around 50% since the early 1980s, reducing the acidification impacts on ecosystems. Nitrogen oxides have decreased much more slowly, largely due to our continued demand for cheap car and air travel. NO_x reductions require individuals to change their use of cars and this has proved hard to achieve. Sulphur dioxide reductions have been achieved by structural changes in energy sources and industry. Nitrogen deposition, and the problem of ecosystem eutrophication represents the current focus of attention in the UK.

Fig 5: Sources of UK SO_2 and NO_x emissions, 1999.



Acid deposition and development

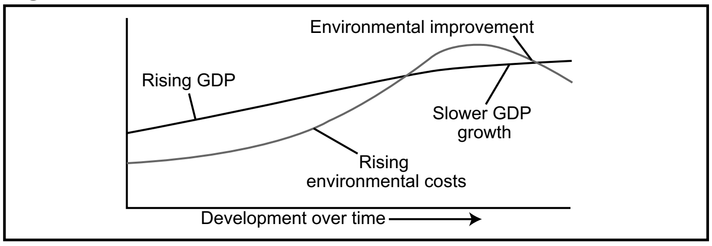
As is discussed in *Case Study 1*, acid deposition is a 'good news' story in terms of the UK. Emissions of sulphur dioxide and nitrogen oxides (NO_x) have fallen in the last few decades, reducing the impact of the problem. This improvement can be related to the development of the UK economy since the 1960s.

Acid deposition is an **externality** of production. Industries burning fossil fuels would rather emit SO_2 and NO_x than spend money cleaning it up. This ensures profits are not reduced by paying environmental costs. The pollutants then spread away from the pollution source and degrade the environment. Other people pay the 'costs' of the pollution, not the polluter (these costs are outlined in *Fig. 2*).

Acid deposition is a **directional externality**, as pollution travels away from the source in a direction determined by prevailing winds. UK acidic pollution is carried into Central Europe and Scandinavia - in other words crossing national borders and becoming **transboundary pollution**.

During industrialisation and development, people are prepared to accept negative environmental consequences as they are offset by increasing economic benefits. However as wealth increases further and the environment degrades more and more, a point is reached when an economy can afford to clean up pollution, and society demands it, as the environmental costs have become too great. This is shown in *Fig. 6*.

Fig. 6 Economic benefits – v- environmental costs.



The global pattern of acid deposition

Emissions of pollutants that contribute to acid deposition are strongly related to levels of economic development. This can be seen in *Fig. 7*, showing the global pattern of acid emissions and areas vulnerable to acidification. Europe and North America are acidification 'hot spots', however less economically developed areas, such as China, are affected. *Case Study 2* outlines the growing acidification problem in China resulting from rapid industrialisation and development.

Fig. 7 also shows areas which are vulnerable to acidification. Not all ecosystems are equally sensitive to acidification. Ecosystems on limestone, chalk and some clay soils are **buffered** against acidification as they have alkali or neutral pH. This means they have a higher **acid neutralisation capacity** than acidic soils such as podsols and peat. The concept of **critical loads** measures how much acid deposition an area could tolerate before lasting damage occurs. Where acid deposition exceeds critical load, damage to ecosystems occurs.

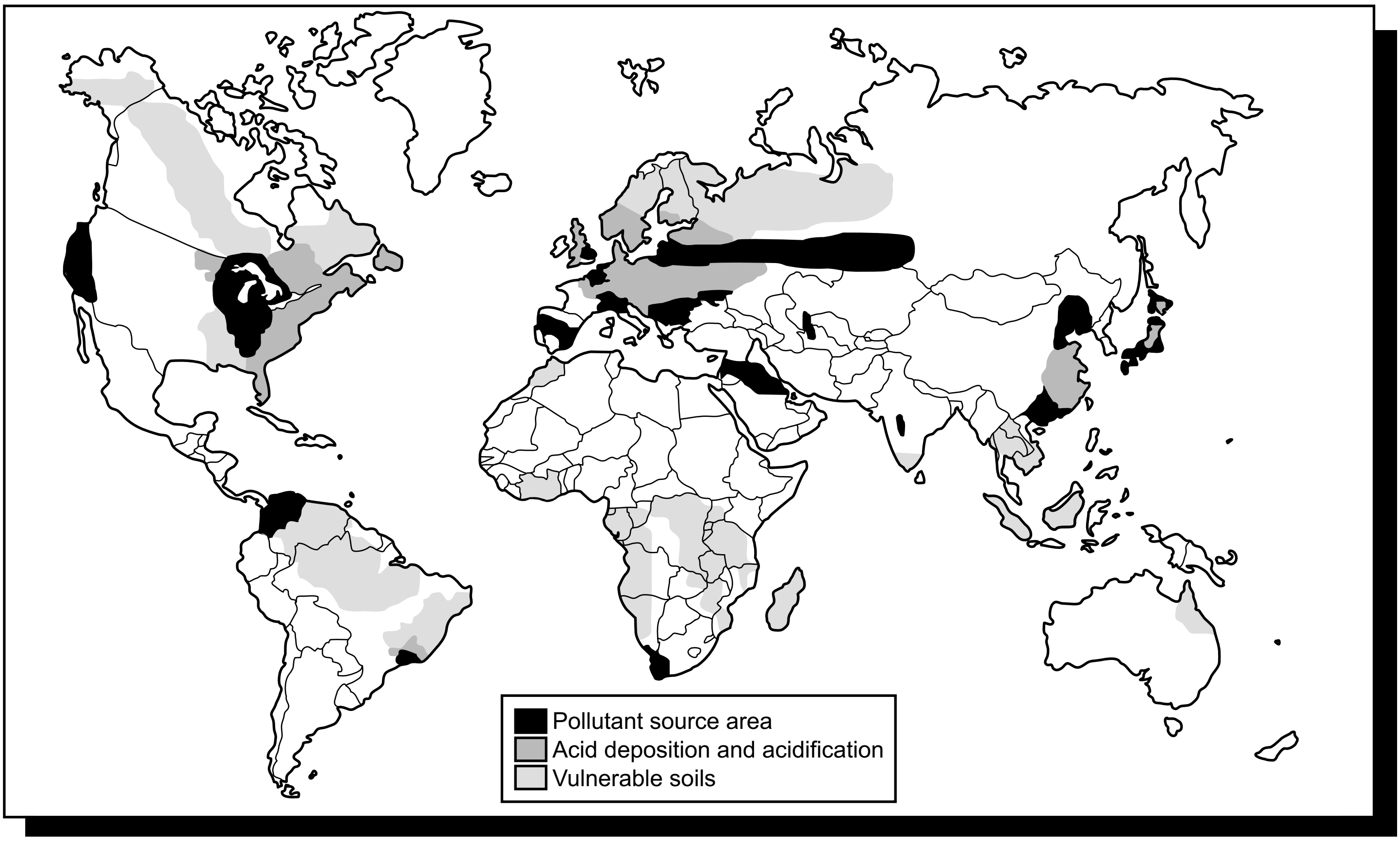
Exam Hint: Draw the global-north south divide to Fig. 7 and name the pollution source areas south of the line. Why are these areas particular sources of acid deposition?

Worrying trends in Asia

In Asia, growing combustion of fossil fuels and biomass linked to industrialisation and land clearance has resulted in the so-called 'Asian Brown Cloud' or South Asian Haze. The brownish haze is composed of:

- 32% sulphate particles
- 26% hydrocarbons
- 10-15% black carbon (soot)
- The remainder is a mix of dust, particulates and ash

Fig. 7 The global acid emissions and deposition pattern.



The cloud is as polluted as a suburb in a large American city, even when measured over the Indian Ocean, several thousand kilometres from its source area in the NICs of south and south east Asia. The limited research carried out on the haze so far has concluded that:
- Around 10% less solar radiation reaches the ground under the haze, as incoming solar radiation is reflected and scattered by the haze particles.
- This leads to cooling at ground level, which is currently balanced by the impact of global warming.
- Rainfall distribution and quantity is being affected by the haze.
- Crop production is likely to be lowered by lower surface solar radiation, acid deposition and altered precipitation patterns.
- The haze has serious human health implications for the region.

More research is needed, however the reduced surface solar radiation under the haze is a cause for concern. This phenomenon has been measured around the world and is known as **global dimming**.

Some researchers have suggested that global dimming due to low level pollution is balancing **global warming** resulting from carbon dioxide emissions. In Europe, where we have cleaned up our own 'brown cloud' (see *Page 3* and *Case Study 1*) we could be in for a nasty surprise as we feel the full impact of global warming.

Case Study 2: China

According to China's State Environmental Protection Administration (SEPA), over 30% of China experiences acid deposition including 50% of its major cities. The cost of acid deposition - to health, farming, the environment and management costs is estimated at US$13 billion per year. Acid deposition in China is a side-effect of rapid industrialisation in the last 20 years. In Asia, it is not only China which is suffering but other RICs and NICs. Fig. 8 shows the expected growth rate of sulphur dioxide emissions to 2020 if Asian countries continue to industrialise at their current rates.

Fig. 8 1990 and 2020 (projected) sulphur dioxide emissions in Asia.

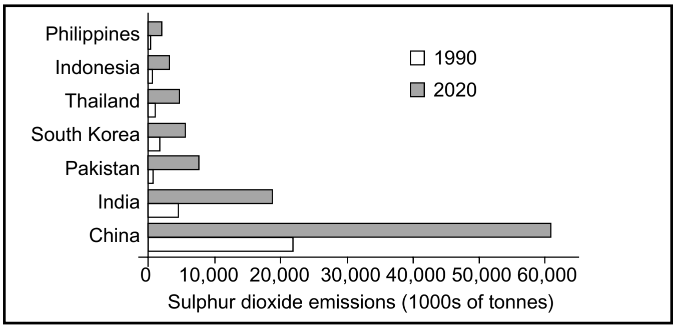


Fig. 8 suggests huge increases in sulphur dioxide as these countries continue to demand more power generation, road and rail transport and develop polluting industries. In China, 94% of sulphur emissions are a result of burning coal either for electricity, industry or in homes. Coal use is expected to increase by around 200% between 2000 and 2020. Many areas in the industrialising south of China, and in the east around Shanghai, currently have a serious acid deposition problem as Fig. 9 shows.

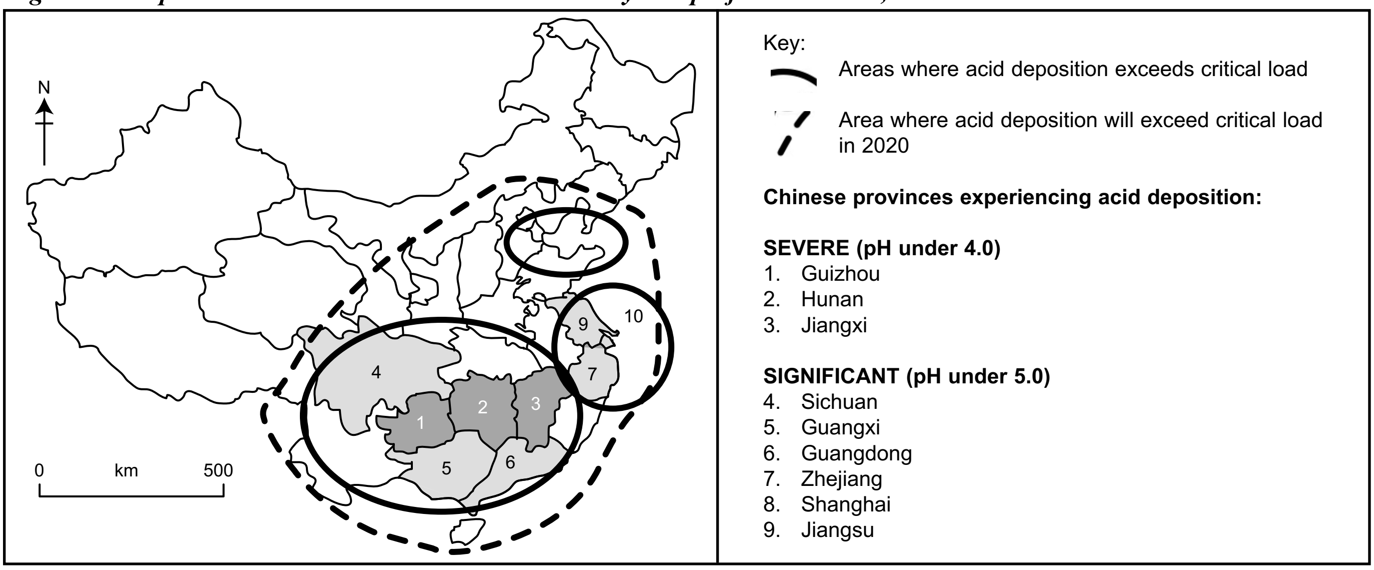
Management

China is attempting to manage its growing acid deposition problem using a number of measures:
- *Setting up 'acid rain control regions'(areas where precipitation is less than pH 4.5) and 'sulphur dioxide control regions' in the worst afflicted areas.*
- *Restricting mining of high-sulphur coal, and introducing coal-washing to remove sulphur prior to combustion.*
- *Setting emissions limits on power plants and fitting flue gas desulphurisation equipment to 'dirty' power plants.*
- *Using emissions fees as part of a 'polluter pays' system.*
- *Joint initiatives with Japan on clean combustion technology.*

In the future pressure is likely to grow for China, and other Asian RICs and NICs to become part of an international agreement on acid deposition control, possibly an extension to the UNECE Convention on Long Range Transboundary Air Pollution. In its original form this Convention involved only European Countries, however the USA, Canada and other countries are now signatories. Projections suggest that acid deposition critical loads will be exceeded in many Asian areas by 2020 including:
- *Most of southern and eastern China*
- *Much of South Korea*
- *Southern Japan*
- *Areas of Thailand, the northern Philippines and Taiwan*
- *Parts of Malaysia and Indonesia*
- *Large areas of eastern and northern India*

This makes it even more necessary that management and control is both a national priority and a subject of international co-operation.

Fig. 9 Acid deposition and critical load exceedance today and projected to 2020, in China.



Acid deposition management

Case Study 1, of the UK, shows the impact legislation can have on reducing emissions and the negative consequences of acid deposition.

As acid deposition is often a transboundary issue, legislation has to involve many countries. The **UNECE 1979 Convention on Long-Range Transboundary Air Pollution** was crucial in beginning the acidification clean-up in Europe as it:

- *brought together polluter and polluted.*
- *set clear targets for pollution reduction.*
- *made polluters recognise their international environmental responsibilities.*

The UK, as an EU member, is now a signatory to the **1999 Gothenburg Protocol** to abate acidification, eutrophication and ground level ozone. This commits the UK to reduce its emissions significantly as is shown in *Fig. 10*. If the UK meets these targets it will significantly improve the environment and help tackle the issue of eutrophication from nitrogen deposition.

Fig. 10 Gothenburg protocol emissions reduction targets

	1980-2010	1990-2010
Sulphur dioxide	85%	75%
Nitrogen oxides	49%	50%
VOCs	53%	56%
Ammonia	16%	15%

Exam Hint: Draw a spider diagram to show how acid emissions could be reduced by action at a range of scales:
• Personal • Local • National • Global
Use the two Case Studies of China and the UK as well as your own ideas.

Conclusions

Long-term action and international agreements have succeeded in reducing the negative impacts of acid deposition in MEDCs. Success has been achieved by a combination of action to clean up sources of pollution and 'natural' economic change such as deindustrialisation and a switch to using gas rather than coal.

In the UK the current focus of attention is on reducing nitrogen oxides emissions. This may prove more difficult than expected due to the MEDC dependency on road and air transport. In many parts of Europe and Canada, ecosystems have not recovered as acid deposition has fallen. This may suggest that damage to forests and lakes is much more fundamental and long-term than scientists once thought. The acid deposition issue has not been solved, it has simply moved to areas of the world which are currently industrialising. Acid deposition represents a tangible and growing threat to ecosystems and human health in many parts of Asia. In China, Asia's largest source of sulphur dioxide and nitrogen oxides, there is the potential for an acid deposition disaster if management measures are not rapidly implemented. Recent research on the 'Asian Brown Cloud' suggests a complex link between low level pollution and global warming. Acid deposition is far from yesterday's problem.

Sources

- *Acid Rain: Downpour in Asia,* World Resources Institute (2004)
- *China's View of Acid Rain,* JE Sinton, Lawrence Berkeley National Laboratory (2002)
- *Acid Rain: is the UK coping?* MR Heal. Education in Chemistry (2002)
- *Environment, Resources and Conservation.* S Owens & PL Owens. CUP (1996)
- *The Asian Brown Cloud.* UNEP (2002)

Useful websites for further research:

The Environment Agency website www.environment-agency.org.uk is a good starting point for UK information on acid emissions and deposition.
The UK National Air Quality Information Archive website is a good source of data and statistics: www.airquality.co.uk
The International Institute for Applied Systems Analysis (IIASA) at www.iiasa.ac.at has links to the RAINS Europe and RAINS Asia projects which model future air pollution scenarios.

Questions

Your A-level specification may contain essay style questions on pollution directly, and / or questions on ecosystems and the impact of pollution.

1. Acid rain is yesterday's problem. Discuss.
   The case studies presented here allow you to argue for and against this statement. In some areas, such as Europe, emissions have been successfully reduced due to a combination of legislation, industrial change and fuel switching (gas for coal). In other areas emissions are rapidly increasing due to industrialisation combined with a lack of environmental legislation e.g. China. The potential for further economic growth in south east Asia is huge, ensuring acid rain / deposition will continue to be a challenge in decades to come. Even in rich, environmentally conscious MEDCs NO_x emissions are proving stubborn problem as car and aircraft use continue to escalate.

2. Pollution does not respect international boundaries. Explain this statement with reference to acid deposition.
   Acid deposition was the first 'transboundary' pollution issue to gain popular attention. As such, it became a hot political topic in the 1970s and 1980s. Carried by prevailing winds, acids travelled from the UK to Germany and Scandinavia and contributed to the UK being dubbed 'the dirty man of Europe' as we exported our pollution elsewhere. International agreements such as the UNECE 1979 Convention and Gothenburg Protocol are further evidence - transboundary agreements to deal with a transboundary issue. Bring your case up to date with the 'Asian Brown Cloud' - this cloud was first measured in detail over the Maldives, hardly a major polluter itself but feeling the impact of pollution originating in India and China. The world map (Fig. 7) should guide your choice of examples.

3. Acid rain is an inevitable consequence of economic development. Discuss.
   Both the UK and China case studies suggest this is true, however is it? Do we need fossil fuels to industrialise and develop or are there viable alternatives? What is the role of legislation is preventing acid emissions? Could a country such as China, desperate to develop, be persuaded onto an alternative course?

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