Air Pollution: A Problem of Regional and Global Scale and the Effects of Climatological Factors The 1980,s experience

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ص. ص. 1 - 22

1 Introduction

2 Local Scale Pollution: The Case of Urban Air Quality.

2.1 Transport Related Air Pollution.
2.2 Economic Effect of Transport Pollution.
2.3 Measures of Combat Traffic Pollution.
2.4 Municipal Solid Waste Incineration.
2.5 Control Technology.
2.6 Heat Waste.

3 Regional Scale Pollution: The Case of Acid Percipitation.

3.1 Pollutants Involved in Acid Deposition.
3.2 Sources of Acid Pollution.
3.3 Control Technologies.

4 Global Scale Air Pollution: The Destruction of Stratospheric Ozone.

4.1 The Process of Depletion.
4.2 Health Implications of Ozone Depletion.
4.3 Measures to Combat Ozone Depletion.

5 The Effects of Climatological Factors on Air Pollution.

5.1 The Spread of Pollution and Global Circulation.
5.2 Surface Weather Systems and Pollution.

Acid Rain in Europe.
The Chernobyl Accident, 1986.

6 High Pressure Systems.

7 Upper Air Streams.

8 Microclimate and Pollution.

8.1 Air Movement and Tropography.
8.2 Urban Climates.

9 Conclusions.

1. Introduction.

Pollution can cause major disruption in energy and nutrient cycling in ecosystems. Examples of this are legion but the following are significant. The effects of air pollution have been recorded since the early days of the industrial revolution. Smoke and dust cause reductions in photosynthesis whilst acid rain causes soil and groundwater to be acidified. It is believed that acid rain is the main cause of forest decline in western germany. In 1985 some 55% of coniferous trees showed symptoms of dieback of all or part of stands of trees (Goudie, 1990).

Water pollution is also a major destabiliser of ecosystems. Pollution by inorganic nitrate fertilisers used in developed countries causes the lush growth of algae in watercourses. In turn these clog up the flow of water and deoxygenate it. The result is that animal and plant life in the stream is wiped out due to lack of dissolved oxygen. This process is termed *eutrophication*.

2 Local Scale Pollution: The Case of Urban Air Quality

Cities with major air pollution problems are to be found on every continent (excluding Antarctica). The complexity of urban physical structure makes measurements and comparisons of air quality in different cities difficult but urban pollution is important: cities are now the major source of anthropological emissions affecting global quality.

The percentage of the world's population living in urban areas has increased from 33.6% in 1960 to 41.6% in 1985 (International Institute of Economic Development 1987). Most of this growth has occurred in the Developing Countries; the populations of Mexico City, Bombay and Seoul have overtaken those of New York and London during this 25 year period. It is from these cities that future problems are likely to come. A combination of high population density, warm climate and no established clean air legislation provide conditions in which air pollution may become devastatingly harmful. The need for capital investment in these countries is often considered more important than the need to impose environmental limitations on industry. Indeed, foreign ivnestment in developing countries is often attracted by the lack of expensive emission control technology needed and can lead either to long term environmental destruction (in the case of the heavily industrial Carara Velley in Brazil described by Dickenson et al.) or to short term environmental disasters like that at Bhopal in Northern India when thousands died after emissions of poisonous gas from an American Union Carbide factory in 1984.

Of particular importance when discussing urban pollution are the problems caused by transport emissions, the disposal of municipal waste and the creation of waste heat.

2.1. Transport Related Air Pollution

Of the pollutants already discussed it is NO_2, Ozone and Lead which are prevalent in transport related air pollution.

i) **NO_2:** This is a major transport related air pollutant, particularly when found in conjunction with temperature inversions. If trapped at lc.. levels by a higher layer of cold air a highly acidic, brown layer occurs. Athens has been badly affected by exhaust emissions of NO_2 & the accelerated disintegration of the Parthenon over the last 20 years has caused particular concern.

ii) **Ozone:** Photochemical smog is caused almost soley by traffic emissions into the urban atmosphere. Los Angeles is prone to serious smog during rush hours as are many other cities where long hours of intense sunlight are common (photochemical reactions only occur in the presence of sunshine). This build-up of ozone during the day can be seen in Figure

iii) **Lead:** Has become notorious as a cause of brain damage in children. After children living in densely trafficked areas were found to perform up to 25% less well than non-urban dwelling children, the US National Ambient Air Quality Standard set a level of 1.5mg/m^3 of air (NAAQS

1979). Similar limits have been set throughout Europe and Scandinavia. Most lead enters the air from the combustion of 'anti-knock' petrol to which lead compounds have been added. Since 1979 US car manufacturers have built all vehicles to accept lead free petrol, reaction has been slower elsewhere.

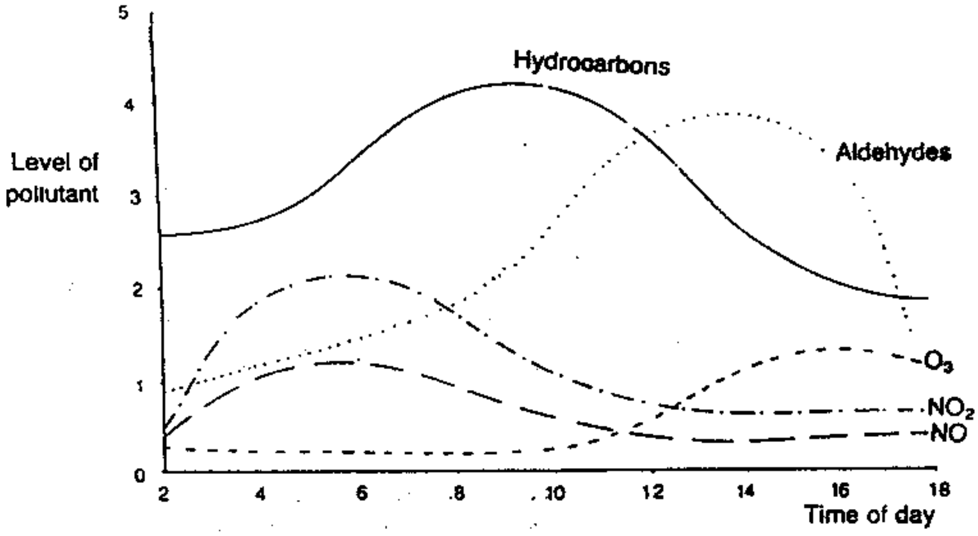


Fig 1 Los Aneles study showing formation of ozone according to time of day and diurnal variation of smog pollutants (Brimblecombe 1986).

2.2. Economic Effects of Transport Pollution

The health effects of common traffic pollutants was described earlier. In economic terms the cost of hours of labour lost through pollution-related illness is hard to gauge. Because such illness often takes the form of respiratory complaints like bronchitis, estimates of the costs to health services are impossible because most pollution merely intensifies problems which already exist. Cleaning and repairing facades of buildings costs municipal authorities millions of pounds per annum.

2.3 Measures To Combat Traffic Pollution

These vary greatly between cities. Most countries now have legislation limiting vehicle exhaust emissions although encorcement varies greatly. From 1991 UK Ministry of Transport Tests carried out annually on all privately owned vehicles will include exhaust emission quality tests without which a vehicle will not be allowed on the road. In the USSR, however, enforcement is not carried out effectively despite the country having the longest established and most stringent limits on emissions. Limits were set in the 1920s and are often several times lower than Western limits set later. For example the upper limit for lead is 0.2mg/m^3 (s opposed to 1.5mg/m^3 in the US) but it has been estimated that if these limits were enforced Soviet metropolitan systems would grind to a halt (Goldman 1986). This emphasises the importance of the installation of pollution control technology in conjunction with setting feasable emmission limits.

Catalytic converters are being installed in all new US cars and EEC guidelines suggest that all new European cars will be fitted with them by 1996 (although some manufacturers already fit them as standard e.g. Audi). These catalyze the reduction of Nitrous oxides to Nitrogen and oxidize HCL and CO rendering them stable and harmless. Lead-free petrol has not been banned in the UK but tax incentives since 1987 have made it cheaper than leaded petrol as an incentive to drivers to have their cars converted.

An alternative approach to emission quality controls is that used by the Green government in Athens and the Venezuelan government in Caracas. They have instead limited the numbers of private cars allowed into the city on any day by barring odd and even numbered license plates on alternate days and thus cutting urban traffic by around half. The effectiveness of this measure is debatable, particulalry as the 1960s Venezuelan oil boom enabled many people simply to buy another car with a different license number and drive into Caracas every day!

It is not easy to determine how well various measures work in controlling traffic emissions since all cities have adopted different measures and have different problems. However, in general a change in attitude towards the over-use of the private car is necessary before any measure can be wholly successful. By subsidising public transport people can be encouraged to leave their cars outside the city and travel to work by train or bus. This provision of more environmentally friendly transport has been deemed to be successful in Paris in reducing road users by subsidising Metro fares by around 35% (Baker + Barker 1988).

2.4. Municipal Solid Waste Incineration

Because of the high cost of transporting waste, most is incinerated in the urban areas where it is produced. Municipal solid waste (MSW) incineration has been found effective in reducing volume and weight significantly and allowing some energy recovery in the form of strem/electricity.

It may, however, have an adverse effect upon the health of the surrounding community, particularly considering that the preferred location for the incinerators is in heavily populated urban centres. Waste incineration is carried out throughout the world but most recent statistics and legislation concern the US where concerns over health risks are growing.

Incomplete combustion of MSW leads to pullutant emissions, especially of toxic metals and chlorinated organics. the incinerators are also significant producers of acid gases from the combustion of heterogeneous refuse containing Chlorine, Sulphur and Fluorine (found in plastics, rubber and paper amongst other things). All these contribute to local scale pollution.

i) SO_2: The typical value of Sulphur in MSW is 0.23% with 30-60% converted into SO_2. Actual levels of up to 0.35% of MSW emissions have been found to be SO_2 (Californian Air Resources Board 1984).

ii) $NO + NO_2$: Conversion of the Nitrogen compounds in MSW and the conversion of the Nitrogen in the combustion air stream lead to the production of Nitrogen oxides (NO_x). Nitrogen compounds can form as much as 0.83% of MSW in areas where a lot of garden waste and textiles are burnt (CARB 84).

iii) CO: Emitted as a result of incomplete combustion of organic materals in the waste. Carbon monoxie is very toxic. It is caused if their is an insufficient stream of combustion air, a low combustion temperature or inadequate residence time in the incinerator (DE Paul 1989).

iv) HFl + HCl: Produced by a reaction of the Fluorine and Chlorine in waste with Hydrogen ions from the combustion of Hydrocarbons. Chlorine content of MSW ranges form 0.3-0.7% depending upon the plastics content of the refuse. The conversion of Chlorine into HCl is estimated at 46-86% (CARB 84).

v) **Heavy Metals:** The greatest problems with toxic metal pollution arise from the combustion of disposable batteries. Lead, Nickel, Zinc, Mercury and Cadmium enter the atmosphere from the stack in a vapour state or as particulates in flyash. Table 1 shows the quantities of various metals (some toxic, others found naturally in the body) which can enter incinerator emissions.

Element	concentration ppm average	Element	concentration ppm average
Ag	3.0	K	1300.0
Al	5000.0	Li	2.0
Br	170.0	Mg	1600.0
Ca	9800.0	Mn	130.0
Cd	9.0	Na	4500.0
Co	3.0	Ni	22.0
Cr	55.0	Pb	330.0
Cu	350.0	Sb	45.0
Fe	2300.0	Sn	20.0
Hg	12.0	Zn	780.0

Table 1.: Sources of metals in Municipal Incinerator Emissions (S L Law + G E Gordon)

Before considering measures to combat urban emissions it is usual to look at the local human effects rather than long distance effects. In other words it is the more toxic acid gases and heavy metals which are of more concern than CO_2, SO_2 etc. in control considerations.

2.5 Control Technology

The US government pioneered the concept of 'Best Available Control Technology' (BACT) which can be defined as:

> **"An emission limitation based on the maximum degree of reduction of each pollutant subject to regulations... on a case by case basis, taking into account energy environmental and economic impact and other costs" (US Clean Air Act 1977).**

Thus precise emission limits vary between places according to BACT factors.

Before 1971 available technology was only able to control particulate emissions, using electrostatic precipitators (ESPs) to collect particles which would otherwise be carried out of the stack. Now, however, concerns include Nitrous oxides and acid gases etc. as well and regulations which began in Europe, US and Japan are now spreading worldwide.

These regulations enforced the development and installation of ESPs and fabric filters to remove particulates. Spray Dryer Absorbers are also extensively used to remove acid gases and Chlorinated organics from the exhaust stream. One of the most effective ways of reducing pollution has been to remove potentially harmfull elements before incineration. For example, the Swedish government found that 60% of Cadmium and 60% of Mercury emissions were the result of the combustion of metals and batteries which could be removed before the refuse stream reached the incinerator. Similarly 25% of Cadmium and 10% of Mercury emissions into the atmosphere were found to come from plastics which could be removed from the solid waste and recycled (D L Klass + C Sen 1987).

This information was put to practical use in Gallatin, Tenesse where the MSW incineration process involved the removal of all non combustible material from the solid waste stream. Emissions were reduced by 52% for lead and 73% for Cadmium. The consequent slower refuse stream meant more complete combustion and CO emissions fell by 63% (Crowder 1989).

2.6 Heat Waste

Heat, lost into the atmosphere from a variety of point sources, is an important pollutant when considering its effect upon the urban environment. The seminal work on the effect of waste heat is that of Landsberg (1981) in which he describes the city as an "Urban Heat Island". He estimated that the effect of waste heat was to increase the air temperature of a city by an average of 15°C, precipitation by 10-20%, lower wind speeds and to increase the frequency of fog by 100% (in comparison with the surrounding countryside). These factors result in a mesoscale ciculatory system within the urban environment which acts to trap other pollutants in the immediate area of the city.

Sources of waste heat include transport exhausts, industrial emissions, power plant plumes, poor household insulation and air conditioning. Pankrath (1980) estimated the percentage of heat emitted from varous sources in the Rhine region;

Energy Conversion	16%
Major ndustry	33%
Domestic Releases	38%
Transportation	13%

Heat can be prevented from entering the atmosphere through insulation in the case of domestic release, or energy recovery int he form of steam driven turbines in the case of industry, power plants or MSW incinerators.

3. Regional Scale Pollution: The Case of Acid Precipitation

It is the Mid-Latitudes where an organised meteorological system exists that the Long Range Transport of pollution is allowed without much dispersal or loss of the constituent parts. This probably accounts for why the greatest environmental damage caused by pollution from sources more than a few 100km away is to be found in the North Eastern United States, S.E. Canada, North Eastern Europe and Scandinavia. Of greatest current concern in this category of air pollution is the incidence of acid precipitation throughout these areas.

Acid precipitation includes both the impact of wet and dry atmosphere on the environment. Acid rain only refers to pollutants carried in water droplets and falling to the ground as rain, snow or dew. Acid deposition describes the unloading of pollutants at ground level, once atmospheric material has already reached the surface.

Since 1972, when acidification of lakes and forests was first reported by the Swedish government, acid precipitation has been held responsible for the destruction of life in 1000s of lakes and forest areas. In Germany 53000 Ha of forest has been damaged with over 50% of trees affected (OECD), much of the Vosges' forests in France have been affected too but it is the Scandinavian countries which have been hit worst. Lake and forest ecosystems have been decimated and acid precipitation has damaged buildings, works of art and lost the countries millions of pounds in revenue from tourism (Ambio Vol 18 1989).

3.1 Pollutants Involved in Acid Deposition

Regional acid deposition is caused mostly by soluble acidic oxides. Both SO^2 and NO_x contribute to the problem after having been emitted from high chimneys, from where they can be transported over long distances. The major constituents affecting the quality of rainwater are shown in Table 2.

Atom/molecule	Ion density	Anthropoloical source	Comments
Hydrogen	H^+	(naturally occurring	Amount determines rainwater acidity
Sulphate	SO_4^+	Fossil fuel combustion	Strong acid, gas + liquid reactions
Nitrate	NO_3^+	fossil fuel + transport	Same as SO_4^+
Chloride	Cl^-	Industry	Acid, mainly gas, reactions

Table 2 : Major Inorganic Ions Affecting Rainwater Quality + Acidity (Bridgeman 1990)

Clean background rainwater will be slightly acidic because CO_2 naturally present in the atmosphere reacts weakly with water to form carbonic acid. Thus 'clean' precipitation emasured in antarctica was found to have a pH of between 4.9-5.6 (Galloway et al 1984). Areas prone to acid damage have been found to experience precipitation acid levels of less than 4.5.

Acid rain may also contain Ammonia and the precursors of photochemical oxidants, all of which are emitted from tall chimneys and are more likely to travel further afield. The main acid rain component, H_2SO_4, is placed above the boundary layer and disperses uniformly to be carried long distances. (NO_x emissions are usually from cars and are more important in local deposition).

3.2. Sources of Acid Pollution

Transport, conversion and deposition of acid oxidants is a complex process about which there is much debate. The damage caused depends much on the location and sensitivity of the receptor site and there are even suggestions that acidification of ecosystems is a natural process and not related to acid emissions (e.g. CEGB 1988). Superficial support for this argument is provided by the fact that while emissions remain cosntant over the seasons, acid deposition at receptor sites is variable. However this variability is more likely to be a result of seasonally changing weather conditions causing differing transportation rates than proof of no association between emissions and damage.

In the areas from where acid pollutants are thought mainly to come (US industrial North East, UK, Eastern Europe, Ukraine), the fuel burnt by power stations and industry ahs a high sulphur content. Coal contains an average of 1.5-2.0%, oil 2.5-3.5% (Bridgeman 1990). Table 4 shows the acid emissions from various fossil fuel cycles (from mining or drilling to combustion)

Fuel cycle	SO_2 (gs/GJ)	NO_x (gN/GJ)	Total acid gs/GJ equivalent to SO_2
Coal (UK ave.)	1930	440	2430
Oil	2280	210	2520
Coal (with control technology)	170	230	430
Gas, combined cycle	67	74	150
Total 1987 UK electricity supply	1530	327	1900

Table 3 : The acid emisisons from various fossil fuel (N J Eyre, DOE paper 1990).

Table shows the importance of electricity generation in contributing to acid emissions. The UK has been held responsible for much European acid damage since the most typical operating practise is coal and oil fired steam turbine generating plants which have no gaseous pollution *abatement control technology*. The UK is the largest producer of air pollutants in Europe with the electricity sector emitting 62% of the UK total gaseous emissions.

A total of 4677kg × 10^6 of SO^2 is emitted annually from the UK, Italy following with 3608kg × 10^6 is the next highest and then West Germany with 319kg × 10^6. Switzerland, Austria and Sweden are the least polluting countries respectively emitting just 127,354 and 482 kg × 10^6 of SO^2 annually (After Lubkert and de Tilly 1989).

3.3 Control Technologies

In the UK '*scheduled processes*' (including power stations) must be registered annually with the Industrial Air Pollution Inspectorate who control emission levels on a national scale. Since Britain *refused* to sign an EEC *emission reduction agreement* in 1982, the levels allowed remain high and are set nationally, even though the resulting problems are on an internaitonal scale. The typical coal and oil fuel cycles would have emmissions cut by 80% and 90% respectively if modern emission controls were used (Haigh 1989). Gas Flue Desulphurisation equipment is expensive and establishing source/receptor links difficult, however and the Central Electricity Generating Board, accepting no responsibility for the long range transport of its emmissions, has plans to fit only a tiny proportion of its power stations with controls.

4 Global Scale Air Pollution: The Destruction of Stratospheric Ozone

The effects of industrial and domestic emissions into the air have been highlighted recently when it was discovered that the region with supposedly the cleanest atmosphere had been polluted with HCl, Chlorofiurocarbons (CFCs) and $ClONO_2$. The British Antarctic Survey routinely monitors levels of Stratospheric ozone over meterological stations at hally Bay and Argentine Islands. In 1984, a team led by John Farnham made the startling discovery that spring values of total zone during the 1980-1984 period had fallen dramatically. This annual decrease lasts for about 6 weeks in the Southern Hemisphere spring at a height of 10-25 km and started to appear in 1979. The discovery of a 'hole in the sky' fuelled concern over possible health and environmental effects. Verification of the depletion of stratospheric ozone came from US balloon and rocket soundings which also measured high levels of trace gases like Nitrogen species and CFCs.

4.1 The Process of Depletion

At the end of the Southern Hemisphere winter (Stptember-October) the circumpolar vortex circulation is at its strongest and is extremely stable and durable. This tight circulation system blocks invasions of warmer air and allows very low temperatures over the continent (193K or less). The low temperatures allow the formation of *Polar Stratospheric Clouds* at 10-25 km above the surface. As air flows through the clouds, pollutants like HCl, CFCs or $ClONO_2$ release free chlorine (Malina 1987). In the presence of frozen water, the following reactions take place:

$ClONO_2 + HCL$ ---------> $Cl_2 + HNO_3$

$ClONO_2 + H_2O$ ---------> $HOCl + HNO_3$

The HOCl from these reactions photodissociates in sunlight releasing more free Cl and the HNO_3 falls to the ground in snow. The Cl then combines with ozone destroying the molecule:

$Cl + O_3$ --------> $ClO + O_2$

Increased measurements of Chlorine in atmosphric reservoirs help to verify this theory of ozone destruction. (Farmer et al 1987).

4.2 Health Implications of Ozone Depletion

During the Antarctic spring, the polar votex disintigrates as temperature rises. The ozone 'hole' then splits up into several large areas and travels northward. Until 1989 the holes never reached other land masses before filling with undepleted ozone stocks but in that year an area of depleted ozone was recorded over Melbourne in Australia. Ozone absorbs the ultra violet radiation which causes malignant skin melanomas and the implications for the icnrease in skin cancer are being taken seriously by the Australian and US governments. Last year the US government spent an estimated $10 million on skin cancer research alone.

4.3. Measures to Combat Ozone Depletion

The control of chlorine compound production needs a coordinated global response. CFCs are used widely in refrigerants and insulation, foam blowing, solvents and aerosol propellants. They are chemically stable so do not break down in the lower atmosphere and in this way can travel the length and breadth of the globe.

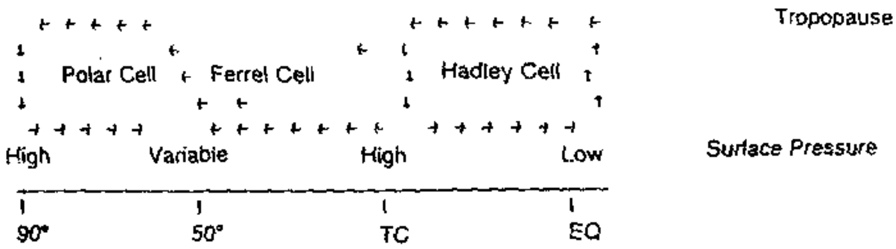
In 1985 the Vienna convention on 'Protection of the Ozone Layer' was adopted. This set the way for cooperation on research and regulatory action. This action was confirmed in 1987 in the 'Montreal Protocol on substances that deplete the ozone layer' in which each party to the Protocol has to control independently its production of CFCs. The chemical industry estimates that a 60% global reduction in the consumption of CFCs will be achieved by 2000 and also 'has plans' for the other 40% (DTI 1989).

Despite this farly prompt respeonse, since 1987 depletion in ozone levels in the Northern Hemisphere have also been recorded and the Montreal Protocol is under review with a greater sense of urgency.

5 The Effect of Climatological Factors on Air Pollution

5.1. The Spread of Pollution and Global Circulation:

All atmospheric circulation ultimately is the result of the incidence of solar radiation upon the planet's surface and the consequent heating and convection of the air. In broad terms the circulation pattern follows the cell pattern illustrated in figure 2.



Source: Pearce 1987

Fig 2 Major circulation structure of the atmosphere (diagrammatic).

Surface and upper air movements are influenced by Coriolis Force and this gives rise to the characteristic surface low and high pressure weather system and westward flowing upper air, including the polar and subtropical jet streams.

The circulation of air, in both upper atmosphere and at the surface has two consequences for pollution, one positive and one negative. On the positive side, air circulation moves pollutants from their production point and effectively dilutes them. On the negative side, it means that pollutants are spread more widely voer space. Lack of circulation will concentrate a pollutant within a spatial area and this may result in high concentrations which are potentially harmful.

5.2- Surface Weather Systems and Pollution:

There are two basic types of surface system, low pressure and high pressure. Low pressure systems represent vortices of rising air and surface air is drawn upwards. The net surface movement of air is anticlockwise into the centre of the weather system.

In mid-latitude and tropical areas, deep low pressure systems create a substantial pressure gradient resulting in strong winds. This will have the net effect of mixing pollutants and transferring them away from their point of production. For low level emissions of pollutants, this mixing will have the effect of reducing their concentration and amelioration localised harmful effects upon the biotic environment. In particular, cyclonic/frontal weather systems greatly reduce the buildup of toxic levels of the type of pollutants described in the next section on high pressure systems.

On the other hand, low pressure systems can create serious problems where large quantities are present in the atmosphere and are spread. Pollutants carried in this way are usually the type that reach the surface in non-gaseous form, mostly in precipitation a phenomenon known as rainout (Huggett & Meyer, 1981). Smoke and dust may either be carried along and deposited dry whent he wind velocity falls below the critical deposition velocity or act as condensation nuclei for precipitation to occur. In either case, constant air movement is require to keep solid particles in transport and as a result, particulate matter tends to be deposited relatively close to its source but examples do exist where strong winds, particulalry in the upper atmosphere, can carry material for some time and distance (see section on upper winds).

Two of the most serious problems in recent years have been caused by the spreading of pollutants in weather systems — acid rain and the radioactive fallout from the Chernobyl disaster of May 1986.

Acid Rain in Europe

On a local level, acid rain has been well documented over many years. Sulphur dioxide (SO_2) emitted from the burning of fossil fuels combines with water vapour to form sulphurous and sulphuric acids. Nitrous and nitric acids are also formed from the oxides of nitrogen. Although natural rain is slightly acid (around pH 5.6), these acids reduce it to around pH 4.1 in parts of central Europe and individual storms can be as low as pH 3.0. These have the following consequences for the area on which they are deposited.

— acidification of soils, reducing the nutrient availability and therefore fertility. In northern Europe, and northern North America, acid pollutants from rainfall has decreased the pH of the soil in an order of magnitude that would have taken thousands of years naturally (Pearce, 1987).

— acidification of inland lakes that have resulted in the reduction of fish stocks. In the seven main rivers of southern Norway, salmon stocks have been wiped out (Pearce, 1987).

— defoliation of forests in the Netherlands about 20% of trees were moderately or seriously defoliated and in West Germany 20% (Pearce, 1987).

— damage to infrastructure — acid attack on stone, concrete and steel structures weakens them and results in failure. In the UK estimates of annual damage due to acid rain range between 16 and 100 million (Greenpeace, 1988).

The main emitters of SO_2 the UK are listed below, but the pattern is similar for most other developed countries:

Source	Percentage
Power Stations	60.2
Other Industries	17.7
Domestic	8.9
Other Consumers	13.2

Table 4 UK SO_2 emissions. Source: Pearce, 1987

Emissions of SO_2 are carried by weather systems to areas much further than their immediate locations. Figure 3 shows the extent of sulphur emissions in Europe in 1987. The areas burning sulphurous brown coal in eastern Germany, Czechoslovakia, Poland and the USSR are clearly visible

Figure 4 shows the pattern of acid rain over north-western Europe. There are strong concentrations in the low countries and Scandinavia — where SO_2 emissions are minimal. The source of this acid rain appears to be from the UK, a major "exporter" of SO_2. In 1982 it was estimated that some 55% of all sulphur emissions were carried on the prevailing south westerly wind into northwestern Europe. In contrast, central Europe, which has a more continental climate and experiences more high pressure systems and stable weather tends to experience higher

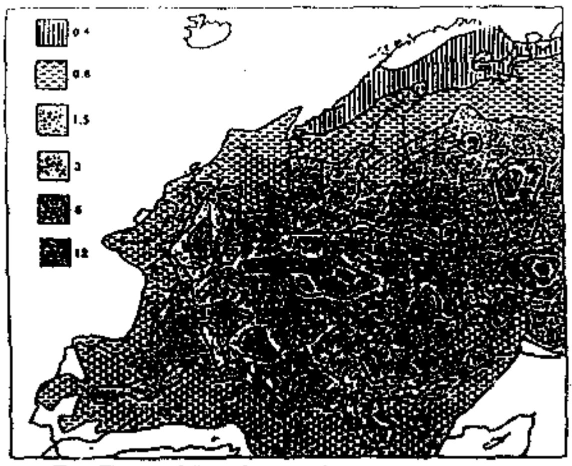


Fig 3 The total fallout of sulphur, in grams per square metre, over Europe in one year. Nitrogen shows a similar pattern

Acid Rain Pollution in North-western Europe

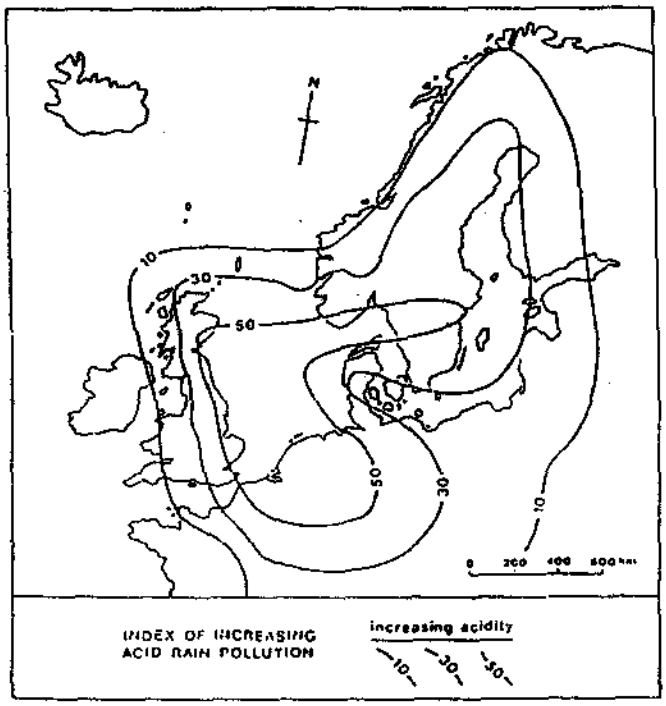


Fig 4 Generalised pattern of Acid Rain Pollution in north western Europe (Source not known)

levels of home produced acid rain in Bulgaria 76% of all emissions are deposited at home Yugoslavia 72%, Germany 67% and Hungary 62% (Pearce, 1982). This situation has not been helped by the building of taller chimneys to educe localised acid rain. The problem is simply transferred elsewhere

Figure 5 shows how different weather conditions can influence acid rain patterns. The map of the UK on the left shows the incidence of acid rain in January under anticyclonic conditions. As Britain is an island, moist easterly anticyclonic winds passing over the cool land surface in winter ofter cause rainfall. Most of the acid rain corresponds to the major centres of population where the SO_2 is produced. However under strong low pressure frontal conditions on the 21st of January, acid rain is much reduced, the SO_2 being transferred away north-westwards into Scandinavia.

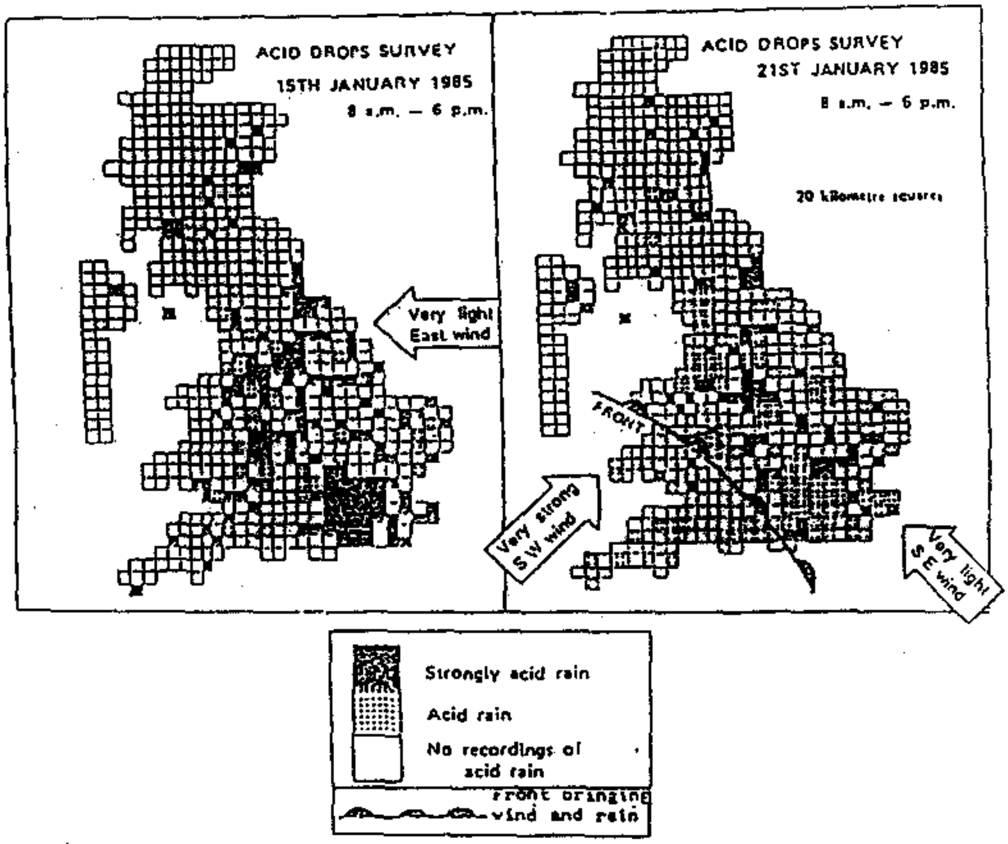


Fig 5 Results of a survey organised by the Royal Society for Nature Conservation on acid rain, January 1985

In the European Community, directives have been signed by members to reduce their emissions of sulphur dioxide and other gases producing acid rain. This includes Flue Gas

Desulphurisation (FGD) plants at power stations and the fitting of catalytic converters in new cars to reduce emissions of oxides of nitrogen. The technology exists to remove the vast majority of acid rain producing pollutants from the atmosphere, but it costs. Some richer European countries like Germany are committed tor educing SO_2 emissions by 70% by 2000 but the UK is only committed to a 33% reduction.

Eastern European countries, struggling with poor economies, are committed to only 3% reductions in emissions up to 2000 even though it is generally agreed that a 70% reduction would be most likely to offset the worst effects of the present high levels (Traynor, 1991).

For emergent developing countries the problem is even more acute. In order to compete in world markets, pollution control may not be high on the environmental agenda. In areas of South East Brazil, areas of sparsely populated rainforest have been defoliated in the Cubilao region (BBC, 1985). The action of acids in tropical climates is much faster and damage potentially more acute.

The Chernobyl Accident, 1986

Chernobyl is another example of how weather systems can carry pollutants over a wide area. In this case an experiment at the Chernobyl nuclear power plant in the Ukraine went wrong and led to the reactor core melting down and igniting, releasing radioactive gases into the atmosphere. The fire continued for six days and weather systems drove material into Northwestern Europe and the Western Mediterranean. Fallout in the immediate vicinity was highest and 135,000 people were evacuated as a consequence. The larges concentrations outside the USSR were experienced in Scandinavia where a high pressure system drove the radioactive cloud. Once radioactive isotopes were precipitated in rainfall, they passed into the human food chain through grazing cattle. Livestock movements were restricted for a period in some countries where unacceptable levels of radiation were detected.

6 High Pressure Systems

Unlike low pressure systems, most high pressure systems are characterised by light winds or still air. Under these conditions the atmosphere tends to be stable and little precipitation occur, with the exception of fog (see later). Such conditions lead to a cloud free sky, with radiation from the sun being able to reach the ground easily in the day, but heat being easily lost into space at night. This is due to the air being almost transparent to short-wave infra-red but surface geology and soil being able to absorb it more easily and re-raditat it at a slightly longer wavelength. This change results in hot days and cool nights and a pattern of weather that can cause serious pollution problems. This is best explained with the assistance of lapse rate diagrams.

Figure 6 a shows the conditions pertaining on a warm day during the late morning. The Environmental Lapse Rate (ELR) curve (which indicates the temperature of the atmosphere for any given height) is relatively constant. The Dry Adiabatic Lapse Rate (DALR) curve (which shows the temperature loss with altitude of a parcel of unsaturated air that may rise from the surface) is also marked. As the ELR is slower than the DALR, any parcel of air spontaneously rising from the surface is likely to sink back to ground level as it will be colder and therefore heavier than the surrounding air. This situation of stability results in air being held near the surface and under such conditions, pollutants are not dispersed very rapidly.

Figure 6B shows late afternoon/early evening temperatures. In this case the heating of the ground has caused the air in contact with it to be also heated, making the ELR close to the surface more rapid than the DALR. Any parcel of air rising from the surface will continue to rise spontaneously. In this situation of instability, rising air continues to rise until it becomes stable again. If sufficient vapour is present in the air, it may condense once the condensation level is reached and cause precipitation. In temperate humid climates on hot days and tropical humid climates, rain is quite a common end to the day.

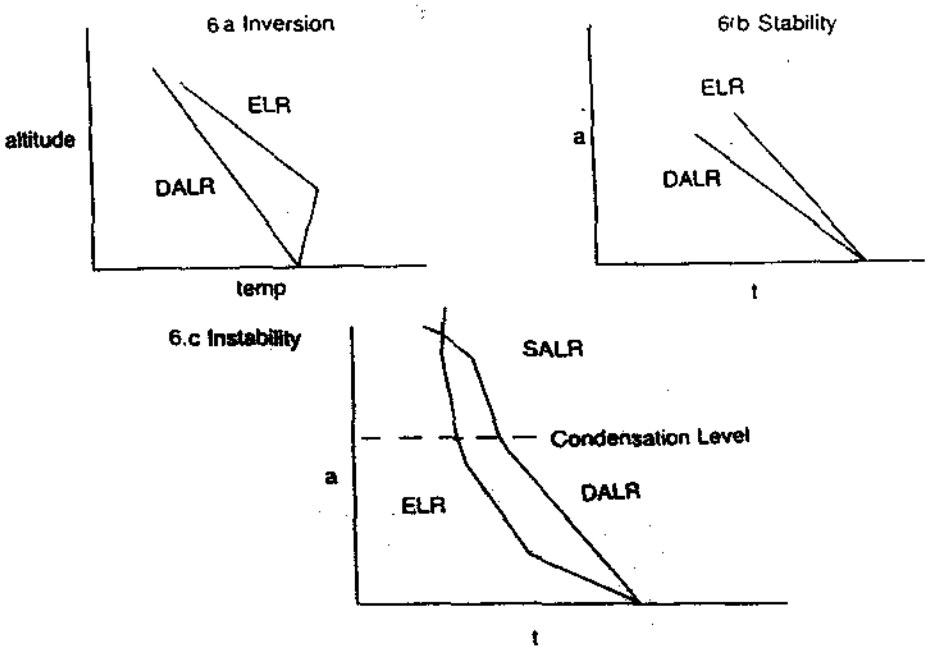


Fig 6 Generalised Lapse Rate diagrams for a hot day under anticyclinic conditions

From the pollution point of view, this may be considered beneficial as pollutants are cleared upwards or scavenged (Huggett & Meyer, 1981) from the air and deposited with the precipitation. Although this may clear the air of pollutants, it tends to transfer the problem elsewhere, by carrying the pollutants somewhere else or depositing them as acid rain.

Figure 6 c shows the night time situation. Heat is lost rapidly to space from the ground, and as a result, the ground absorbs heat from the atmosphere immediately in contact with it. An inversion results whereby cold air is trapped close to the ground and any pollution in it is unable to escape. In more temperate climates, chilling of the air cause the water vapour in the air to become saturated and condense to form fog — radiation fog. In many parts of the world where high pressure weather systems dominate the climate, inversions occur frequently and pollutants become trapped under the inversion layer. Inversion situations also occur in temperate climeates in winter but a reduced level of heating of surface air tends to occur due to short hours of daylight.

Trapping of air in temperate climates traditionally resulted in smog (smoke + fog). Britain first developed as an industrial nation based on coal as a source of energy, which was directly burned to provide heat for steam production. Where high pressure systems prevailed for a number of days during the winter months, the smoke became noxiously thick in industrial towns as it could not escape; called by the Londoners a "pea souper" as it was thick and green like pea soup. Water droplets combined with SO_2 to form an acid drops. In December 1952, a high pressure system remained static over Britain for almost two weeks. In that time the pH of fog was as low as 1.6 resulting in some 4000 deaths, mostly from bronchial complaitns (Brimblecombe, 1987). A consequence of this was Clean Air legislation which was copied by most Western European Countries, although problems still exist with the buildup of vehicle exhaust emissions under similar conditions.

However, the problem is still present in countries of Eastern Europe. In Czechoslovakia, the burning of sulphurous brown coal has resulted parts of Bohemia experiencing severe health management problems. The WHO's minimum annual limit for SO_2 deposition is 50 μgm^{-3} but in northern Bohemia it is around 100-170 μgm^{-3} and can be as high as 1000 μgm^{-3} in places. A third of children in northern Bohemia suffer respiratory problems, infant mortality rates are 30% higher than in Western Europe. (Traynor, 1991).

In warm temperate and tropical countries, a further problem is experienced due to the high levels of solar radiation: photochemical smogs. These were first identified in Los Angeles during the 1950s and 1960s where high levels nitrous oxide (NO) and nitrogen dioxide (NO_2) produced by vehicle exhausts were trapped under inversions. These form peroxacyl nitrate (PAN) under conditions of high solar radiation and are extremely toxic in concentrations as low as 10 parts per 100 million. 10 μdm^{-3} can cause visible damage to crops and even concentrations as low as 1 μdm^{-3} cause severe eye irritation to humans (Mellanby, 1972).

In Athens, problems caused by acid fog and PAN are now becoming acute. The photochemical cocktail known as *nefos* or "the cloud" consists of pAN and ground level ozone which can reach levels of nealry 400 mgm^{-3} of air — well above the 300 mgm^{-3} danger level (Smith, 1991).

The problems of pollution under high pressure conditions are accentuated at a microclimatic level and a later section discusses this.

7 Upper Air Streams

The upper air streams occur near the tropopause (10-18km above the surface) and have a rapid velocity of between 100 and 300 km/h. Any pollutants that are entrained into upper winds can be rapidly spread around the world. Pollutants can be incorporated into upper wind systems in two ways.

1. By being driven upwards by low pressure systems where air is forced upwards from the ground. The intensity of the upward force depends upon the circumstance. Mid-latitude depressions, particularly deep ones below 980mB can generate upward air movement and incorporation of polluted surface air into the associated jet stream. Ironically, it is in these latitudes in the northern hemisphere that the greatest levels of air pollution have traditionally been experienced.
   In tropical areas, deep depressions caused by conventional updraught also contribute to pollutants rising into the upper atmosphere.
2. By their nature most pollutants are seen to be harmful to the environment by their producers and attempts have been made to push the gases as high up into the atmosphere as possible by building high chimneys and using fans to assist the rise of hot gases. The intention is to use the more rapid upper wind velocities to dilute the concentration of pollutants as rapidly as possible.

Clearly, dilution of pollutants is desirable, but many conservationists now argue that if all industrialised countries take this policy, then this dilution effect will no longer apply and the global level of pollutants may rise to an undesirable level.

The most notable example of this at the current time is that of Carbon Dioxide. The ability of CO_2 to allow solar radiation to the surface but not allow the longer wave re-radiated heat from the ground to leave the lower atmosphere is well known (the Greenhouse Effect) and its effects are experienced routinely in urban areas as shall be noted later. More recently the influence of other greenhouse gases such as chloroflourocarbons (CFCs), methane, nitrous oxide and trophospheric ozone have also been studied as agents of global warming (Greenpeace, 1988). Although all are mixed by the movement of air int he atmosphere, they have reach levels within the atmosphere generally that give cause for concern.

The burning of fossil fuels and the decline of the world's forest areas have both contributed to a steady rise in CO_2 concentrations in the last half century. The long-term impact of the rise in global CO_2 levels is still uncertain. Although organisations like Britain's Meteorological Office and the USA's NASA Goddard Centre for Space Research both confirm recent rises in global temperatures, it is unclear whether these are due to levels of greenhouse gases or natural variations in global climate (Schoon, 1990).

The behaviour of smoke in the upper atmosphere is different to that of gases. The weight of particles is such that they will ultimately be precipitated at the surface. The igniting of oil wells during the Gulf War of early 1991 created a pall of smoke over the Gulf area and eastwards into Iran. However, participate matter and liquid hydrocarbon droplets reached the upper atmosphere. Two French climbers reported in April 1991 that a layer of oily snow 2cm deep had been found high up in the Himalayas.

8 Microclimate and Pullution

The most serious effects of air pollution are usually felt close to the point at which they are discharged into the atmosphere. Local climatic conditions may exacerbate adverse effects of pollutants upon the local environment, and in turn be altered by the presence of pollutants. This section will examine the influence of factors that influence climate on a local scale which influence pollution levels, and then deal more specifically with the urban environment.

8.1. Air movement and topography

Topography strongly affects the movement of air in most climatic regimes under anticyclonic conditions where there is still air and clear skies. Durng the night, colder air from higher areas, being heavy tends to sink into lower areas, there being no solar radiation to heat the ground and keep it aloft. In upland areas, the descent of air may be so rapid that it causes katabatic winds. Such winds are common in alpine areas. During the next day, the heating of the ground forces the cold air upwards and again in alpine areas creates anabatic winds. Figure 7 illustrates this.

The sinking of air into depressions tends to occur even if the topography is relatively gentle and rolling. The net effect of cloud air settling in basins is to create an inversion effect similar to that noted in a previous section. Some of the world's major pollution hit cities lie in natural basins where cold air becomes trapped: Athens, Los Angeles, London, Tokyo, Mexico City. In temperate climates, chilling of air at night causes fog which exacerbates the situation.

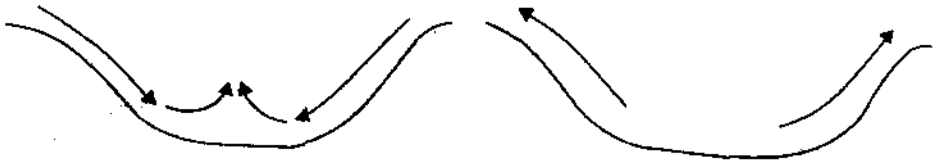


Fig 7 Anabatic and Katabatic Winds

Mexico City is a prime pollution trap being 2200m above sea level in a low atmospheric oxygen regime and being surrounded by high mountains from which clod air sinks during the night and is not cleared until well into the next day. It is growing rapidoy — present population is estimated as being around 28 million. It is estimated that around 11000 tonnes of pollutants are released into the atmosphere daily. Being in a natural pollution trap, in a climate experiencing hot, high pressure conditions, photochemical smog forms. Air pollution has been estimated at being 100 times over the WHO acceptable level, said to be the equivalent of smoking over 40 cigarettes a day (Knapp, 1987).

A similar problem was experienced in Los Angeles during the 1960s and the solution proved to be expensive: stringent laws requring the fitting of catalytic converters to cars were introduced, clean air laws for industry and the siting of power stations burning coal in sparsely inhabited New Mexico. The cost could easily be borne byt he local economy can stand (Erlich et al, 1973).

8.2 Urban Climates

Urban areas present the greatest problem with relation to air quality as most pollution originates in such areas. Urban areas represent a distinct climatic regime within themselves.

Element	Comparison with Rural Areas	
Temperature	winter minima	1 to 2%
	annual minima	0.5 to 0.8%
Radiation	total	−15 to −20%
	winter UV	−30%
	sunshine Hours	−5 to −15%
Wind	annual mean velocity	−20 to −30%
	calms	5 to 20%
Cloudiness	cloud	5 to 10%
	winter fog	100%
Precipitation	days with <5mm	10%
Atmospheric Composition	particulates	× 3.7
	CO_2	× 2.0
	SO_2	× 200
	N Oxides	× 10
	CO	× 200
	Hydrocarbons	× 20

Table 5 Generalised Climatic and Air Pollution Comparisons between Urban and Rural Areas (from Yapp, 1972).

The Heat Island temperature effect is due to the solid surfaces of the urban area absorbing and re-radiating infra red at a much higher level than vegetated countryside does, which causes the air close to the surface to be warmer. This is increased by the burning of fossil fuels, the heating of buildings and a greenhouse effect caused by raised levels of CO_2 and other greenhouse gases which create a pollution dome over large cities

The conditions shown in the table are mostly exacerbated by the presence of anticyclonic conditions, when winds are insufficiently strong to transfer heat away. However, the much higher temperatures close to the urban surface cause the air immediately above it to be unstable, and it is not unusual to fine a layer of unstable air trapped under an inversion layer. Fig 8a illustrates this under light wind conditions. Fig 8b indicates the type of pollution experienced (compare with Fig 8a.)

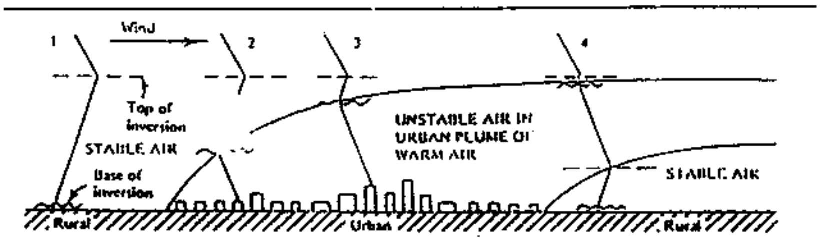


Fig 8a An elevated inversion due to stable rural air moving over a warm city at night. 1, 2, 3, & 4 are temperature profiles.

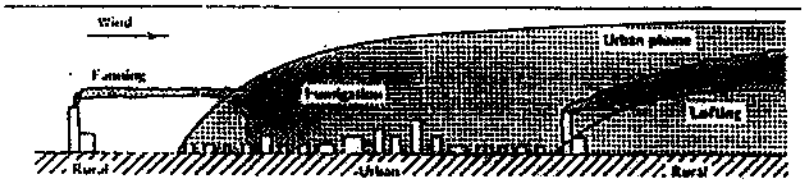


Fig 8b Behaviour of a smoke plume in relation to 8a. (Source: Oke, 1978)

Other climatic modifications within urban areas resulting from pollution is a greater incidence of light rain and fog as the increased particulate matter in the air provides condensation nuclei.

9 Conclusion

The term 'air pollution' is used to encompass many areas of environmental degradation through the medium of the atmosphere. The ability of Man to ameliorate the damage being caused is very much dependent upon which scale of pollution is looked at; local scale pollution can be eased by the actions of single governments in a relatively short space of time while regional and global problems take an enormous amount of planning and cooperation. However, the general acceptance of cooperative responsibility which has been seen in recent years (particularly at the vienna and Montreal Conferences) suggests that the problem is being taken seriously and while the effects of past unplanned development will be felt for many decades to come, the international community have already made important steps in the direction of cleaner, more environmentally sensitive and therefore more sustainable development.

Although the production of pollutants is at the hand of man, their distribution depends entirely upon global, regional and local climates. In broad terms global and regional weather systems tend to move pollutants from their point of production and dilute them whereas more local conditions such as inversions and the katabatic effect tend to concentrate them.

This knowledge has important practical implications. Whereas many countries have relied in the past on diluting the concentration of air pollutants by driving them high into the atmosphere; for SO_2 and CO_2 emissions concentrations globally are now such that this policy is no longer practical. On a local level, uncontrolled emissions of any pollutant might prove problematic is the area is prone to inversions, particularly if it in a basin area.

Pollution is easy to track and research; paying for measures to control pollution and reduce the environmental and health consequences is a problem in countries seeking to widen their industrial base and unable to afford the stringent controls found in the USA, Japan or the European Community. For city areas, reduction of pollutants from vehicles and no smoke policies are essential, particulalry in countries with high atmospheric stability.

The second political issue air pollution raises is international. As pollution is carried by weather systems, the victims of pollution may not be the nations that produce it. There are two notable examples of this at the present time.

The Scandinavian countries of Norway, Sweden and Finland receive between 100 and 500% more sulphur pollution than they emit (Pearce, 1982) which is causing the kind of environmental damage noted earlier. Who will pay? The European Community, one source of the pollution, has undertaken to reduce emissions, but what about the Eastern European countries who are not able to reduce emissions so easily?

A second example concerns global warming. The majority if CO_2 emissions are from the developed world, yet should sea levels be raised as a reusit, it is the developing world that is most likely to suffer. Even a modest sea level rise of about 5m would wipe out the 75% of the land area of Bangladesh that is less than 5m above sea level.

Air pollution is a product of economic growth and progress, and it is not inconceivable that these can prevent may of the problems outlined in this paper. What man cannot control is the weather. At the heart of preventing the worst kinds of environmental damage is not the control of nature, but the control of pollution.

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