THE ENVIRONMENTAL EFFECTS OF AIR POLLUTION FROM THE ENERGY SECTOR IN SOUTH AFRICA

R GERSON, BSc (Elec Eng), WITS

Energy for Development Research Centre
Energy Research Institute, University of Cape Town

April 1992

Declaration

I declare that this dissertation is my own original work. It is being submitted in partial fulfilment for the degree of Master of Science in Engineering at the University of Cape Town. It has not been submitted before for any degree or examination at any university.

Signed by candidate

R GERSON

9th day of April 1990

Abstract

The literature and data describing the environmental effects of air pollution in South Africa were examined, with a focus on the effects that are produced by the use of energy. This examination consisted of three parts:

The emissions resulting from the use of the different fuels were calculated, with a complete sectorial and regional breakdown for pollution sources.

A review of the data obtained from pollution monitoring programmes conducted in South Africa was completed. It was found that while monitoring is conducted in various regions and urban districts, there are areas with recognised pollution problems, such as townships, where little or no monitoring has been conducted. Often the results of monitoring programmes were not published, or only available in unprocessed form.

The literature describing environmental effects related to air pollution was reviewed. The number of studies pertaining to South African environments was found to be limited and tended to focus on certain areas, while neglecting others.

Areas requiring further study and research were identified.

Acknowledgements

I would like to thank the following:

Dr Anton Eberhard for his supervision of this dissertation in its initial stages and for criticism of later drafts chapters.

Professor Dutkiewicz for his supervision of this dissertation until its completion, his criticisms of draft chapters, and guidance.

The staff and postgraduates of EDRC and ERI for their support, and especially Glynn and Mark B. for their patience and help.

Table of Contents

List of Tables

List of Figures

Abbreviations and Acronyms

The following abbreviations and acronyms were used in the text:

ha	hectare
kt, Mt	thousand and million tonnes (metric)
MJ, PJ	10^6 and 10^{15} Joules
MW	megawatt
yr	year

Chapter One

Introduction

The pollution produced by various human activities is one of the primary causes of environmental problems. One of the major sources of pollutants is the use of energy. Air pollution, especially that caused by the combustion of carbon-based fuels (coal, petroleum and biomass), is resulting in a deterioration of atmospheric quality. The atmosphere is an integral component of the global ecosystem, and terrestrial and aquatic ecosystems are sensitive to changes in its composition. The monitoring of these pollution levels and studies of their effects is now given a high priority in many countries

In South Africa air pollution levels have been monitored since the 1950s. This monitoring was first conducted in cities and later extended to other areas. The effects of air pollution on South African environments have only been studied more recently. This thesis reviews and summarises the data and literature from these investigations in order to gain an overview of these effects and their relation to energy use.

1.1 THE FORMATION OF POLLUTANTS

Carbon-based fuels release specific types of pollutants when they are burnt. The conditions under which combustion occurs and the constituents of the fuel are the principle factors which determine the exact nature and quantity of the products formed.

The pollutants produced directly as a result of fuel combustion are termed primary pollutants. The most important of these are described here.

1.1.1 Primary pollutants

The non-combustible mineral content of fuels gives rise to particulates, while smoke is formed by particles of unoxidised carbon from the fuel.

Oxides of sulphur (SO_x) occur when sulphur present in the fuel is oxidised. Normally most of the sulphur present in fuels is oxidised and the rest remains in the ash or char. The most important of these oxides are sulphur dioxide (SO_2) and sulphate (SO_4).

Nitrogen oxides (NO_x) are formed by the oxidation of nitrogen present in the atmosphere and in the fuel. The quantity of NO_x produced is influenced by the flame temperature, the air supply and the nitrogen content of the fuel.

The incomplete combustion of carbon-based fuels produces various hydrocarbons (HC_x). High combustion temperatures limit hydrocarbon emissions, while low temperatures increase their emission levels.

Carbon dioxide (CO_2) is the final product of carbon oxidation, and usually forms the most substantial part of emissions. Carbon monoxide (CO) is also of considerable importance.

Once pollutants are released to the atmosphere they may react with the other constituents of the atmosphere to produce secondary pollutants. Often the products of one reaction may participate in another reaction. Other compounds may not take part in any reactions and are removed by precipitation, settle out by gravity or are removed by impaction.

1.1.2 Secondary pollutants

The most important secondary pollutants are produced by two sets of reactions. Photochemical smog and atmospheric acid generation both produce products which are toxic to plants and organisms (these effects will be discussed later in this chapter).

Photochemical pollutants are formed in numerous reactions involving sunlight and several pollutants, NO and non-methane hydrocarbons (NMHC) being the two most important. The products include ozone and peroxyacetyl nitrate (PAN) - both strong oxidants - and various other compounds. The major source of NO is vehicle emissions and so photochemical pollution tends to occur most often in urban areas.

Acids are formed in the atmosphere in a number of reactions involving water vapour, sunlight, air, ions and various primary and secondary pollutants. These reactions can occur in various phases.

Gas phase reactions are responsible for producing nitric and sulphuric acids (HNO_3 and H_2SO_4) and inputs for other reactions (Wells,1987:4-6). SO_2, NO_2 and hydrocarbons can be oxidised to acids by ozone and various other chemicals. Other reactions occur in fogs, clouds and rain droplets (ERL,1983:46). Other possible reactions involve absorption onto solid particles.

Secondary pollutants may also occur in the form of aerosols. The most important of these are sulphates and nitrates, which are the ultimate result of the oxidation of NO_x and SO_x.

1.2 THE MAJOR ENVIRONMENTAL EFFECTS OF POLLUTANTS

Once present in the atmosphere, pollutants interact with their surroundings and have effects on the system with which they have contact. The magnitude of these effects depends on a variety of factors. These include the type and quantity of pollutant and the capacity of the natural system to dispose of or neutralise pollutants. The ability of the system to regenerate or repair any damage also determines whether a system can regain its equilibrium. Biospheric systems are exceedingly complex and even their most fundamental mechanisms are unknown, and moreover the projections of possible effects are often largely speculative.

The mechanisms of the three major environmental concerns related to air pollution - global warming, the consequences of urban-industrial pollution and the acidification of natural environments - are introduced here.

1.2.1 Global warming

The incoming rays of the sun are able to pass through the atmosphere and reach the surface of the earth. Most of these incident rays are absorbed, while the remainder is reflected. The earth re-emits some of the absorbed heat as infra-red radiation, and a fraction of this is absorbed by gases in the atmosphere.

This absorption of heat by certain gases in the atmosphere - the greenhouse effect - is responsible for maintaining biospheric temperatures which can support life. Atmospheric concentrations of certain of these greenhouse gases are increasing owing to anthropogenic emissions, and a consequent rise in global temperature is predicted. This in turn could lead to major disruptions in the workings of the global ecosystem.

Various gases have been identified as greenhouse gases, the most significant being CO_2, methane, nitrous oxide and the chlorofluorocarbons (including CFC-11 and CFC-12) (Hahn,1990:7). CO_2 is the most important of these gases, but others are becoming increasingly influential. Many are more efficient absorbers of heat than CO_2 and their atmospheric concentrations are rising at a greater rate. These gases are thought to account for 45% of observed global warming (see Appendix 1.1). Energy usage is thought to have contributed 43 to 60% of global warming derived from human activities.

Various climatic models have indicated that a doubling of the atmospheric CO_2 concentration would result in surface temperature increases of 1,5 to 4,5°C. Stratospheric cooling and an increase in global average precipitation would also result (IPCC,1990:142). A decrease in the area of sea-ice and seasonal snow cover is also predicted. Any alterations in rainfall, wind and temperature distributions would have profound effects on natural and managed ecosystems. The melting of the Antarctic and Greenland ice sheets and the thermal expansion of sea-water could cause a rise in sea-level and consequent inundation of coastal cities (IPCC,1990:264).

The magnitude of the possible effects depends on the quantity of radiative gases emitted, but also on a multiplicity of feedback mechanisms which could limit or enhance climatic instability. There are indications that positive feedback effects would override any stabilising influences (Leggett,1990:29).

1.2.2 Damage to vegetation

Many pollution compounds have been found to be phytotoxic (toxic to plants). The most important of these are sulphur and nitrogen oxides, and the oxidants formed by photochemical pollution, ozone and PAN.

The damage caused by the interaction between these pollutants and plant tissues depends on several factors. The most important of these are:

a) the type of pollutants and whether they show any synergistic effects;
b) the concentration of the pollutants;
c) the length of exposure;
d) the type of plant;
e) the age and lifespan of the plant; and
f) climatic and soil conditions.

Acute effects are the most thoroughly understood and generally result from exposure to concentrations of pollutants. Some of the typical effects are the localised destruction of tissue on an otherwise healthy plant (necrosis) and a loss of chlorophyll (chlorosis). Chronic exposure to low concentrations of pollutants can lead to reduced plant growth and certain other effects. If such effects are severe enough they may eventually lead to the death of the plant.

1.2.3 Human health

All pollutants can have some effects on human health, though the dose at which damage may occur varies widely according to the pollutant. Exposures to high concentrations of a pollutant for short periods will have different effects to those caused by lengthy exposures to medium or low concentrations. It is not known whether there is a linear relationship between exposure to pollutants and resulting effects on health and different studies have given conflicting results. It is clear, however, that certain population groups are at greater risk than others. Among these are the very young, the old and those with heart and lung diseases (El-Hinnawi,1980:58).

Sulphur oxides have been implicated in effects on the pulmonary system, increased frequency and severity of asthma and increases in the incidence of chronic respiratory disease (El-Hinnawi,1980:58). SO_x may also have synergistic effects with other pollutants, though these are still not described.

Little is known about the effects of NO_x on health, though NO_2 has been implicated in various effects on the respiratory system, including an enhanced risk of infection (El-Hinnawi,1980:61).

The most common effects of particulates are irritation of the eyes and the respiratory tract. Particulate pollution has been implicated as a cause of cancer of the respiratory and digestive tracts, as well as reduced lifespan and increased infant mortality (Stewart,1979:25). Smaller particles (less than 1 μm) easily penetrate deep into the lungs and are thought to be most responsible for irritation of the lungs and respiratory tract.

Particulates containing trace elements, such as heavy metals, may be involved in various toxic effects. The most important sources of these are lead compounds and particles emitted on the combustion of leaded petrol. Radionuclides contained in coal may also be released on combustion, though levels of these have not been measured for South African coals.

Ozone and PAN are the most important of the toxic pollutants produced in photochemical pollution. The effects of these oxidants vary, though there are some which are common. These include effects on the pulmonary system; eye, nose and throat irritation; nausea and headaches; and damage to lung tissue (El-Hinnawi,1980:63).

Carbon monoxide (CO) is a hazard only when it occurs in high concentrations in enclosed spaces, when it can lead to asphyxiation.

1.2.4 Acidification

The generation of acid precipitation in the atmosphere was discussed earlier. When these acids are removed from the atmosphere they come into contact with organisms or materials and they may then react and bring about chemical changes in that organism or object. These effects are known as direct effects.

Indirect effects occur when pollutants act on the ecosystem which in turn leads to effects on the organism or object. The mechanisms of indirect effects are very complex and not fully understood.

Acid precipitation has direct effects on plants, but is also one of the causes of soil acidification. The conversion of ammonia in the soil to nitrogen compounds (nitrification) is another. Agricultural practices where nutrients are accumulated in biomass and not returned to the soil can also lead to soil acidification.

The displacement of basic cations from soil particles by H^+ and Al^{3+} ions is thought to be the most important mechanism of soil acidification. The increased acidity of the soil, the decrease in the availability of nutrients and the increased mobility of toxic metals such as aluminium, can all affect the health of plants (ERL,1983:67). The impact is dependent on the geology, type of soil and vegetation and the use of the soil.

The major source of surface water acidification is the soil/soil solution of the catchment area. SO_2 forms elemental sulphur and various sulphur compounds when it is precipitated during dry periods and these compounds are oxidised to acids by rainwater. Accumulated nitric and sulphuric acids are freed when rainfall occurs and increase the acidity of surface waters. If the solution is not neutralised by contact with soil and bedrock, run-off with low pH can result. The buffering capacity of water bodies, i.e their ability to absorb acidity without changing pH, is determined largely by the concentration of calcium and magnesium carbonates.

Most species of aquatic plants and animals have specific pH tolerance ranges and sensitivity varies from species to species (McCormack,1988:40). Changes in water chemistry caused by enhanced acidity can also lead to the death of biota. Increased acidity in streams in Europe has been correlated with a reduction in the number of fish and bottom-dwelling (benthic) species (ERL,1983:103).

1.2.5 Other effects

Various other effects are associated with air pollution. The increased corrosion of building materials shortens their useful life and has a resulting economic cost. The deterioration of visibility is mainly an aesthetic problem, but it can have economic effects.

Corrosion rates are determined by various factors. Relative humidity, variation in ambient temperature and rainfall levels are amongst the most important (Tyson et al,1988:73). Particulate pollutants act to lengthen the wetting period by absorbing moisture and increase corrosion rates. Chemical pollutants increase the conductivity of the electrolytes causing corrosion, and break down the protective corrosion products which occur naturally.

Particulates deposited on power transmission equipment can form a conductive layer on insulators leading to electrical faults and eventual degradation of the insulating material.

The reduction of visibility in areas where tourism is of importance has direct economic consequences. Particulates and aerosols (from 0.1 to 1 μm) are not trapped by electrostatic precipitators and have the greatest ability to scatter light (Wells et al,1987:46). These particulates can reduce visibility and the amount of incident solar radiation received in an area. Air transport can also be affected.

1.3 AIMS AND STRUCTURE OF THIS DISSERTATION

The dissertation examines the literature describing the environmental effects of air pollution in South Africa. The focus is on air pollution which is derived from the use of energy. Research has been conducted by a variety of organisations, but no effort has been made to bring these related studies together, to determine the extent and quality of the available information.

Accordingly, the major aims of this project are to:

a) determine what information is available;
b) summarise and order this information to make it more easily accessible; and
c) conclude what possibly important effects or consequences have not been described, and require further research.

The remainder of this thesis is structured according to the type of data which is reviewed.

Chapter two describes fuel consumption patterns in South Africa and quantifies the emissions which result from this usage.

Chapter three reviews the results of atmospheric pollution monitoring programmes. These results are summarised and grouped according to pollutant type and the region where they were measured.

Chapter four reviews the studies which have examined the effects of air pollution on various ecosystems. The findings of these studies are organised according to the type of region and ecosystem.

Chapter five summarises the findings of chapters two, three and four. Some conclusions are made about the extent and quality of the available knowledge of these environmental effects.

Chapter Two

Energy Consumption and Pollution Emissions

Energy consumption patterns in South Africa show characteristics of both first and third world countries, with most energy requirements obtained from fossil fuels, mainly coal, while a large portion of the population relies on biomass fuels for their domestic energy needs.

Tables 2.1 and 2.2 give estimated primary and nett energy consumption in South Africa (including the "homelands"), where total primary energy usage is the energy contained in the fuel before it is converted into other forms, and final energy consumption is the energy delivered to the user.

The dominance of coal as a source of primary energy can be attributed to its abundance, ready availability and low extraction costs. The use of coal in the SASOL process has the effect of reinforcing the role of this fuel as the major provider of primary energy.

Energy Source	[PJ]	[%]
Coal	4179	77,2
Petroleum	694(1)	12,8
Renewables	441(2)	7,6
Nuclear	98	1,8
Hydro	30	0,6

(1) Includes petrol, diesel, oil, paraffin and LPG
(2) Includes estimated energy value of wood used in the production of charcoal

Table 2.1 *Total primary energy consumption by source (1989) (NEC,1990a:26; Geringer,1990 and International Energy Agency,1991:267)*

The importance of biomass fuels can be seen in the final energy consumption breakdown shown in Table 2.2. This 15% of final energy consumption is used predominantly in rural and peri-urban areas, where it provides for domestic energy needs in low-income groups.

Electricity accounts for almost a quarter of final energy usage and is becoming increasingly important as an energy carrier as it replaces coal as a source of energy in many applications. The dependency of certain sectors - especially the transport sector - on liquid fuels for their energy needs ensures a fairly constant contribution to final energy consumption.

Energy carrier	[PJ]	[%]
Coal	633	31,0
Petroleum	556	27,3
Electricity	476	23,3
Renewables	375	18,4
Town gas	1	-

'-' indicates a negligible contribution

Table 2.2 *Total final energy consumption by carrier (1989) (NEC,1990a:26 and Geringer,1990)*

Only those fuels contributing to air pollution will be considered here, and so the discussion is limited to the consumption of coal, petroleum and renewables. The use of each of these fuels is described in a separate sub-section, which includes an estimate of the pollutants produced by the use of that fuel.

2.1 COAL

2.1.1 Coal consumption

In 1989 the estimated total saleable coal production was 176,4 million tonnes. Of this total, exports amounted to 47,7 million tonnes and local consumption 128,7 million tonnes. Most of this consumption was of bituminous coals, with anthracite contributing 4,2 million tonnes.

Sector	[Mt]	[%]
Electricity generation	73,34	57,0
Synfuels	35,22	27,4
Industry	5,59	4,3
Metallurgic	7,95	6,2
Households and merchants[1]	6,15	4,8
Transport	0,16	0,1
Mining	0,29	0,2
Total	128,69	100,0

(1) The majority of the coal consumed in this category is used in small scale industry and commerce

Table 2.3 *Sectorial breakdown of coal usage (1989) (Geringer,1990; NEC,1990a:17 and NEC,1990b:17)*

The electricity generation industry is the single biggest consumer of coal, and most of this total is used in Eskom power stations. At the end of 1989 there were 18 Eskom coal-fired power stations in operation, with a total installed capacity of 29 881 MW (ESKOM,1990:12). Further generating capacity was made up of oil-fired, hydro-electric, pumped storage and nuclear stations. The total installed rating of power stations operated by municipalities was 2 062 MW of which 1 543 MW was coal fired (UMESA,1989:481).

Coal used for the production of synthetic fuels is consumed in the three SASOL plants (SASOL I is situated at Sasolburg and SASOL II and III are situated at Secunda). These plants use the Fischer-Tropsch process for the liquefaction of

coal. In this process coal is gasified and the gas is cleaned and purified. A catalytic reactor is then used to synthesise hydrocarbons, and the liquid product is fractionated to separate the different components. Some of the by-products of the process are utilised as raw materials for other processes. Virtually all town gas is produced by SASOL and coal used in it's manufacture is included in the total for synthetic fuels manufacture, as is that consumed in the production of petrochemicals.

Industrial coal consumption includes that used in the chemical (excluding oil-from-coal synthesis and petrochemicals), non-metallic minerals, manufacturing and commercial sectors. In this sector coal is used mostly in boilers for steam generation and heating. Coal used for feedstock in chemical processes accounts for approximately 700 000 tonnes (LHA,1990:61).

In the metallurgical sector coke and coal are used in the reduction of ore, while mining industries use coal in boilers and for smelting. Coal used by steam locomotives still accounted for 32% of the nett energy consumption of rail transport in 1988, but locomotives are being phased out for economic and environmental reasons (LHA,1990:85).

National Energy Council (NEC) statistics give the domestic consumption of coal as 1,64 million tonnes in 1988 (Geringer,1990). The use of coal for domestic energy supply is most common in township and peri-urban dwellings, with 47 and 53% of households in these respective sectors using coal (Eberhard,1990:336). Fossil fuels have also replaced traditional fuels, such as wood, in areas where they have become scarce and/or expensive and 12% of rural homeland households now use coal.

The regional consumption of coal is strongly related to the location of the major coalfields. Hence, for example, the most important chemical and metallurgical manufacturing complexes are situated in close proximity to the sources of coal. South Africa has 18 major coalfields, most of which are concentrated in the main Karoo Basin (an area taking in parts of the Southern Transvaal, the Orange Free State and Northern Natal). There are other fields in the Northern Transvaal and the Eastern Cape, but these are smaller (Mehliss,1990:43).

2.1.2 Pollution emissions due to coal use

The quantity and type of pollutants produced by burning coal are largely dependent on the constituents of the fuel, which varies more widely in coal than in other fossil fuels. Of all the fossil fuels, coal is the most polluting. This is due to its high mineral and inorganic chemical content relative to other fuels and also because it is difficult to obtain the optimum conditions for its combustion.

South African coals have a high ash content (around 20%) and a relatively low sulphur content, typically 1%, when compared to the coals of other countries which usually range from 2% to 3%. This results in proportionately less SO_2 being produced, but increased particulate emissions. Table 2.4 shows the total quantities of the major pollutants which are produced by the use of coal (the assumptions used in the calculation of these emissions appear in Appendix 2.1).

Sector	SO_2 [kt]	NO_x [kt]	CO_2 [kt]	Particulates [kt]	HC_x [kt]	CO [kt]
Electricity generation	1 393	660	147 902	44	11	37
Synfuels[1]	3	6	35 905	1	246[2]	-
Industry	179	51	20 680	281	9	28
Metallurgical	151	60	17 490	310	4	8
Mining	6	2	638	11	-	-
Transport	3	-	352	2	2	7
Domestic	31	2	3 608	16	16	74
Total	1 766	781	226 575	665	288	154

'-' denotes a contribution of less than 500 tonnes

(1) SASOL II and III only

(2) Els (1990:9)

Table 2.4 *Sectorial pollution emissions due to coal consumption (1989)*

Electricity generation produces proportionately more oxides of nitrogen and less hydrocarbons and carbon monoxide per unit of fuel than other sectors. This is largely due to the high temperatures and generally high efficiency of utility boilers, which aid the formation of NO_x, but limit hydrocarbon and CO emissions.

In power stations, particulates present in the exhaust gases are removed by electrostatic precipitators (ESP's) which have efficiencies ranging from 96 to 99.9%. These are the only pollutants removed from power station flue gases. The large amounts of ash produced by coal combustion in power stations - approximately 18,3 million tonnes in 1989 - creates a sizeable disposal problem which also has various environmental implications.

No data was available for SASOL I, but production from this plant is small in relation to the other two plants. The non-methane hydrocarbons emissions from SASOL II and III are thought to be small due to recycling and flaring (Reynolds, 1991), though fugitive emissions (emissions occurring due to accidents and leakages) are unquantified and may be substantial. Els (1989:9) estimated hydrocarbon emissions from the three SASOL plants for 1987 at 245 527 tonnes, which would make SASOL's contribution to total hydrocarbon emissions amongst the largest of any source.

Domestic coal burning usually occurs under conditions which are far from optimal, and even commercially available domestic coal burning stoves tend to have low combustion and heat utilisation efficiencies (Dickson and Baldwin, 1990:201). The estimates used here were conservative, and in reality the conditions for combustion are probably less favourable. The relatively high levels of CO emissions are indicative of the poor combustion efficiencies.

2.2 PETROLEUM

Petroleum products include a wide variety of waxes, tars, oils (crude and distilled) and gases. These products have a large variety of uses, but only the use of petroleum products for combustion purposes will be considered.

2.2.1 Petroleum consumption

Access to official statistics on the import, synthesis and consumption of petroleum fuels is restricted and no statistics are available to the public. The estimates of the International Energy Agency (IEA) for total consumption of the major liquid fuels were used here. Six types of fuel are distinguished: residual fuels; diesel; petrol; liquid petroleum gas (LPG); paraffin and jet fuel. It was necessary to estimate the

sectorial breakdown of petroleum fuel use. This was done using the information in LHA (1990), Borchers and Eberhard (1991), Eskom (1990) and UMESA (1989).

In Table 2.5 it can bee seen that the transport sector accounts for the major share of liquid fuels consumption (75% of all fuels by mass). The majority of this is petrol used in light and medium vehicles, and diesel used in trucks and other heavy vehicles. Jet fuel used in air transport make up a relatively small amount of the total consumed in the sector (7% by weight). A negligible amount of petrol is used in small generators.

Industrial uses of petroleum include fuel for furnaces and boilers, and heating and cooking in the commercial sector. The agricultural consumption of liquid fuels - mostly diesel - includes use in engine-driven agricultural equipment, conveyer equipment and pumps, and generators. Diesel is also used in the mining sector in underground and surface transport.

Domestic paraffin consumption is principally for lighting, heating and cooking. The use of LPG in homes is not widespread and is concentrated in certain regions. The small amounts of petroleum fuels consumed by the electricity generating sector are mainly used in back-up systems, such as gas turbines and diesel sets, though some residual oil is used for boiler start-up.

Sector	LPG [kt]	Petrol [kt]	Jet fuel [kt]	Paraffin [kt]	Diesel [kt]	Residual fuels [kt]
Electricity	-	-	-	4	-	-
Domestic	136	-	-	410	-	-
Mining	-	-	-	-	845	-
Industrial	112	-	-	46	-	950
Agriculture	-	-	-	-	845	-
Metallurgical	-	-	-	-	-	106
Transport	-	5 909	777	-	3 942	-
Total	248	5 909	777	460	5 632	1 056

Table 2.5 *Estimated sectorial fuel consumption (1989) (IEA,1991:47; Borchers and Eberhard,1991; LHA,1989)*

2.2.2 Pollution emissions due to petroleum use

Table 2.6 shows sectorial sources of pollution resulting from the use of petroleum fuels. Assumptions and information used in their calculation can be found in Appendix 2.2. It is clear that petroleum fuels produce proportionately less SO_2 and particulates per unit of energy than coal. This can be attributed to their lower sulphur and mineral contents.

Sector	SO_2 [kt]	NO_x [kt]	CO_2 [kt]	Particulates [kt]	HC_x [kt]	CO [kt]
Electricity generation	-	-	13	-	-	-
Industrial	11	8	3 496	3	-	1
Metallurgical	1	1	336	-	-	-
Mining	5	26	2 680	13	16	7
Agriculture	5	26	2 680	13	16	7
Transport	39	236	33 383	61	276	2 356
Domestic	4	1	1 709	1	-	-
Total	65	298	44 297	91	308	2 371

'-' denotes a contribution less than 500 tonnes

Table 2.6 *Sectorial pollution emissions due to petroleum fuel usage (1989)*

Emissions from road transport have certain characteristics which result from the predominance of the combustion engine. The relatively large proportion of NO_x emitted is due to the high combustion temperatures which encourage their formation. HC_x emissions are derived from unoxidised hydrocarbons releases due to inefficient combustion and to evaporative losses from vehicles and from the fuel dispensing system. Untuned engines, especially diesel engines, can release high quantities of unoxidised carbon compounds and soot in emissions.

The use of lead compounds in petrol to enhance octane rating and prevent knock, results in the release of particulate lead on combustion and elemental lead

emissions totalled approximately 3 400 tonnes in 1989 (based on IEA statistics for petrol consumption and an average lead content of petrol of 0,4 g/l).

2.3 RENEWABLE FUELS

2.3.1 Renewable fuels consumption

Renewable fuels include fuelwood, wood-wastes, bagasse and agricultural wastes. Charcoal produced from wood is also included in this category. The existing statistics are, at best, rough estimates and there is very little data on how renewable fuels are used. NEC statistics (1989) for the consumption of wood, wood-waste, bagasse and charcoal, which appear in Table 2.7, are based on the estimates of various authors, and projections.

Fuel	Energy value [PJ]	Mass [Mt][1]
Wood	295	16,67
Wood-wastes	17	1,03
Bagasse	40	5,71
Charcoal	23	0,77

(1) Calorific values: Wood 17,7 MJ/kg; Wood-waste 16,5 MJ/kg; Bagasse 7 MJ/kg; Charcoal 30 MJ/kg

Table 2.7 *Energy value and mass of biomass fuel consumption (1989) (NEC,1990b:43)*

By far the most important of these fuels is wood. It is estimated that approximately half of South Africa's population living in rural areas are dependent on wood as their main source of energy for cooking and heating. In addition a fifth of the population in urban and peri-urban areas relies on wood as fuel for domestic energy needs (Aron et al,1989:4).

Wood waste and bagasse may be burnt as waste or to provide energy for other processes, as sometimes occurs in the sugar processing and wood pulping industries.

2.3.2 Pollution emissions due to renewable fuels use

The emissions due to the combustion of renewable fuels are shown in Table 2.8 (see Appendix 2.3 for the method of calculation).

The high proportions of hydrocarbons and carbon monoxide released by the combustion of biomass fuels are due to the properties of biomass fuels and the generally poor combustion efficiencies of open fires and most wood burning stoves. In addition, where biomass wastes are burnt as a method of disposal, little attention is paid to the efficiency of the combustion process.

Low temperatures allow the volatiles - a variety of chemical compounds and hydrocarbons - to escape without being oxidised, increasing hydrocarbon emissions. These same low temperatures limit the formation of NO_x. Biomass typically has little sulphur content, so sulphur dioxide emissions are small.

Pollutant	Domestic [kt/yr]	Industry [kt/yr]	Total [kt/yr]
SO_2	13	5	18
NO_x	82	35	117
CO_2	15 021	6 438	21 459
Particulates	386	165	551
HC_x	330	141	471
CO	375	160	535

Table 2.8 *Sectorial pollution emissions due to renewable fuels usage (1989)*

Chapter Three

Pollution Monitoring Data

Pollution levels are most often described as the average value of instantaneous concentration measurements taken over a set period of time. For example, a 24-hour average would be the average value of all the instantaneous readings taken over 24 hours. Data may also be described by centiles (the pollutant level at which a certain percentage of all readings have lower values). Pollutant concentrations are measured in parts per million (ppm), parts per billion (ppb) or $\mu g/m^3$ ($\mu g/m^3$ are used here). Smoke concentrations are described by a soiling index (S/m^3) - a measure of the soiling that occurs on a filter when an air sample is passed through it. When converting soiling index to atmospheric particulate or smoke concentration, natural background dust levels must be taken into account (conversion factors for various pollutants appear in Appendix 1.2).

In South Africa there are no maximum limits for atmospheric pollutant concentrations. The Department of National Health and Population Development (DoH) has guidelines (Table 3.1) which are based on the standards of various countries and organisations, such as the United States' Environmental Protection Agency (EPA) and the World Health Organisation.

Pollutant [$\mu g/m^3$]	Monitoring period			
	1 hour	24 hour	Monthly	Annual
SO_2	780	255	130	80
NO_x	1080	540	300	270
O_3	240	100	60	-
NMHC	260	130	100	40
Pb	-	-	-	2.5
Dust particles	350	150	-	-
Smoke [S/m^3]	-	50	-	30

Table 3.1 *DoH guidelines for air pollutants (DoH,1990:17 and Buys,1992)*

A general guideline for other pollutants is that they should not exceed 1/50th of the Threshold Limit Value (TLV) concentration provided by the American Conference of Government Industrial Hygienists for air in indoor workplaces (DoH,1990:18). Data obtained from the monitoring of pollution levels is also often compared to the standards of other countries, and the EPA standards are the most commonly used (see Appendix 1.3). Guidelines for pollutant levels in stacks also exist.

3.1 THE EASTERN TRANSVAAL HIGHVELD AND ADJACENT REGIONS

The Eastern Transvaal Highveld (ETH) is situated to the east of the PWV complex, has an area of approximately 30 000 km^2, and borders on the northern Orange Free State and northern Natal. 70% of the region consists of grassland and the remainder is used for crops or forestry.

Some of the most important coalfields in the country fall within its boundaries, making it a prime site for industries which consume large quantities of coal. As a result the concentration of industries is amongst the highest in the country. The various pollution sources in the region include: coal fired power stations; smelters; two Sasol plants; fertilizer factories; plastic, explosives and general chemicals manufacture; and many smaller specialized factories.

The climatology of the region is unfavourable for the dispersion of pollutants, with frequent surface inversions (Tyson et al,1988:37). This factor, combined with the concentration of low level pollution sources, creates the potential for a severe pollution hazard.

This hazard has been recognised and the monitoring of pollution levels in the region is given priority by a number of organisations. The pollution monitoring stations in the ETH are maintained by Eskom, the Atmospheric Sciences division of the CSIR, the Department of Environment Affairs, the Hydrological Research Institute, the Department of Water Affairs and the South African Forestry Research Institute (Tyson et al,1988:60). Eskom is the only organisation that monitors ambient atmospheric concentrations and deposition levels. Monitoring also takes place in the north-eastern Free State and Natal.

38 exceedences of the hourly guideline and eight of the daily guideline (see Appendix 1.4). There were no annual average concentrations exceeding the annual guideline.

Turner (1990) analysed the data obtained at Eskom monitoring sites from 1983 to 1988. The results from 22 sites in the ETH and adjacent regions are summarised in Table 3.2. Exceedences of the hourly guideline occurred at six sites, while the daily average guideline was exceeded at two sites. The maxima and the highest averages all occurred at two monitoring sites, Kriel and Komati, which are situated in the central region of the ETH. Monthly, annual and five-year period averages were well below the DoH guidelines.

Period	Type of measurement	SO_2 concentration range [$\mu g/m^3$]
1 hour	median	5,2 - 16,4
	99th centile	28,9 - 348
	maximum	213 - >1300(1)
24 hour	median	6,8 - 22,4
	99th centile	22,4 - 193
	maximum	36,4 - 419
Monthly	median	7,3 - 30,7
	maximum	14,3 - 76,7
Annual	maximum	9,1 - 45,2
Period	mean	7,5 - 34,6

(1) Value out of range of monitoring equipment

Table 3.2 *SO_2 concentrations in the ETH and adjacent regions (1983 to 1988) (Turner,1990:33)*

Using various methods, Held and Pretorius (1987:83) analysed Eskom SO_2 monitoring data obtained from 1979 to 1983. The data was analysed initially for the first 24 months and then for the full 49-month period. An increasing trend in ground-level SO_2 concentrations was shown for both periods. An analysis of the same data by Tyson et al (1988) indicated a significant increasing trend for SO_2 concentrations.

Turner and Rorich (1986) studied the effects of the installation of new power stations on ambient concentrations of SO_2 at nine sites. Data for SO_2 concentrations and wind direction for three complete 12 month periods (1979/1980, 1980/1981 and 1984) was analysed. Exceedences of a 130 $\mu g/m^3$ (50 ppb) level showed an increasing trend for the years examined - with the exception of levels at Grootpan and Bethal - demonstrating the impact of new power stations (Table 3.3). Ground level sources, principally coal discard dumps were thought to be responsible for the levels experienced at Grootpan (Turner and Rorich,1986:13). A similar analysis of data for 1985 and 1986 showed a levelling off of SO_2 concentrations in these years (Tyson et al,1988:50).

Site	Number of hours where 130 $\mu g/m^3$ hourly concentration is exceeded				
	1979/80	1980/81	1984	1985	1986
Arnot	69	59	338	129	336
Bethal	14	40	20	46	117
Elandsfontein	110	158	828	74	275
Grootpan	256	846	174	104	89
Hendrina	25	26	76	38	74
Komati	63	59	265	349	712
Kriel	33	87	204	132	230
Rockdale	12	23	57	21	88
Wildebeest	11	13	31	64	78
Total	593	1311	1993	957	1999

Table 3.3 *Number of hours per year that hourly SO_2 concentrations in the ETH exceeded 130 $\mu g/m^3$ (50 ppb) from 1979 to 1986 (Tyson et al,1988:51)*

Turner (1990:14) found an overall increase of 15,4% in SO_2 concentrations in the central ETH from 1983 to 1988. This increase correlated with the 12,4% increase in electricity generation in the region. Sites on the boundary of the ETH showed similar trends (Turner,1990:15).

3.1.2 Aerosols and particulates

Sulphates were monitored at Elandsfontein and Verkykkop during 1985 and 1986 (Wells et al,1987:39) in order to determine SO_2 to SO_4 conversion rates. Mean sulphate values for the 19 month monitoring period were 4,5 and 7,0 $\mu g/m^3$ at Elandsfontein and Verkykkop respectively.

Nephelometer readings made by Eskom from 1983 to 1988, indicated that suspended particulate levels were well within the DoH guideline (Turner,1990:24). The largest annual mean concentration for the period was 36 $\mu g/m^3$.

Nephelometer readings taken by Eskom at Elandsfontein and Slangheuwel and CSIR particulate measurements taken at Slangheuwel, during 1985 and 1986 were analysed by Wells et al (1987:50). The results indicated that the upper limit of visibility was determined by sulphate and nitrate concentrations (Wells et al,1987:52). Visibility was not degraded at either site: at Elandsfontein it was seldom less than 19 km, while at Slangheuwel it was generally better still.

Ground-level sulphate readings during this period did not correlate with the readings taken at two elevated sites - Verkykkop and Kendal - indicating that higher concentrations of sulphates were confined to a stratified layer which did not experience daytime mixing. The readings were attributed to the intersection of plumes or the existence of a layer of polluted air which is subject to variation in altitude (Wells et al,1987:73).

3.1.3 Nitrogen oxides

Measurements made by Eskom at Phoenix in 1985 indicated that nitrogen and sulphur oxides had common sources (Tyson et al,1988:53). Burning discard dumps were found to be major sources of ground level SO_2 and NO_x.

No NO_x levels above DoH guidelines were observed at four Eskom monitoring sites in the ETH and Vaal Triangle during the period 1983 to 1988 (Turner,1990). Annual averages for the five year period ranged from 10,7 to 17,6 $\mu g/m^3$ (see Appendix 1.5 for a summary of the data).

3.1.4 Ozone

Monitoring at five sites, from 1983 to 1988, showed that ozone concentrations frequently exceeded DoH guidelines (Turner,1990:20). The hourly guideline was exceeded at four out of five sites, and the daily, monthly and annual guidelines were exceeded at all the sites during the five year period (Table 3.4). Annual averages and mean averages for the five-year period were two to three times greater than the DoH guideline of 20 $\mu g/m^3$. 24,6% of all monthly means were above the recommended limit.

Sufficient data to determine trends was only available from Phoenix and Vaalpark, which showed marked increasing trends.

Site	Hourly [$\mu g/m^3$]			Daily [$\mu g/m^3$]			Monthly [$\mu g/m^3$]		Annual [$\mu g/m^3$]	Period average [$\mu g/m^3$]
	50th	99th	Max	50th	99th	max	50th	max	max	
Central ETH										
Komati	38,2	144,0	270	41,2	101	160	43,8	61,8	44,2	42,0
Elands	62,4	189,4	1072	65,8	154	218	67,0	94,4	68,8	68,0
Phoenix	38,6	128,2	714	40,2	87,0	172	43,2	65,8	44,8	43,2
Boundary ETH										
Verkykkop	52,4	148,4	226	52,2	134	146	59,8	87,8	60,2	56,8
Vaal Triangle										
Vaalpark	48,8	154,6	1560	51,0	117	276	52,6	89,6	63,8	54,4

Table 3.4 *Ozone concentration centiles and mean annual averages in the ETH (1983 to 1988) (Turner,1990:43)*

3.1.5 Rain chemistry

The pH of unpolluted rainfall may range from 4,9 to 6,5, but is usually around 5,6 (McCormick,1989:18). According to Turner et al (1990) the pH of unpolluted rain in inland South Africa is 4,5 to 4,6. During 1985/1986 (a dry year) rain pH ranged from 3 to 5,5 for 60% of samples and for the remaining periods from 3 to 5,5 for 80% of samples (Bosman,1990:8). pH readings from various sites appear in Appendix 1.6.

Botha et al (1990:3) reviewed the data obtained from the Eskom rain monitoring network from 1985 to 1989. An increase in pH at monitoring sites to the south-east of the PWV/ETH industrial region was noted from 1985 to 1989.

Wet and dry deposition, specifically hydrogen, sulphate, nitrate and ammonium ions, have been linked to the acidification of natural environments. There are no guidelines for deposition levels that may endanger ecosystems, though a 20 kg/ha/yr sulphate deposition rate has been postulated as the maximum deposition rate at which aquatic ecosystems can remain unaffected (Tyson et al,1989:63).

The mean sulphur deposition at Eskom's rain chemistry monitoring sites in the ETH (1985 to 1989) was 5,4 kg/ha/yr (Botha et al,1990:5). Similar levels of pollutants have occurred in the north-eastern Free State and north-western Transvaal, indicating that pollution is dispersed to these areas. The ratios of nitrate to sulphate depositions (0,4 to 0,6) obtained at these sites were typical of polluted regions (Botha et al,1990:3). Sulphate deposition levels at Topfontein (Vaal catchment) and Sabie (eastern Transvaal) have exceeded 20 kg/ha/yr (Appendix 1.7), which indicates a possible ecological threat (Tyson et al,1988:63).

Van Wyk (1990) studied the atmospheric depositions of 16 chemical species at three mountain catchment sites: D R de Wet (Sabie), Winterton (Cathedral Peak) and Jonkershoek (Stellenbosch). Cl^-, $SO_4^=$ and NO_3^- levels at Sabie and Cathedral Peak were high, indicating the influence of anthropogenic sources of pollution (van Wyk,1990:9) (see Appendix 1.8). The high deposition rates of basic ions at Cathedral Peak may help to increase the pH of otherwise strongly acidic deposition (van Wyk,1990:15).

3.1.6 Dry deposition

Dry deposition occurs when gaseous pollutants are deposited due to gravitational settling or removed by impaction. The exact mechanisms of dry deposition are still largely unknown and there are no well defined procedures for its measurement (Wells et al,1987:97).

Estimates for dry deposition made by Wells et al (1987:101) showed that the sulphate deposition rate calculated from the lower range of ambient SO_2 concentrations was greater than the highest wet sulphate deposition levels measured. Tyson et al (1988:65) estimated the annual dry deposition of sulphur at 11 to 52 kg/ha/yr, which contrasted with the 3,6 to 6,4 kg/ha/yr of wet sulphur deposition observed by Mrozek and Dunn (1986). It is possible, therefore, that dry deposition of certain pollutants exceeds wet deposition.

3.1.7 Other pollutants

A study conducted in the vicinity of Secunda showed the presence of various volatile organic compounds, but not in concentrations which exceeded DoH limits (Tyson et al,1988:60).

3.2 URBAN AREAS

The Earth, Marine and Atmospheric Sciences Division of the CSIR is responsible for collecting and publishing most data relating to pollution levels in urban environments. Municipally organised monitoring is conducted in various towns and cities, but concentrations of pollutants besides SO_2 and smoke are seldom measured. Monitoring usually falls under the jurisdiction of the Health Department of the local authority.

The following municipal authorities conduct independent monitoring: Bloemfontein, Cape Town and the Western Cape Regional Services Council (WCRSC), Durban, Germiston, Johannesburg, Port Elizabeth and Pretoria. Lead and NO_x levels are most commonly measured. Some results were published in the reports of the Medical Officer of Health for the different cities. Other monitoring is usually conducted on a short term basis as part of studies.

3.2.1 Sulphur dioxide

A programme for the monitoring of smoke and SO_2 is coordinated by the CSIR, which has collected and processed data since 1959. The network consists of 150 sites measuring smoke concentrations and 114 sites measuring SO_2 (Ellerbeck et al,1990), and all sites are maintained by municipalities. Data has been accumulated since 1959, enabling analysis of both short and long-term trends.

Monitoring data for 1988/1989 showed one exceedence of the annual guideline (Boksburg East), and 11 exceedences of the DoH monthly guideline (Durban 3, Alberton 1, Boksburg 3 and Springs 4) (Ellerbeck et al,1990). Exceedences of the 24-hour average occurred in Durban at the Halifax road site, at Boksburg East, and at the Springs City Hall. Maximum 48/72 hour concentrations and the range of monthly and annual averages in the various municipalities are shown in Appendix 1.9.

Ellerbeck et al (1990) analysed long term (1959 to 1989) and short term trends (1985 to 1989) in data obtained from the network. The results are summarised in Table 3.5 according to the type of land use (the full results appear in Appendix 1.10). Long term trends showed a slight decreasing trend (12 sites showed increases, 23 decreasing levels).

Short term trends showed a levelling off of concentrations in recent years, with increases or decreases occurring at small numbers of sites. The number of monitoring stations yielding insufficient data to detect any trend was significant for both long and short term trends.

Dominant land-use type	Trend	SO_2				Total sites	Smoke				Total sites
		I	O	D	*/-		I	O	D	*/-	
Central	Long	0	11	8	10	29	3	15	16	7	41
	Short	0	13	2	14	29	3	27	4	7	41
Industrial	Long	7	19	10	9	45	4	21	24	6	55
	Short	2	25	2	16	45	2	38	1	14	55
Residential	Long	5	16	5	12	38	2	24	12	14	52
	Short	1	16	3	18	38	1	32	3	16	52
Total	Long	12	46	23	31	112	9	60	52	27	148
	Short	3	54	7	48	112	6	97	8	7	148

I = significant increase
O = no significant change
D = significant decrease
*/- = insufficient data

Table 3.5 *Trends in winter SO_2 and smoke concentrations (according to land use type) (Ellerbeck et al,1990:16)*

3.2.2 Smoke

No smoke levels exceeding DoH guidelines for 24-hour and annual average smoke concentrations were recorded in the CSIR coordinated network during 1988/1989 (Appendix 1.11). Long term and short term trend analyses were similar to those for SO_2, though the long term decreasing trend for smoke was quite marked. 52 sites showed decreasing levels and nine sites showed increasing levels. The number of sites with insufficient data sets to determine a trend was again significant (see Table 3.5 and Appendix 1.12).

3.2.3 Photochemical pollutants

Photochemical pollutants have been monitored in Johannesburg, Cape Town and Pretoria, and more recently in Pietermaritzburg. The only data published consistently is that obtained by the Cape Town Municipality.

The main precursors and products of photochemical smog (NO_x, NMHC and O_3) have been monitored together when photochemical pollution has been studied.

The data for these pollutants are grouped here according to city. PAN levels have been monitored by Grosser (1990), who conducted monitoring in Johannesburg, Pretoria and Cape Town.

Johannesburg

Stevens (1984,1987a and 1987b) examined data obtained at four sites in central and greater Johannesburg, from May 1982 to August 1985. O_3 and NO_x concentrations were measured at all sites while CO, NMHC and some meteorological data were monitored at certain sites.

NO_x annual arithmetic means for the years 1982 to 1985 varied from 27,9 $\mu g/m^3$ to 31,1 $\mu g/m^3$ (Stevens,1987a:111). The mean hour average (06h00 to 09h00) for 1984/1985 was 108 $\mu g/m^3$ (Stevens,1987b:527).

Hourly average ozone levels were greater than the DoH guideline of 240 $\mu g/m^3$ on 22 occasions during 1984/1985: 21 times at the South Hills monitoring site and once at the Rondebult site. A maximum hourly average concentration of 604 $\mu g/m^3$ was recorded during this period. Variations in ozone concentration levels showed similar patterns at the Rondebult, South Hills and City Hall sites (Stevens,1987:529).

The EPA NMHC hourly concentration limit (157 $\mu g/m^3$ for 06h00 to 09h00) was exceeded for more than 50% of the time during the winter of 1983 (Stevens,1987b:525). During the same period the hourly limit was exceeded 955 times (Stevens,1987a:115). The 1984/1985 mean hour average (06h00 to 09h00) was 236 $\mu g/m^3$ (Stevens,1987b:527).

Cape Town

Dutkiewicz et al (1980) in a survey of pollution in the greater Cape Town region found that average annual O_3 concentrations varied from 34 to 64 $\mu g/m^3$ over five sites, while peak 15-minute concentrations varied from 90 to 568 $\mu g/m^3$ (Dutkiewicz,1980:13).

Data on photochemical pollutants has been collected at a site in central Cape Town since 1984 by the Cape Town City Council (CCC) Department of Health.

From 1984 to 1989/1990 there were no exceedences of the annual guidelines for NO_x, NO, NO_2 and O_3 guidelines (Appendix 1.13). In 1986, the single year that hydrocarbons were measured, an annual average of 72 $\mu g/m^3$ was obtained.

Loewenheim (1988) analysed Cape Town NO_x, NMHC and O_3 monitoring data obtained from a network of automatic samplers from 1984 to 1986 and conducted a spatial survey of these pollutants in April and May of 1987. NO_x levels were found to be highest near major roads, NMHC concentrations were less spatially dependent and O_3 levels were relatively uniform in their spatial distribution (Loewenheim,1988:iii). Concentrations of NO_x were highest in the city centre, while ozone levels tended to be highest in the suburbs.

Pretoria

NO_x, O_3 and NMHC concentrations were monitored in Pretoria from January 1986 to June 1988 as part of the CSIR's Motor Vehicle Pollution Project. All guidelines for ozone and non-methane hydrocarbon concentrations were exceeded during this period. From January 1987 to June 1988 monitoring of NMHC at two sites showed 12 exceedences of the monthly guideline of 100 $\mu g/m^3$ (Table 3.6). The annual mean was exceeded at both sites, and the maximum hourly and daily means were 12 times greater than the DoH recommended levels. Ozone monitoring at four sites showed that the annual guideline (20 $\mu g/m^3$) was surpassed at three sites and the monthly guideline (60 $\mu g/m^3$) was exceeded once. There were no exceedences of the NO_x standard during this time.

Pollutant	Max hourly mean [$\mu g/m^3$]	Max daily mean [$\mu g/m^3$]	Max monthly mean [$\mu g/m^3$]	Range of annual means [$\mu g/m^3$]
NO_x	1262	424	254	16 - 182
O_3	272	106	64	18 - 54
NMHC	3357	1607	654	40 - 155

Table 3.6 *O_3 , NO_x and NMHC concentrations in Pretoria (1987/88) (Bryszewski,1988:5-7)*

Grosser (1990) measured peroxyacetyl nitrate (PAN) levels in Pretoria, Johannesburg and Cape Town (Appendix 1.14). The monthly average daytime PAN concentrations varied from 0,10 ppb to 0,66 ppb (Grosser,1990:66). The maximum concentration of 8,56 ppb was measured in Cape Town, as was the highest daily average of 2,81 ppb (Grosser,1990:66-67).

PAN levels in city centres were found to be lower than levels in suburbs, this was thought to be due to the presence of high NO to O_3 ratios which slowed its formation, and measured levels were generally comparable to those reported in other cities in the world (Grosser,1990:66).

3.2.4 Lead

Atmospheric lead levels are monitored in Cape Town, Pretoria, Johannesburg, Durban, Bloemfontein and Germiston. As with photochemical pollutant monitoring, very little of the results of these monitoring programmes are made available and the CCC and the WCRSC are the only authorities to consistently publish this data.

The CSIR monitored atmospheric lead at 32 sites throughout South Africa. This programme was funded by the DoH, and its aim was to detect long term trends in pollution levels (Wells and Briggs,1989:162). Other monitoring has been conducted by independent researchers.

Von Schirnding and Fuggle (1984:5) measured roadside atmospheric, dust and soil lead concentrations in the Woodstock, Cape Town from May 1983 to June 1984 (Table 3.7 shows the mean lead concentrations at various sites). While there is a relationship between traffic volumes and lead levels, various other factors - recognised and unknown - make the relationship more complicated (von Schirnding and Fuggle,1984:5). The EPA quarterly atmospheric lead standard of 1,5 $\mu g/m^3$ was exceeded at the first three sites, while levels at site one were continually close to this standard (von Schirnding and Fuggle,1984:6).

Lead concentrations monitored by the CCC Health Department (Appendix 1.15) showed that only one site - City Hall - experienced levels approaching EPA standards, but these fell far short of the DoH guideline. The highest annual

concentration measured at six sites from 1987 to 1989 by the Western Cape Regional Services Council was 0,6 µg/m^3 (WCRSC Medical Officer of Health, 1987-1989).

Site	Traffic volume [vehicles/day]	Quarterly atmospheric Pb conc [µg/m^3]	Soil Pb conc[1] [µg/g]	Dust Pb conc[2] [µg/g]
1	>20 000	1,3-2,7	2 040	3 620
2	17 675	0,7-1,6	-	2 900
3	7 752	0,8-1,7	1 700	3 250
4	241	0,3-1,2	6 680	2 580
5	907	0,5-1,1	-	790
6	260	0,3-0,5	160	410

(1) Natural soil lead concentrations are usually in the range 2 to 200 µg/g
(2) EPA standard for the dust lead concentration is 500 µg/g

Table 3.7 *Traffic volume and mean atmospheric, soil and dust lead concentrations at six sites in Woodstock (Cape Town) (von Schirnding and Fuggle,1984:5 and 6)*

3.2.5 Carbon monoxide

The CSIR's Motor Vehicle Pollution Project included the monitoring of CO in Cape Town for 10 days in August 1985. The largest hourly mean was 27 209 µg/m^3 (EPA standard 40 000 µg/m3), and the largest daily mean 8 073 µg/m^3 (Bryszewski,1987a:6).

Monitoring for the same programme was conducted in Pretoria in the same year and from January 1986 to June 1988. A maximum hourly average of 21 114 µg/m^3 was observed, and annual averages ranged from 460 to 3 174 µg/m^3 for three sites (Bryszewski,1987b:4-5; and Bryszewski,1988:6).

3.3 TOWNSHIPS

In most townships, coal is the principal source of domestic energy, and this has often caused high atmospheric pollution levels. While certain townships are included in the network of SO_2 and smoke monitors (Ellerbeck,1990), Soweto is the only township where a wider variety of pollutants has been measured. This township had an estimated population of 1.5 million people in 1988 and lies 15 kilometres to the south-west of the Johannesburg city centre (Kemeny et al,1988:152). Electrification of this township commenced in 1981 and was mostly completed by 1983 (Turner,1984:2).

Intermittent monitoring has been conducted over the last twenty years by the CSIR, the Johannesburg City Health Department and Eskom, sometimes in cooperation and at other times autonomously. Measurements have been made of smoke, particulates, NO_x and SO_2 concentrations and haze (Table 3.8).

Pollutant	Site	Period	Reference
Smoke	Tladi Clinic	June 1972 to September 1973 April to August 1982	Kemeny et al (1988) and Walker (1987)
	Shanty Clinic	July to September 1983	
	Mofolo Clinic	April to August 1982	
Total Suspended Particulates	Jabavu Clinic	September to October 1978	Annegarn et al (1981)
SO_2 NO,NO_2 Haze	Shanty Clinic	June to December 1983	Turner (1984) and Turner et al (1984)
TSP	Gravimetric	August and November 1983	ibid
SO_2 NO_x TSP Haze	Shanty Clinic	July to August 1984	Rorich (1986) and Rorich (1988)
SO_2	Various sites	July to August 1987	Walker and Wells (unpublished)

Table 3.8 *Pollution monitoring in Soweto (After Annegarn,1990:16)*

3.3.1 Sulphur dioxide and nitrogen oxides

Turner et al (1984) monitored SO_2, NO and NO_2 levels at Shanty Clinic (Soweto) from June to December in 1983 and in July and August of 1984. SO_2 levels exceeded the one-hour guideline in July 1984, and the one and 24-hour standards were exceeded in October 1983 (Table 3.9), and the monthly guideline was surpassed in August 1983. NO_2 concentrations were never greater than half the EPA limit (Appendix 1.16) (Turner et al:1984:9). The accumulation of pollution, especially during winter months, was attributed largely to meteorological and geographical factors which caused frequent periods of stagnation, especially during winter months (Turner et al,1984:11).

NO_x and SO_2 levels decreased in spring months and this was thought to be partly due to meteorological factors. The reduction in SO_2 levels in spring months (Table 3.9) was ascribed largely to the decrease in coal use as the weather warmed (Turner et al,1984:9). NO_x levels were similar to those in the city centre and were thought to be due to the emissions of vehicles from the city centre and the major roads which border the township (Turner et al,1984:5).

Month/Year	Monthly mean [µg/m³]	Instantaneous maximum [µg/m³]	One-hour maximum [µg/m³]	24-hour maximum [µg/m³]
June 1983	99	1108	681	169
July	114	861	629	200
August	135	858	684	221
September	57	627	406	117
October	47	1635	1570	307
November	26	330	120	42
December	36	329	135	57
July 1984	100	1035	816	146
August	111	1443	720	156

Table 3.9 *Soweto SO_2 concentrations (1983 and 1984) (After Turner et al,1984:9 and Rorich,1986:30)*

3.3.2 Smoke

Kemeny et al (1988) described the monitoring of smoke concentrations by the Air Pollution Research Group, and the Atmospheric Sciences Division of the CSIR. Three clinics were used as sampling sites: Tladi, Mofolo and Shanty (Kemeny et al,1988:152).

Diurnal variations in pollution levels showed the effects of coal-fires being used before sunrise and at sunset, with peak concentrations occurring in the morning and evening. A seasonal variation was also detected, with higher peak concentrations occurring in winter than in warmer seasons (Kemeny et al,1988:162).

The annual average for the 1972/1973 period was 140 µg/m³ with a summer (October to March) average of 55 µg/m³ and a winter (April to September) average of 220 µg/m³ (Kemeny et al,1988:155). The DoH 24-hour guideline of 250 µg/m³ was exceeded at Tladi Clinic between May and September 1973 and

between April and August 1982 (Kemeny et al,1988:161) (Appendix 1.17). The same standard was exceeded at Mofolo Clinic between April and August 1982. During June 1982 daily means were above the DoH limit with an 86 and 90% frequency at the respective sites (Kemeny et al,1988:162).

3.3.3 Particulates

Annegarn et al (1981) sampled atmospheric particulates from three sites (the city centre, Soweto and Lanseria airport) in the Johannesburg area for three weeks in September/October 1978. A variety of elements were detected in the samples (Appendix 1.18).

Hourly sulphur concentrations demonstrated the effects of a large local source, with daily peaks at approximately 07h00 and 19h00 (Annegarn et al,1981:437). Lead, bromine and iron particulate concentrations showed peaks which coincided with maximum traffic concentrations (Annegarn et al,1981:439). It was concluded that levels for most elements in Soweto were three to five times higher than background levels or levels in the city centre (Annegarn et al,1981:439).

Monitoring of total suspended particulates in August and November of 1983 (Turner et al,1984:6) showed 23 and five exceedences of the 24-hour DoH guideline in the respective months. The monthly mean 24-hour concentration was 220 $\mu g/m^3$ in August and 124 $\mu g/m^3$ in November.

Chapter Four

The Environmental Effects of Air Pollution

Most of the available literature on the environmental effects of pollution in South Africa describes effects observed in the Eastern Transvaal Highveld (ETH) environment, with little devoted to the environmental effects of pollution in other environments and regions. An added feature of the literature is that in specific environments studies may focus on one particular effect of pollution, and ignore others. Both these shortcomings are inevitably reflected here.

4.1 THE EASTERN TRANSVAAL HIGHVELD AND ADJACENT REGIONS

The CSIR report "Atmospheric pollution and its implications in the ETH" by Tyson et al (1988) was the first report to assemble all the related studies and information on the ETH environments, and this section draws heavily on its findings. More recent studies and reports are also included. The investigations of environmental effects are classified according to the type or part of the ecosystem or environment examined i.e soil, surface waters, vegetation, human health and the effects on building materials.

4.1.1 Soils

Most soils in the ETH and adjacent regions are either strongly ($pH<5.2$) or moderately ($5.2<pH\leq6$) acidic. Generally the soils most likely to suffer damage are those with a sandy topsoil, while those with loamy or clay topsoils have been found to be less sensitive to acidification (Tyson et al,1988:76). Naturally acidic soils will lose base cations with the addition of relatively small amounts of acids.

The nett annual precipitated proton load (mainly H^+) has been calculated to be in the range of 39 to 66 kg/ha/yr (Tyson et al,1988:80), only 1 to 3% of the acidification typically caused by the application of ammonium fertilizers. This makes any effects on agricultural land caused by acidic precipitation difficult to

distinguish. Less is known about forest soils, though most are thought to be moderately sensitive.

4.1.2 Surface waters

The streams of the ETH form an integral part of the Vaal catchment area, which is the country's most important supply of water for use in industry, agriculture, households and power stations (Skoroszewski, 1990:9). Water quality not only affects natural ecosystems, but has implications for human water use. Polluted water may require treatment before it is potable and any increase in acidity may increase corrosion rates in pipes, thereby increasing costs.

Increased surface water acidity has a variety of causes. Drainage through acidified soils is a more significant cause of surface water acidification than the direct effects of atmospheric pollutants (Tyson et al,1988:81). Alkali content determines the susceptibility of a body of water to acidification, 10 mg/l being classified as very sensitive and 10 to 20 mg/l as moderately sensitive (Tyson et al,1988:81). Most water bodies situated in the ETH have high alkalinities, especially those that drain basalt slopes i.e. those of the Natal Drakensberg (Tyson et al,1988:82). Streams situated to the north can have lower alkalinities and are moderately to highly sensitive to acidification (Tyson et al,1988:82).

There are indications that sulphates may be accumulated in ETH catchments during dry periods, and released into streams when rain occurs, causing abrupt increases in water sulphate content (Tyson et al,1988:82). Monthly sampling of water from a stream near Dullstroom showed a decrease in pH and an increase in various ion concentrations during flooding (Skoroszewski, 1990:3).

Skoroszewski (1990) surveyed the benthic (bottom dwelling) communities and water chemistry in 25 streams along the Drakensberg Escarpment and found indications of damage to benthic communities, possibly caused by air pollution, in a group of streams (Skoroszewski,1990:3).

4.1.3 Vegetation

80% of South Africa's commercial forests lie on the eastern seaboard, and 50% are situated in a region which may be affected by atmospheric pollution from the ETH region (Tyson et al,1988:83). Pine, eucalyptus and some acacia are the species most commonly grown and most of the species studied have shown varying sensitivities to the more important pollutants (Tyson et al,1988:88).

While there has been no observed damage to plantations which can be directly linked to pollution of any form, various incidents of damage and decline in plantations have been reported. Incidents of chlorosis (a deficiency of chlorophyll, resulting in yellow-brown marking) and necrosis (localised tissue destruction) have been observed at sites throughout South Africa but no causes have been identified. Damage to two species of pine in the vicinity of Rosehaugh and Belfast may have been due to ozone, sulphur dioxide, or their synergistic effect, or to acid mist (Tyson et al 1988:85).

Olbrich and Kruger (1990) conducted a survey of plantations of Pinus patula in Swaziland, Transvaal and Natal in order to establish whether trees in areas under threat from pollution showed indications of increased needle damage. The survey did not reveal any noticeable increase in premature foliage senescence (aging) in trees located in the Eastern and South-eastern Transvaal, two areas thought to be the most likely to be affected by pollution (Olbrich and Kruger,1990:10). Chlorosis was found on 70% of all the needle groups (cohorts) examined, though the damage was usually slight (less than 5% of the leaf area was affected) and thought to be unrelated to pollution sources. Broad chlorotic banding (a chlorotic band greater than five millimetres wide that encircles a needle) of foliage was more common in those regions though it was not known whether this was due to air pollution (Olbrich and Kruger,1990:11).

Tyson et al (1988:91) drew attention to the large body of literature which indicates that effects are possible at the levels of pollution experienced in the ETH. Research has indicated that maize, the most important crop, is tolerant to sulphur and nitrogen oxides and sensitive to ozone, while sunflowers are sensitive to SO_2 and NO_x, but tolerant to ozone.

The sensitivity of various species of indigenous plants to SO_2 were investigated by Ashton (1977). Sixty-three different tree, shrub and herbaceous species were fumigated with varying doses of sulphur dioxide (Ashton,1977:79). The degree of damage occurring to a plant species at a specific dose was noted and this information was used to classify the

sensitivity of each species. The plants displayed a wide range of susceptibility, with individual species from the same family often displaying similar characteristics.

4.1.4 Human health

Zwi et al (1990) studied 1031 children from schools in the ETH and 978 schoolchildren in "unpolluted areas". Information provided by the parents of each child, relating to the child's health in the previous year and the parents' smoking habits was compiled, and the children were medically examined to determine their physical condition (Zwi et al,1990:4). A spirometer was used to evaluate various lung function parameters (Zwi et al,1984:5).

After correction for age it was found that children in the ETH were an average of 0,83 cm shorter than the children in the control areas (Zwi et al,1990:6). There was a greater prevalence of respiratory complaints in girls from the ETH than in girls from rural areas, while boys from the "exposed" areas were more prone to be asthmatic than their counterparts in other areas (Zwi et al,1990:8). There were however, no statistically important differences in lung function parameters between the two groups (Zwi et al,1990:7).

4.1.5 Corrosion in building materials

Polluted atmospheres are responsible for accelerating corrosion in a variety of building materials, including masonry and concrete. The effects of pollution levels on corrosion rates in some metals and metal building materials, e.g. galvanised sheeting have been investigated locally.

A study by Eskom using CLIMAT (bolt on wire test) units at five pollution monitoring sites in the ETH and adjacent regions was conducted to determine the correlation between atmospheric SO_2 and particulate levels, and the corrosion of metals (Hearn and Lennon:1990,7). No correlation was found, and it was thought that pollution levels were too low to have an impact on corrosion rates (Hearn and Lennon,1990:8). The role of humidity may be important, but as humidity levels were not monitored, it is not yet known whether any correlation exists (Hearn and Lennon:1990:11).

4.2 URBAN ENVIRONMENTS

Besides one study of the respiratory health of children in the area of Sasolburg, and various studies which deal with lead pollution and its impacts on health, there is a paucity of literature describing the effects of air pollution on the health of South African urban populations. The same is true for townships where, despite the seriousness of the pollution problem, there have been no studies on the consequences of pollution levels for the health of township inhabitants.

4.2.1 Health effects

A study by Coetzee et al (1984) focused on children in the Sasolburg area. The effect of pollution on the health of 674 children in Sasolburg primary schools was investigated, while 332 children in Parys, Heilbron and Frankfort were used as control subjects (Coetzee et al,1984:3). A similar method to that used by Zwi et al (1984) was followed, i.e. a questionnaire was distributed, the weight and height of the children was recorded, and lung function parameters were measured.
The questionnaire and medical examination showed no important differences between respiratory health (the incidence of respiratory diseases) in the two groups (Coetzee et al,1984:6-7). The lung function tests showed significantly lower forced expiratory volume and maximum voluntary ventilation in boys from Sasolburg (Coetzee et al,1984:8). The control group generally performed better in all parameters.

Trace levels of lead are present naturally in most environments, but in the urban environment anthropogenic sources dominate. Lead particulates in motor vehicle exhausts are the major source of atmospheric lead while paint, water-piping and

tins for canned food contribute further sources of blood lead. Lead toxicity in humans is well described and documented, though the physiological effects of non-toxic concentrations of lead on the body, most notably the effects on classroom performance, are still the subject of controversy. Research conducted in South Africa has sought to determine blood lead concentrations in susceptible populations and, in certain studies, to correlate these levels with one, or some, of a variety of possible sources. Children are the most susceptible to lead exposure and tend to be the focus of research. The work of von Schirnding (1982 and 1988), White et al (1982) and Deveaux et al (1986) has been concerned with blood lead concentrations in Cape school and pre-school children.

Von Schirnding (1982) examined lead absorbtion in sub A (grade 1) schoolchildren from 19 Cape Town schools. Levels of Zinc Protoporphyrin (ZPP) - an indicator of blood lead levels - were found to be significantly higher in children attending schools in mixed residential/urban-industrial areas. Children who went to schools situated on through roads were also found to have higher ZPP levels than those children attending other schools (von Schirnding,1982:43).

Blood lead tests were performed on those children with elevated ZPP levels (von Schirnding,1982:27) and blood lead levels were highest in children from Woodstock and central Cape Town. Examination for lead sources in the home environments of children with high blood lead levels showed few correlations and no common source of lead exposure was established (von Schirnding,1982:107).

In a later study von Schirnding (1988) examined various factors affecting the risk of lead exposure amongst Woodstock (Cape Town) school children. Tests for blood lead levels and other indicators were analysed, together with questionnaires to determine "relationships between biological, environmental, social factors and blood lead" (von Schirnding,1988:ii). Another aspect of the study sought to determine whether there were different risk factors for those children with elevated blood levels and those with low blood lead levels.

The study suggested that while the presence of lead in the environment made it possible for lead exposure to occur, various cultural and economic factors influenced the accessibility of lead (von Schirnding,1988:278-279). Lead in dust and soil, ingested via pica (the craving for, or ingestion of, non-food items) and

mouthing activities, was a possibly important means of exposure. Lead present in vehicle emissions (von Schirnding,1988:281) was indicated as a potentially important source of lead in dust and soil. It was suggested that further controls on lead in petrol would contribute to decreased atmospheric lead concentrations (von Schirnding,1988:282) which would in turn reduce the risk of exposure in children attending schools located near roads with high traffic densities.

Grobler et al (1984) measured blood lead levels in four groups of people: rural dwellers, marathon runners, motor mechanics and urban dwelling non-runners (Grobler et al,1984:2). The results (Table 4.1) indicate that people exposed to traffic exhausts showed elevated blood lead levels (Grobler et al,1984:4). Symptoms of lead poisoning occur at levels of 70 to 80 µg/dl of blood and the mean blood lead concentration of the most exposed group - runners - was approximately 60% of these levels.

	Rural dwellers	Marathon runners	Motor mechanics	Urban non-runners
mean [µg/dl]	3,4	45,8	28,4	9,7
σ [µg/dl]	1,5	21,8	11,3	4,1
median [µg/dl]	3,3	37,5	26,0	10,0
sample size	30	27	31	25

Table 4.1 *Blood lead levels of four different groups of people (Grobler et al,1984:5)*

Studies of dentine lead levels in children have been made by White et al (1982) and Grobler and van Wyk (1983), while Grobler et al (1985) studied blood lead levels in teenagers in a remote area. Deveaux et al (1986) examined lead levels in 293 pre-school children in metropolitan Cape Town.

Other studies have examined the carcinogenicity of air samples and the pollution hazard in an underground car park.

Cox (1984) applied samples of air taken from Soweto and Johannesburg to the Ames Salmonella/mammalian microsome bacteria test in order to determine their carcinogenic possibilities (Cox,1984:1). The tests showed the Johannesburg

samples to be cytotoxic and the Soweto samples to have a high mutagenic activity (Cox,1984:4). The cytotoxicity demonstrated by the Johannesburg air samples was thought to be due to vehicle emissions (Cox,1984:6). The further mutagenic activity of the Soweto samples was attributed to the polycyclic aromatic hydrocarbon content in the samples (thought to be the product of inefficient coal-burning stoves) (Cox,1984:5)

Slabbert (1990) monitored NO_x, CO and hydrocarbon levels in a Pretoria underground parking garage. High concentrations of hydrocarbons, NO_2 and CO occurred, and tended to coincide with peaks in traffic (Slabbert,1990:18). The pollutant levels were sufficiently high to pose a threat to the health of those who worked in the garage.

4.2.2 Corrosion in building materials

Various studies of corrosion rates in metals have been conducted by the CSIR. The two decade Long Term Atmospheric Corrosion Programme run by the CSIR (Callaghan,1983 in Hearn and Lennon,1990:11), has shown corrosion rates for zinc and mild steel in industrial areas to be two or three times greater than in rural areas. In addition, a reduction in the service life of galvanized steel roofing and side-cladding, from 14-16 years to 8-10 years, has been observed in Pretoria (Tyson et al,1988:73).

4.3 RURAL AREAS

In rural areas the major energy related environmental concern is the denudation that results from the exploitation of the wood resource in an non-sustainable way. This issue cannot be examined within the scope of this dissertation.

The use of fires for cooking and heating has a variety of possible health implications (Gandar,1982:4.12). Woodsmoke has been linked to various respiratory diseases, cancers and eye disease. Various carbon compounds produced during the combustion of wood, most importantly the polycyclic aromatics, have impacts on human health. The danger of burns is a further risk and is difficult to eliminate, with old people and young children at most risk.

Chapter Five

Summary and Conclusions

This dissertation has aimed to provide an overview of the existing information on environmental effects in South Africa that are caused by air pollution which results from the use of energy. Three separate aspects of this relationship were examined: the amount of pollutants emitted; the ambient concentrations of these pollutants and secondary pollutants produced by various processes; and the affects of these pollutants on the environment. The links between these data are exceedingly complex and it was beyond the scope of this thesis to examine them in any detail.

5.1 ENERGY CONSUMPTION AND POLLUTION EMISSIONS

Tables 5.1 and 5.2 summarise the results of calculations made in Chapter two and show the sectoral and regional breakdown for emissions of the major pollutants.

In Table 5.1 it can be seen that electricity generation is the largest source of SO_2, NO_x and CO_2, contributing 75,4; 55,2 and 50,6% of the respective totals. This is to be expected, since this sector is the largest consumer of coal. The relatively small contributions to particulate, HC_x and CO emissions can be attributed to the generally high efficiency of utility boilers, which limit hydrocarbon and carbon monoxide releases, and the use of electrostatic precipitators to control particulate emissions.

Industry is the second largest source of SO_2, CO_2 and CO, and the largest source of particulates, contributing just over half the total. This sector also makes a substantial contribution to hydrocarbon emissions.

The transport sector makes an important contribution to NO_x emissions (19,7% of the total). This can be attributed to the predominance of the internal combustion engine, whose high operating temperatures encourage the formation of nitrogen oxides. Emissions from the same sector make up over three-quarters of total CO, and over one-quarter of total hydrocarbon air pollutants.

The domestic sector is the most important source of hydrocarbon emissions, contributing 29,2% of the total. Available information indicates that domestic wood and coal burning appliances typically have low combustion efficiencies, so a relatively high ratio of pollutants emitted to fuel consumed is expected in this sector. This sector is also the third biggest source of particulates, behind the industrial and metallurgical sectors.

Sector	SO_2 [kt]	NO_x [kt]	CO_2 [kt]	Particulates [kt]	HC_x [kt]	CO [kt]
Electricity generation	1 394	660	147 915	44	11	37
Synfuels[1]	3	6	35 905	1	246[2]	-
Industry	195	94	30 613	589	186	300
Metallurgical	152	61	17 826	310	4	8
Mining	10	28	3 318	24	16	7
Agriculture	5	26	2 680	13	16	7
Transport	42	236	33 735	63	277	2 363
Domestic	48	85	20 339	263	312	336
Total	1 849	1 196	292 331	1 307	1 068	3 058

(1) SASOL II and III only
(2) Els (1990:9)

Table 5.1 *Pollution emissions according to sector (1989)*

In Table 5.2 regional emissions are given according to the Development Regions used by the Central Statistical Services. These regions (Figure 5.1) correspond approximately with the provinces in the following way: the Cape - regions A,B and D; The Orange Free State - region C; Natal - region E and the Transvaal - regions F,G,H and J.

The method of calculation and errors in rounding cause the total emissions in the two tables to differ slightly (the assumptions made in the calculation of Table 5.2 appear in Appendix 2.4).

Pollutant	A [kt]	B [kt]	C [kt]	D [kt]	E [kt]	F [kt]	G [kt]	H [kt]	J [kt]	Total [kt]
SO_2	65	8	34	46	107	952	130	497	8	1 847
NO_x	59	17	45	58	118	477	99	299	22	1 194
CO_2	12 676	2 705	7 877	11 397	24 279	140 820	19 535	69 430	3 589	292 308
Particulates	114	17	43	88	245	145	51	575	27	1 305
HC_x	82	22	52	89	177	305	75	231	34	1 067
CO	297	81	202	364	684	194	321	778	135	3 056

Table 5.2 *Pollution emissions according to development region (1989)*

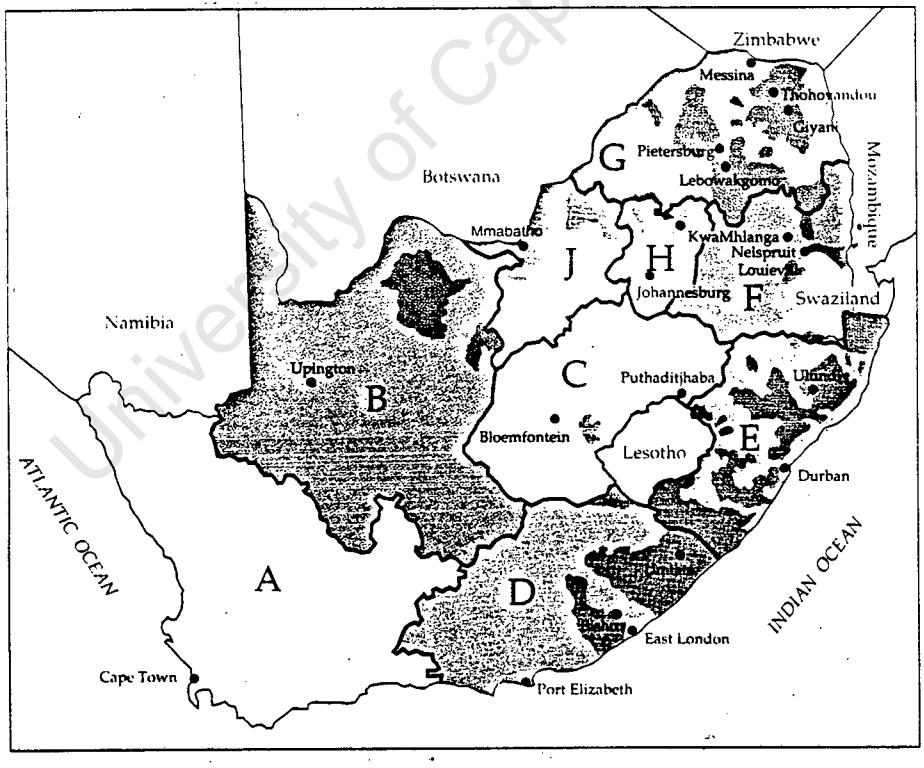

Figure 5.1 *Development regions (DBSA,1991:10)*

The two regions of most interest are F and H, which correspond to the eastern and central Transvaal. The emissions of these two regions make up the majority of all emissions of pollutants with the exception of CO.

Pollution sources in the eastern Transvaal are responsible for 51,5% of total SO_2 emissions, 39,9% of total NO_x and 48,2% of national carbon dioxide emissions. Sources in this region also make major contributions to particulate and hydrocarbon emissions. Most of these emissions are due to the number of power stations in the region. SASOL plants are responsible for 80,7% of the total hydrocarbon emissions in region F.

The central Transvaal takes in most of the PWV industrial complex, and the pollution produced by the various industries in this overlapping area will be reflected in the region total. The emissions of SO_2, NO_x and CO_2 from this region are second to those from the eastern Transvaal in magnitude and contribute 26,9%; 25,0% and 23,8% of the total for each pollutant.

Particulate emissions are greatest in region H (44,1% of the national total). This can be attributed to the use of coal in domestic, industrial and metallurgical environments. Controls on particulate emissions in these sectors are not as stringent as those applied in power stations, which would explain the larger regional contribution to total particulate emissions than the ETH, where more coal is consumed.

The major source of CO is the transport sector and it can be expected that emissions will be greatest in regions where population and vehicles numbers are greatest. This is observed in the regional emission breakdown, with the central Transvaal and Natal having the highest emissions, followed by the eastern Cape, the Northern Transvaal and the western Cape.

5.2 MONITORING OF POLLUTION LEVELS

Where possible, information in this section has been presented so as to enable comparisons between regions and similar environments. Often this is difficult as data is published in different forms. Frequently pollutants are measured as part of short-term projects lasting only a few weeks or months at a time. This

lack of chronological continuity makes it difficult to analyze the data in a meaningful way, especially when determining trends.

5.2.1 The Eastern Transvaal Highveld and adjacent regions

The ETH together with the Pretoria - Witwatersrand - Vereeniging (PWV) region constitute the two most important of South Africa's industrial regions. There is a concentration of power stations and industries - including the two larger SASOL complexes - within the borders of the ETH and the regional climatology is unfavourable for the dispersion of pollutants.

Annual average SO_2 concentrations in the region for the years 1979 to 1986 varied from 8,8 to 41,3 $\mu g/m^3$ (Tyson et al,1988:46). There were 38 exceedences of the hourly guideline, and eight of the daily guideline during this period (Tyson et al,1988:48). Pretorius et al (1986), Held and Pretorius (1987) and Tyson et al (1988) analysed various periods of this set of data and observed positive increasing trends in SO_2 concentrations.

Monitoring at 22 sites from 1983 to 1988 showed that the one-hour SO_2 guideline was exceeded at six sites and the daily guideline was exceeded at two sites. The maximum annual averages for the period varied from 9,1 to 45,2 $\mu g/m^3$, and the period means were from 7,5 to 34,6 $\mu g/m^3$. Turner (1990) found that the overall increase in SO_2 concentrations from 1983 to 1988 was 15,4%.

Particulate concentrations measured at six sites in the ETH and neighbouring regions between 1983 and 1988 showed maximum annual means ranging from 14,4 to 36 $\mu g/m^3$ (Turner et al,1990:42). Maximum annual site averages for the entire five year period ranged from 12,6 to 30 $\mu g/m^3$. Visibility measured at two sites (Elandsfontein and Slangheuwel) during 1985 and 1986 was found to be within acceptable limits (Wells et al:1990:42).

Monitoring of NO_x levels showed that the DoH guidelines were not exceeded.

With the exception of one site which showed no hourly averages above the guideline, all guidelines for O_3 levels were exceeded at all sites. Maximum annual O_3 concentrations varied from 44,2 to 68,8 $\mu g/m^3$, while site means for the five year period ranged from 42,0 to 68,0 $\mu g/m^3$. These annual averages are between two and four times greater than

Photochemical pollutants have been measured in Johannesburg, Cape Town and Pretoria (Table 5.3 summarises the data from the monitoring of NO_x, O_3 and NMHC levels in these cities). In Johannesburg NO_x readings were well below the DoH guidelines, while monitoring in the Cape Town city centre showed that the one hour NO_x guideline was exceeded every year during the period 1984 to 1989/1990. Annual NO_x levels in central Cape Town approached the guideline, but did not exceed it.

Ozone concentrations in Johannesburg exceeded the guidelines on 22 occasions during 1984/1985 (Stevens,1987b:527). The one hour maxima in Johannesburg and Cape Town were exceptionally high and clearly a hazard to health.

Johannesburg and Pretoria have both shown high NMHC levels, while no recent reliable data is available for NMHC levels in Cape Town. In Pretoria, the guidelines for hourly and annual NMHC concentrations have been exceeded and the maximum hourly concentrations measured were notably high.

Pollutant	City	Period	1-hour maxima [µg/m³]	DoH guideline [µg/m³]	Annual averages [µg/m³]	DoH guideline [µg/m³]
NO_x	Johannesburg	1982 to 1985	108[1]	1 080	28-31	270
	Cape Town	1984 to 1989/90	2 352-3 501		180-238	
	Pretoria	1986 to 1987/88	1 262		16-182	
O_3	Johannesburg	1984/1985	604	240	-	20
	Cape Town	1986 to 1989/90	121-790		9-16	
	Pretoria	1986 to 1987/88	272		18-54	
NMHC	Johannesburg	1984/1985	236[1]	262	-	39
	Cape Town[2]	1986	558		72	
	Pretoria	1986 to 1987/88	3 357		40-155	

'-' indicates no measurement available

(1) Mean hourly average (06h00 to 09h00) 1984/1985

(2) Readings made of all hydrocarbons

Table 5.3 *NO_x, O_3 and HC concentrations in Johannesburg, Cape Town and Pretoria (Stevens,1984;1987a and 1987b; Cape Town Medical Officer of Health,1984 to 1989/90; and Bryszewski,1988)*

PAN levels measured in the Pretoria, Cape Town and Johannesburg at various times from 1986 to 1989 (Grosser and Baunok,1990) were similar to those encountered in other cities in the world and were under the limits for phytotoxicity. The possibility of phytotoxic levels occurring was not however excluded (Grosser and Baunok,1989:228).

Lead levels are measured in several cities, but except for measurements made by the CCC and the WCRSC the results are not readily available. Levels measured at several sites in Cape Town from 1986 to 1989/90 were below the DoH annual guideline of 2,5 $\mu g/m^3$ and the highest average recorded was 1,2 $\mu g/m^3$. None of the annual average concentrations recorded by the Western Cape Regional Services Council from 1987 to 1989 exceeded 0,6 $\mu g/m^3$.

Carbon monoxide concentrations were monitored in Pretoria in 1987/1988 as part of the CSIR's programme to monitor pollution resulting from vehicle emissions (Bryszewski,1988:6). No exceedences of the one-hour EPA standard occurred and annual average arithmetic averages ranged from 460 to 3 174 $\mu g/m^3$ for three sites. CO was measured in other cities, but for very short - and possibly unrepresentative - periods.

5.2.3 Soweto

Monitoring of levels of various pollutants has taken place in Soweto at various times, though never for a period longer than a year. Table 5.4 summarises the data for pollution levels from the work of Turner et al (1984), Rorich (1986) and Kemeny et al (1988). Either the range of values or the maximum for the monitored period (indicated in brackets) is provided, along with the DoH guideline (where applicable).

There were no exceedences of the NO_x guidelines during the monitored periods and SO_2 levels mostly approached the guidelines. The single exceedence of the monthly guideline for SO_2 occurred in August 1983 and the maximum one and 24-hour averages were recorded in October of the same year. The only other one-hour exceedence occurred in July 1984.

Pollutant	Monitoring period	1-hour means/ (maximum) [µg/m³]	24-hour means/ (maximum) [µg/m³]	Monthly means/ (maximum) [µg/m³]	DoH guidelines [µg/m³]
SO_2	Jun to Dec 1983	120 - 1 570	42 - 307	26 - 135	1-hour 780
	Jul to Aug 1984	720 - 816	146 - 156	100 - 111	24-hour 260
					Monthly 180
NO_x	Jun to Dec 1983	140 - 494	55 - 147	35 - 72	1-hour 1 080
	Jul to Aug 1984	293 - 421	80 - 128	37 - 59	24-hour 540
					Monthly 405
Smoke	Oct 1972 to Sept 1973	(3940)	(685)	(340)	24-hour 250
	Apr to Aug 1982	(4520)	(1040)	(520)	
TSP	Aug and Nov 1983	-	490 - 560	124 - 220	

Table 5.4 *SO_2, NO_x, smoke and TSP concentrations in Soweto (Kemeny et al,1988:155-157; Turner et al,1984:6-9 and Rorich,1986:30)*

Monitoring of smoke levels during 1972/1973 gave an annual mean of 140 µg/m³ (the DoH guideline is 150 µg/m³). There are no DoH guidelines for hourly and monthly smoke levels, but the maximum monthly average smoke concentrations for both monitoring periods exceeded the daily standard and were evidently a danger to human health.

Total suspended particulate levels showed exceedences of the EPA daily guidelines (there is no applicable DoH guideline) in both August and November of 1983. There were 11 exceedences of the primary standard of 260 µg/m³ in August and one exceedence in November (Turner et al,1984:6).

5.3 THE ENVIRONMENTAL EFFECTS OF AIR POLLUTION

5.3.1 The Eastern Transvaal Highveld and adjacent regions

Most attention has been directed at impacts on managed ecosystems (agriculture and silviculture) and human environments (human health and corrosion in materials) and the only effects on natural ecosystems to be noted are concerned with the chemistry and ecosystems of surface waters.

The streams of the ETH have varying susceptibility to acidification (determined by alkalinity and buffering capacity). Most have high alkalinities, but streams situated to the north are generally more sensitive (Tyson et al,1988:82). Skoroszewski (1990) surveyed streams along the Drakensberg Escarpment and found damage to benthic (bottom dwelling) communities in a group of streams down-wind of ETH and PWV pollution sources which were possibly related to air pollution.

There are also indications that pollutants, most notably sulphates, are accumulated in catchments during dry periods and released into streams when rain occurs. Sampling of a stream near Dullstroom showed a rapid increase in ion concentrations and decrease in pH after heavy rains (Skoroszewski,1990:3). The export rate of chlorides and sulphates increased rapidly just after a storm, indicating that these ions had been released from the catchment.

The effects of pollution deposition on soils used for agriculture and forestry, and the impacts on the crops themselves are both of obvious economic importance. No effects on agricultural soils or crops have been noted, but the impacts of pollutant deposition on soils are difficult to distinguish from the acidifying effects of artificial fertilizers. The most important crops (maize and sunflowers) are sensitive to pollution and experiments conducted on beans have shown a sensitivity to low doses of SO_2 (Tyson et al,1988:93).

Little is known about soils used for silviculture, though most are thought to be moderately sensitive (Tyson et al,1988:80). Incidents of damage to pine trees have been reported, but no definite causes have been identified. Olbrich and Kruger (1990) surveyed damage to pine needles in Swaziland, Natal and the Transvaal and found that chlorosis occurred on the majority of trees, though this was thought to be unrelated to pollution (Olbrich and Kruger,1990:10). The cause of broad chlorotic banding that was observed in trees in the Eastern and south-eastern Transvaal was not identified.

There has only been one study in the ETH to examine the effects of pollution on health. Zwi et al (1990) compared the respiratory health of schoolchildren in the region with those living in "unpolluted" areas. The project consisted of two parts: the analysis of information obtained from a questionnaire; and a medical examination which included the evaluation of lung function parameters. Among the findings were a greater prevalence of respiratory complaints (in girls) and asthma (in boys) in children from the ETH than in children from a rural areas control group (Zwi et al,1990:8). A slight difference in height (the control group was found to be an average 0,83 cm taller) was also detected

(Zwi at al,1990:6). ETH children were generally found to be more susceptible to respiratory illnesses and complaints, but there were no statistically important differences in lung function parameters between the groups.

Few studies of the effects of air pollution on corrosion rates in construction materials have been made, even though such effects have substantial economic importance. An investigation conducted by Eskom using bolt-on-wire tests at five pollution monitoring sites showed no correlation between atmospheric SO_2 and particulate levels and corrosion rates (Hearn and Lennon,1990:8).

5.3.2 Urban areas

The effects of pollutants on human health are of primary concern in urban environments, though the number of studies is limited. Coetzee et al (1984) examined Sasolburg children using a methodology similar to that of Zwi et al (1990) in the Eastern Transvaal Highveld. Groups from Parys, Heilbron and Frankfort were used as a control. The results contrasted with the findings in the ETH as forced expiratory volume and maximum forced ventilation were found to be significantly lower in boys from Sasolburg and there were no differences in the occurrence of respiratory diseases between the two groups (Coetzee et al,1984:8). The control groups generally performed better in all lung function measurements (Coetzee et al,1984:6).

Far more attention has been paid to the effects of atmospheric lead on the health of city dwellers, and researchers have sought to determine blood lead levels in susceptible groups, most notably children, and in some cases to correlate these levels with possible sources.

Von Schirnding (1982) examined schoolchildren from 19 Cape Town schools for lead absorbtion. Tests indicated that children who went to schools located in mixed residential/urban-industrial areas or schools situated on busy roads had higher blood levels than children attending other schools (von Schirnding,1982:43). Children with high blood lead levels were selected for examination of lead sources in their home environments, but no common source of lead exposure was found (von Schirnding,1982:107).

In a later study von Schirnding (1988) examined various factors affecting lead exposure amongst Woodstock school children. Lead present in vehicle emissions (von Schirnding,1988:281) was identified as a potentially important source of dust and

soil lead. It was suggested that further controls on lead in petrol would contribute to decreased atmospheric lead concentrations (von Schirnding,1988:282), which would in turn reduce the risk of exposure in children attending schools located near roads with high traffic densities.

Grobler et al (1984) measured blood lead levels in four groups of people: rural dwellers, marathon runners, motor mechanics and urban dwelling non-runners (Grobler et al,1984:2). The results showed that people exposed to vehicle exhausts had elevated blood lead levels.

Studies on corrosion rates have been conducted by the CSIR in urban, industrial and marine environments. The Long Term Atmospheric Corrosion Programme run by the CSIR has determined that corrosion rates of zinc and mild steel are two to three times greater in industrial areas than in rural areas (Hearn and Lennon,1990:11). The useful life of galvanised steel roofing and side-cladding in the Pretoria area has been halved from 14-16 years to 8-10 years (Tyson et al,1988:73).

5.3.3 Rural areas

Woodsmoke has been linked to various respiratory diseases and cancers and eye disease. Various carbon compounds produced during the combustion of wood, most importantly the polycyclic aromatics, have impacts on human health (Gandar,1982:12), but these effects have not been investigated in South African populations.

5.4 CONCLUSIONS

5.4.1 Air pollution monitoring

Besides the monitoring of SO_2 and smoke concentrations in towns and cities, and the Eskom rain-chemistry and pollution monitoring networks in the Eastern Transvaal Highveld, there has been little consistent monitoring of pollution levels over the medium to long-term.

It is often the case that data is not published, or is only available in an unprocessed form. Reports made by the CSIR and Eskom may be regarded as private property, or may only be intended for internal circulation, making it difficult for outside researchers to obtain this data. Information should be more freely available to researchers and the public.

There are also several environments with possible pollution hazards where monitoring has not taken place. Among the most important of these are townships and informal settlements where atmospheric pollution possibly threatens the health of millions of people. In areas where monitoring has been conducted there are several key issues which require further examination.

The Eastern Transvaal Highveld and adjacent regions

There are indications that pollutants which originate in the ETH are being carried to adjacent regions. Further investigations of pollution levels and depositions in neighbouring areas, and their relation to emissions from the ETH, are required. Evidence suggests that an elevated pollution layer is hampering the dispersal efficacy of tall stacks and providing a mechanism for the medium to long-range transportation of pollutants. This evidence for an elevated pollution layer should be thoroughly investigated.

Estimates indicate that dry deposition of pollutants in the ETH and adjacent regions forms a significant part of the total deposition of certain pollutants. These deposition levels should be measured.

Urban areas

The monitoring of photochemical pollution levels in most major cities has been irregular. A consistent and organised monitoring program in all the major cities (Johannesburg, Cape Town, Pretoria, Durban, Port Elizabeth and East London), and certain industrial towns such as Vereeniging and Sasolburg is required. The results and findings of any existing monitoring programmes must be published.

Townships

There has been little monitoring in townships where the burning of coal and wood has created a pollution problem. The existing SO_2 and smoke monitoring network should be extended to these areas and the levels of other pollutants such as NO_x and particulates levels should be monitored.

Monitoring in Soweto has been conducted irregularly yet the available data indicates clearly that it is affected by a severe pollution problem. Electrification has apparently failed to reduce pollution levels significantly, and this failure can be attributed to a variety of social and economic causes. Clearly electrification of an area does not necessarily result in a reduction of pollution levels, and it is necessary to take account of these other factors.

5.4.2 Environmental effects of air pollution

There is a small amount of literature describing the effects of air pollution in South Africa. Most of these studies describe effects in urban areas and the ETH, but there is seldom any depth to the available material.

The Eastern Transvaal Highveld and adjacent regions

The Eastern Transvaal Highveld environment is quite different to environments that have been studied elsewhere. Differences in the types of species and meteorological conditions, amongst others, limit the applicability of findings from investigations in other parts of the world.

Reports of damage to the major ecosystems need to be collected to obtain an overall view of the state of ecosystems in the region. Those areas of which there

is no knowledge should be investigated to determine the extent of damage, if any exists. The results of such investigations should in turn determine which issues receive further monitoring and research.

The research efforts of various organisations need to be coordinated so that all areas requiring research are covered adequately, and to ensure that the most rational use is made of resources. There are common air pollution related concerns in urban environments and the ETH. The effects of pollution on public health and corrosion rates in construction materials are two problems that require further investigation in both environments. The findings in one environment may have validity in the other, thereby reducing the need for separate research programmes, and conserving resources.

Urban areas

Investigations in urban areas in the ETH and Sasolburg have indicated that the health of populations in these environments are affected by air pollution. Research is necessary, but the aims and methodology of this research must be very carefully formulated and should draw on the experience of epidemiological studies conducted overseas. It is also necessary to determine whether photochemical pollution levels in South African cities pose a hazard to health.

The relation between pollution levels and the corrosion and degradation of building materials is of great economic importance. Corrosion studies need to be conducted in close conjunction with the monitoring of pollutants. The relationship between photochemical smog levels and vehicle emissions should be investigated, and the results used to inform future policies on public transport and the control of vehicle emissions.

Townships and informal settlements

The effects of air pollution on the health of residents in informal settlements and townships need to be studied. The 'birth-to-ten' study initiated by the Medical Research Council in 1990 will partially address this knowledge gap. The findings of this research must be used to inform policies which seek to address the energy needs of these populations.

References

ANNEGARN, H.J. (1981). 'PIXE analysis of time-sequence "streaker" filters from Johannesburg'. Nuclear Instruments and Methods, n 181, pp 435-440.

ANNEGARN, H.J. (1990). Air pollution measurements in Soweto. World Environment Day Workshop, Air Pollution in Greater Soweto in the 90's.

ARON, J. ET AL (1989). Demand and Supply of Firewood In the Homelands of South Africa. Post Conference Series No.21, Second Carnegie Enquiry Into Poverty and Development in South Africa, University of Cape Town.

ASHTON, E. (1977). The sensitivity of South African plants to acute dosages of sulphur dioxide. M.Sc. Thesis, University of Cape Town.

BAYMAN, B. (1989). Mesoscale Air Quality Over Soweto. Unpublished, Department of Geographical and Environmental Studies, University of the Witwatersrand.

BORCHERS, M.L. AND EBERHARD, A.A. (1991). Household energy supply and price trends. Energy for Development Research Centre, University of Cape Town.

BOSMAN, H.H. (1990). The impact of atmospheric sulphate deposition on surface water quality in the Eastern Transvaal Highveld. 1st IUAPPA Regional Conference, Pretoria (Oct).

BOTHA, E. ET AL (1990). Rain chemistry : 1985 to 1989. Eskom Engineering Investigations Report TRR/s90/033.

BRYSZEWSKI, W.Z. (1986). Motor Vehicle Pollution Project: Air Quality Data for August 1986, Pretoria Area. Atmospheric Sciences Division, CSIR. Report ATMOS/86/19.

BRYSZEWSKI, W.Z. (1987a). Motor Vehicle Pollution Project; Air Quality Data between 7 and 16 August 1985, Cape Town area - Report to the Department of National Health and Population Development. Report ATMOS/87/5.

BRYSZEWSKI, W.Z. (1987b). Annual Progress Report: November 1987. Motor Vehicle Pollution Project. Atmospheric Sciences Division, CSIR.

BRYSZEWSKI, W.Z. (1988). Annual Progress Report - Pollution by Motor Vehicles Emissions Project, Air Quality Programme, CSIR. Report EMA-C8889.

BUYS, F. (1992). Air Pollution Control Officer, DoH. Personal Communication.

CALITZ, J.M. (1990). Southern African Population - A Regional Profile 1970-1990. Development Bank of Southern Africa - Centre for Information Analysis, Halfway House.

CALVERT, J.G. ET AL (1985). 'Chemical mechanisms of acid generation in the troposphere'. Nature, v.317.

CAPE TOWN CITY COUNCIL HEALTH DEPARTMENT (1986). Summary of data from automatic air pollution monitors in the Cape Peninsula 1984/1985.

CAPE TOWN MEDICAL OFFICER OF HEALTH (1987-1989/90). Annual Reports of the Cape Town Medical Officer of Health.

CSS CENTRAL STATISTICAL SERVICES (1990). South African Statistics 1990. Pretoria.

COETZEE, A.M. ET AL (1984). Effects on Health of Air Pollution in the Sasolburg Area. Sixth International Conference on Air Pollution, Pretoria (23-25 Oct), vol 2.

COX, R.T.E. (1984). Air quality and chemically induced carcinogenesis - A South African Perspective. Sixth International Conference on Air Pollution, Pretoria (23-25 Oct), vol 2.

CSIR (1991). The situation of waste management and pollution control in South Africa. Report to the Department of Environment Affairs by the CSIR Programme for the Environment. Report CPE 1/91.

DANFORD, I.R. AND HONG, Y. (1989). Episodes of high concentrations of pollutants at Verkykkop and Kendal. NACA 'Charting a course for the 90's', Cape Town (9-10 Nov).

DBSA DEVELOPMENT BANK OF SOUTH AFRICA (1991). Annual Report 1990/1991.

DICKSON, B.J. AND BALDWIN, S.A. (1990). The development of low cost fuel-efficient wood burning stoves appropriate for underdeveloped areas of South Africa. E.R.I., University of Cape Town.

DoH DEPARTMENT OF NATIONAL HEALTH AND POPULATION DEVELOPMENT (1990). Draft Air Pollution Control Policy. Chief Air Pollution Control Officer, Pretoria.

DUTKIEWICZ, R.K. ET AL (1980). Air pollution survey of greater Cape Town. Volume five: Conclusions and recommendations.

DUTKIEWICZ, R.K. ET AL (1989). Photochemical Smog Potential in South Africa. Proceedings of the 8th World Clean Air Congress, The Hague, Netherlands, (11-15 Sept).

EBERHARD, A.A. (1990). 'Energy consumption patterns and supply problems in underdeveloped areas in South Africa'. Development Southern Africa, v 7, n 3, pp 335-346 (August).

EBERHARD, A.A. AND GANDAR, M.V. (1984). Energy, Poverty and Development in South Africa. Post Conference Series No.154, Second Carnegie Enquiry Into Poverty and Development in South Africa, University of Cape Town.

EL-HINNAWI, E.E. (1980). The Environmental Impacts of Production and Use of Energy - An assessment prepared by the United Nations Environment Programme. Tycooly Press.

ELLERBECK, R.H. ET AL (1990). Statistics On Smoke and Sulphur Dioxide Pollution in South Africa - Period: Oct 1988 to Sept 1989. Air Quality Programme, CSIR.

ELS, C.J. (1989). Eastern Transvaal Highveld: Air Pollution Scenarios and Control Strategies. Conference of the National Association for Clean Air: 'Charting a Course for the 90's', Cape Town

ERL ENVIRONMENT RESOURCES LIMITED (1983). Acid Rain - A Review of the Phenomenon in the EEC and Europe. Graham & Trotman.

ESKOM (1990). 1989 Statistical Yearbook.

ESKOM (1991). 1990 Statistical Yearbook.

FUGGLE, R.F. (1984). Atmospheric, soil and dust lead levels in the Woodstock area, Cape Town. Sixth International Conference on Air Pollution, Pretoria (23-25 Oct), v 2.

GANDAR, M.V. (1982). 'Some social and environmental aspects of the use of fuelwood in KwaZulu' in Rural studies in KwaZulu, University of Natal.

GANDAR, M.V. (1984). The poor man's energy crisis: Domestic energy in KwaZulu. Post Conference Series No.156, Second Carnegie Enquiry Into Poverty and Development in South Africa, University of Cape Town.

GANDAR, M.V. (1984). Firewood in Kwazulu: quantities and consequences. Energy for underdeveloped areas conference, Energy Research Institute, University of Cape Town (8-10 September).

GROBLER, S.R. ET AL (1984). Blood lead levels of different groups of South Africans. Sixth International Conference on Air Pollution. Pretoria (23-25 Oct).

GROSSER, E. AND BAUNOK, I. (1989). Levels of peroxyacetyl nitrate (PAN) in South African Cities. NACA 'Charting a course for the 90's', Cape Town (9-10 Nov).

GROSSER, E. (1990). Photochemical oxidant air pollution - peroxyacetyl nitrate (PAN) as an indicator of photochemical activity. M.Sc. Thesis, University of Cape Town.

HAHN, J. AND SEILER, W. (1990). Man's impact on the global trace gas budgets. 1st IUAPPA Regional Conference, Pretoria (Oct).

HEARN, I.R. AND LENNON, S.J. (1990). The contribution of atmospheric constituents to the corrosion of materials. 1st IUAPPA Regional Conference, Pretoria (Oct).

HELD, G. AND PRETORIUS, R.W. (1987). Trends in SO_2 concentrations in the Eastern Transvaal Highveld, 1979 to 1983. NACA Air Pollution Conference on Two Decades of Progress?, Pretoria (Nov).

IEA INTERNATIONAL ENERGY AGENCY (1991). World Energy Statistics.

IPCC INTERGOVERNMENTAL PANEL ON CLIMATIC CHANGE (1990). Scientific assessment of climate change. Report prepared for IPCC by Working Group 1.

KEMENY, E. ET AL (1988). An assessment of smoke pollution in Soweto. Proceedings of the International Conference on air pollution, Pretoria (Nov).

LEDBETTER, J.O. (1973). Air Pollution, Part A - Analysis. Marcel Dekker, New York.

LEGGETT, J. (ed) (1990). Global warming - The Greenpeace Report. Oxford University Press.

LHA LOUIS HEYL AND ASSOCIATES (1990). Report for Eskom on regional energy consumption.

LOEWENHEIM, L. (1988). Photochemical smog in greater Cape Town. M.Sc. Thesis, University of Cape Town.

McCORMICK, J. (1985). Acid Earth - The Global Threat of Acid Pollution. Earthscan.

MELLANBY, K. (ED) (1990). Air pollution, acid rain and the environment. Elsevier Applied Science Publishers.

NEC NATIONAL ENERGY COUNCIL (1990a). Annual Report 1989-1990. Pretoria.

NEC NATIONAL ENERGY COUNCIL (1990b). South African Energy Statistics No 1. Pretoria.

OLBRICH, K.A. AND KRUGER, F.J. (1990). Indications of air pollution on Pinus patula in the eastern and south-eastern Transvaal, South Africa. 1st IUAPPA Regional Conference, Pretoria (Oct).

REYNOLDS, E. (1991). Environmental Coordinator, SASOL Technology. Personal communication. Johannesburg.

RORICH, R.P. (1984). Air Pollution Measurements in Soweto July - August 1984 and the correlation between the MRI Integrating Nephelometer and G.M.W. High Volume Air Sampler. Eskom Environmental Specialist Investigations Report TRR/N86/010.

SITTIG, M. (1975). Environmental Sources and Emissions Handbook. Noyes Data Corporation.

SKORSZEWSKI, R.W. (1990). Atmospheric pollution in the ETH, South Africa in relation to water quality. 1st IUAPPA Regional Conference, Pretoria (Oct).

SLABBERT, G.P. (1990). A critical evaluation of the air pollution risk in a typical parking garage in the central business district of Pretoria. 1st IUAPPA Regional Conference, Pretoria (Oct).

STEVENS, C.S. AND RIMMER, R. (1984). The distribution of nitric oxide, nitrogen dioxide, ozone and non-methane hydrocarbons in the atmosphere of Johannesburg. Sixth International Conference on Air Pollution. Pretoria (23-25 Oct), v 2.

STEVENS, C.S. (1987a). 'O3 Episodes and Related Vehicle Pollutant Emission Ratios in the Greater Johannesburg Area', South African Geographic Journal, v 69, n 2.

STEVENS, C.S. (1987b). 'Ozone formation in the greater Johannesburg region'. Atmospheric Environment, v 21, n 3, pp 523-530.

STEWART, C.T. (1979). Air Pollution, Human Health, and Public Policy. Lexington Books.

TURNER, C.R. (1984). Air Pollution Data for Soweto June to December 1983. Eskom Technical Note TRR/N84/001.

TURNER, C.R. ET AL (1984). Air pollution monitoring in Soweto. Sixth International Conference on Air Pollution, Pretoria (23-25 Oct), v 2.

TURNER, C.R. AND RORICH, R.P. (1986). Sulphur dioxide on the Highveld between 1979 and 1984: Its relationship to the development of power stations. Eskom Engineering Investigations Report TRR/N86/002.

TURNER, C.R. (1990). A five year study of air quality in the Highveld region. Eskom Engineering Investigations Report TRR/s90/002.

TYSON, P.D. ET AL (1988). Atmospheric Pollution and it's Implications in the Eastern Transvaal Highveld. South African Scientific Programmes Report No.150.

UMESA UNITED MUNICIPAL EXECUTIVE OF SOUTH AFRICA (1989). 1989 Official South African Municipal Yearbook.

VAN WYK, D.B. (1990). Atmospheric deposition at selected sites in the mountain catchments of South Africa. 1st IUAPPA Regional Conference, Pretoria (Oct).

VLEGGAAR, C.M. ET AL (1980). Trace elements in airborne particulates in South Africa. Atomic Energy Board Report PRL-274. Pelindaba, Pretoria.

VON SCHIRNDING, Y. (1982). A Study of the Impact of Lead in the Environment on School Children In the Cape Town Area. Unpublished M.Sc Thesis, University of Cape Town.

VON SCHIRNDING, Y. AND FUGGLE, R.F. (1984). Atmospheric, Soil and Dust Lead Levels in the Woodstock Area, Cape Town. Proceedings 6th International Conference on Air Pollution, Pretoria (Oct).

VON SCHIRNDING, Y. (1989). Environmental lead exposure among inner city Cape Town children: a study of associated risk factors. PhD Thesis, University of Cape Town.

WELLS, R.B. ET AL (1987). Air Pollution in the Eastern Transvaal Highveld. Atmospheric Sciences Division, CSIR.

WELLS, R.B. AND BRIGGS, A.B. (1989). Changes in lead in petrol in South Africa - their effect on airborne lead. NACA 'Charting a course for the 90's', Cape Town (9-10 Nov).

WORLD COMMISSION ON ENVIRONMENT AND DEVELOPMENT (1987). Our Common Future. Oxford University Press.

WORLD METEOROLOGICAL ORGANISATION (1980). Influence of potential climatic change on energy strategy. 11th World Energy Conference, Munchen (8-12 Sept).

ZWI,S. ET AL (1990). Respiratory health status of children in the Eastern Transvaal Highveld. 1st IUAPPA Regional Conference, Pretoria (Oct).

Bibliography

ALESSANDRINI, A. ET AL (1989). The Beneficial Effects of Energy Savings on Environment. 14th Congress of the World Energy Conference, Montreal (17-22 Sept).

ALLEN, J.W. (1989). Advances in the Combustion of Fossil Fuels. 14th Congress of the World Energy Conference, Montreal (17-22 Nov).

BARBIER, E.B. (1990). 'Thinking Economically About Climate Change'. Energy Policy, v 18, No 1.

BORCHERS, M.L. AND EBERHARD, A.A. (1991). Household energy supply and price trends. Energy for Development Research Centre, University of Cape Town.

BOSHOFF, H.P. AND BARNARD, J.M. (1988). Analyses of coal product samples taken by the Division of Energy Technology, CSIR, during 1987. Bulletin No.102.

BRODINE, V. (1974). Air Pollution. Environmental Issue Series. Harcourt, Brace, Jovanovich, New York.

BRYSZEWSKI, W. ET AL (1987). Motor vehicle pollution project: Air Quality Data for July 1985. Port Elizabeth Area.

CALLAGHAN, B. (1983). 'Long Term Atmospheric Corrosion Programme - Results after 10 years exposure'. Corrosion and Coatings South Africa, June.

CHAPMAN, P. AND WATLING, R.J. (1980). Oil pollution studies in South Africa. South African Journal of Science, v 76, pp 534-535.

CULP, A.W. (1979). Principles of Energy Conversion. McGraw-Hill.

DAY, J.H.; COOK, P.; ZOUTENDYK,P. AND SIMONS,R. (1971). 'The effect of oil pollution from the tanker 'Wafra' on the marine fauna of the Cape Agulhas area'. Zoologica Africana, v 6, n 2.

EBERHARD, A.A. (1984). Energy and poverty in urban and peri-urban areas around Cape Town. Post Conference Series No.155, Second Carnegie Enquiry Into Poverty and Development in South Africa, University of Cape Town.

EBERHARD, A.A. (1986). Energy Consumption Patterns In Underdeveloped Areas In South Africa. Energy Research Institute Report No.94.

EBERHARD, A.A. (1986). South African Energy Crisis: Some Suggested Strategies.Post Conference Series No.13, Second Carnegie Enquiry into Poverty and Development in South Africa, Cape Town.

ECKHOLM, E. ET AL (1984). Fuelwood: the energy crisis that won't go away. Earthscan.

EL-HINNAWI, E.E. (1980). Nuclear Energy and the Environment. UNEP, Nairobi:Pergamon.

FOLEY, G. (1988). Discussion paper on demand management. World Bank Eastern and Southern Regional Seminar on household energy planning. Harare, Zimbabwe.

FUGGLE, R.F. AND RABIE, M.A. (1983). Environmental Concerns in South Africa. Juta AND Company, Cape Town.

GANDAR, M.V. (1985). Comparison of the Environmental Impact of Different Energy Sources. Proceedings of S.A.I.E. Symposium on Nuclear Energy and the Environment in S.A.

GOREAU, T.J. (1990). Balancing atmospheric carbon dioxide. Ambio, v 19, n 5, pp 230-236.

HEYL, L.J. (1988). Smoke pollution in urban areas in South Africa and possible solutions. Proceedings of the International Conference on air pollution, Pretoria (Nov).

HUNTLEY, B. ET AL (1989). South African Environments Into the 21st Century. Human and Rousseau, Tafelberg.

INDICATOR PROJECT S.A. (1990). Rotating the Cube - Environmental Strategies For the 1990's. University of Natal.

KATERERE, Y. (1990). Critical comparison of conventional and contemporary low income energy statistics. Low income household energy conservation planning workshop, ZERO.

KOEBERG ALERT RESEARCH GROUP (1988). 'The Power of the State and the State of Power:Recent Developments in South Africa's Nuclear Industry', South African Review, v 4, pp 469-494.

LAWRENCE, B. (1990). Perceptions of the impact of particulate and gaseous emissions from fossil-fueled power plants in South Africa. 1st IUAPPA Regional Conference, Pretoria (Oct).

LER MURRAY, P.W. AND TERBLANCHE, A.P.S. (1990). Atmospheric aldehydes: A review of health effects. 1st IUAPPA Regional Conference, Pretoria (Oct).

LIENGME, C.A. (1983). A study of wood for fuel and building in an area of Gazankulu. Bothalia, v 14, n 2, pp 245-257.

MACNEILL, J. (1989). 'Strategies for Sustainable Economic Development', Scientific American, v 261, n 3, pp 105-113.

MARVILLET, J. (1990). Environment and oil refining. 1st IUAPPA Regional Conference, Pretoria (Oct).

MEHLISS, A.T.M. (1989). Energy Minerals - Coal. Minerals' Bureau Handbook.

MOWACKI, P. (1979). Coal liquefaction processes. Noyes Data Corporation, New Jersey.

PASZTOR, J. (1989). Toward Sustainable Energy Futures. 14th Congress of the World Energy Conference, Montreal (17-22 Nov).

PETRIE, J.G. (1990). Combined particulate and acid gas removal during solid fuel combustion. 1st IUAPPA Regional Conference, Pretoria (Oct).

PRESTON-WHYTE, R.A. (1987). 'A case study of public and press reaction to an environmental decision', International Journal of Environmental Studies, v 30, pp 23-28.

RUCKLESHAUS, W.D. (1989). 'Toward a Sustainable World', Scientific American, v 261, n 3, pp 114-120C.

SCHNEIDER, S.H. (1989). 'The Changing Climate', ibid, Scientific American, v 261, n 3, pp 38-47.

SCHUMANN, E.H. (1986). 'Assessing oil pollution potentials for the South African coast'. South African Journal of Science, v 82, pp 240-242.

SCHUTZ, C.J. AND WINGFIELD, M.J. (1979). A health problem in mature stands of Pinus taeda in the Eastern Transvaal. South African Forestry Journal, n 109, pp 47-49.

SCOTT, M.J. ET AL (1989). Global Energy and the Greenhouse Issue. 14th Congress of the World Energy Conference, Montreal (17-22 Sept).

SMITH, D.A.M. AND WHITTAKER, R.R.L.G. (1986). The coalfields of Southern Africa. Mineral deposits of Southern Africa, pp 1875-1878.

SNYMAN, G.M. ET AL (1987).'Seasonal variation in airborne sulphate pollution on the South African highveld'. South African Journal of Science, v 83, pp 541-544.

STAUTH, R. (1983). 'The Environmental Implications of Nuclear Power in South Africa', S.A. Institute of Ecologists Bulletin, April, pp 12-48.

STEFFEN, ROBERTSON AND KIRSTEN (1982). An investigation of the disposal of ash from Lethabo Power Station - Assessment of dust pollution. Report No. MI.2548.

STRAHLER, F.B. AND STRAHLER, F.T. (1974). Introduction to Environmental Science. Hamilton.

TERBLANCHE, A.P.S. AND LER MURRAY, P.W. (1990). Health Aspects of diesel emissions. 1st IUAPPA Regional Conference, Pretoria (Oct).

TURNER, C.R. ET AL (1990). The relationship between emissions in the ETH and regional rainfall chemistry. 1st IUAPPA Regional Conference, Pretoria (Oct).

VAN ZINDEREN BAKKER, E.M. (1981). 'Future Climatic Changes', South African Journal of Science, v 77, pp 437-440.

VENN, A.C. ET AL (1979). Environmental planning for coal strip mining. Symposium on shaping our environment, Pretoria (Aug).

VAN NIEKERK, B. v.D. (1979). The Use Of Existing Legal Machinery In The Fight Against Environmental Pollution. Air Pollution '79.

VON SCHIRNDING, Y. (1984). 'Lead in the environment', Society for the protection of the environment newsletter, v 14, n 1-2.

ZOLLNER, E.F. (1989). The Application of Cost-Benefit Analysis to South African Pollution Problems - with special reference to the Eastern Transvaal Highveld. Economic Honours Long Paper, UCT.

Appendices

APPENDIX ONE - REFERENCE TABLES

Appendix 1.1

Gas	Energy	Agric/ Silvic	Anthro	Natural	Total	Incr/yr (%)	Contrib (%)[1]
CO_2 ($X10^3$)	4,5-5,5	0-2,6	0,1	111-169	116-237	0,45	55
CH_4	30-110	80-210	25-135	77-317	212-272	1	15
CO	150-250	120-520	0-80	160-1100	430-1950	?	?
CFC-11	0	0	~0,33	0	~0,33	4	3
CFC-12	0	0	~0,44	0	~0,44	4	7
N_2O	3-6	1-3	N/A	1-3	6-12	0,2-0,3	4
O_3	?	?	?	?	2700-4200	~1	10

(1) contribution to global warming since pre-industrial times

Table A1.1 *Sources of radiatively active trace gases (in millions of tonnes) (After Hahn,1990:21,24 and Scott et al,1989:7)*

Appendix 1.3

Pollutant	Primary Standard[1] [µg/m^3]	Secondary Standard[1] [µg/m^3]
SO_2	80 - annual arithmetic mean 365 - maximum 24-hour concentration[2]	60 - annual arithmetic mean 260 - maximum 24-hour concentration
NO_x	100 - annual arithmetic mean	same as primary
O_3	240 - maximum one-hour concentration[2]	same as primary
Particulates	75 - annual geometric mean 260 - maximum 24-hour concentration[2]	60 - annual geometric mean 150 - maximum 24-hour concentration
Hydrocarbons	160 - maximum one-hour concentration[2]	same as primary
CO	10 000 - maximum eight-hour concentration[2]	same as primary

(1) Primary standards are those which protect public health with some margin of safety while secondary standards are set to protect public welfare

(2) Not to be exceeded more than once a year

Table A1.3 *EPA National Ambient Air Quality Standards (Stewart,1979:37)*

Appendix 1.4

Year	Number of exceedences	
	Hourly	Daily
1979/1980	4	0
1980/1981[1]	10[2]	5[4]
1981/1982[1]	3	0
1982/1983	2	1
1984	2	1
1985	1	0
1986	16[3]	1

(1) Incomplete data may bias results
(2) Eight of these exceedences occurred at a site (Grootpan) which was under the influence of a nearby burning coal discard dump
(3) 15 of these exceedences occurred at a site which is adjacent to Komati power station, which has extremely short stacks
(4) All these exceedences occurred at Grootpan

Table A1.4 *Exceedences of DoH guidelines for ambient SO_2 concentrations in the ETH (1979 to 1986) (Tyson et al,1988:48)*

Appendix 1.5

Site	Hourly [µg/m³]			Daily [µg/m³]			Monthly [µg/m³]		Annual [µg/m³]	Period average [µg/m³]
	50th	99th	max	50th	99th	max	50th	max	max	
Central ETH										
Komati	15,8	118	262	19,3	67,6	115	21,5	29,6	21,6	22,3
Elands	10,1	72,4	263	12,8	35,9	64,7	13,9	21,2	14,3	14,4
Phoenix	12,4	74,7	321	12,8	46,7	91,4	13,5	31,6	18,6	14,7
Vaal Triangle										
Vaalpark	20,7	83,8	193	21,3	43,1	69,0	22,7	43,9	29,2	23,8

Table A1.5 *NO_x concentration centiles and mean annual averages in the ETH (1983 to 1988) (after Turner,1990:42)*

Appendix 1.6

Region	Period	pH
E.T.H.		
Ermelo	1985/1986	4,0
Standerton	1985/1986	3,9
Amersfoort	1985/1986	4,1
Piet Retief	1985/1986	4,0
Volksrust	1985/1986	4,2
Topfontein	1985/1986	4,6
Lowveld		
D R de Wet (Sabie)	1986	4,2
	1986/1988	4,2
Punda Maria (Kruger N.P.)	1983/1984	4,8
OFS		
Frankfort	1985/1986	4,1
Warden	1985/1986	4,0
Natal		
Vryheid	1985/1986	4,2
Ladysmith	1985/1986	4,3
Winterton (Cathedral Peak)	1986/1988	4,8

Table A1.6 *Selected rain pH readings in the ETH and adjacent regions (Tyson et al,1988:61 and van Wyk,1990:4)*

Appendix 1.7

Region	Year	H^+	$SO_4^{=}$	NO_3^-	H_4^+
ETH					
Ermelo	1985/1986	0,60	18,17	9,17	3,27
Standerton	1985/1986	0,75	19,06	11,35	4,88
Amersfoort	1985/1986	0,53	15,89	9,53	3,41
Piet Retief	1985/1986	0,60	17,85	10,46	3,98
Volksrust	1985/1986	0,47	16,00	9,08	3,15
Topfontein	1985/1986	0,31	24,00	4,00	-
Lowveld					
D R de Wet	1986/1988	0,82	32,89	2,58	3,38
OFS					
Frankfort	1985/1986	0,44	14,04	7,14	2,79
Warden	1985/1986	0,52	11,20	7,99	2,04
Natal					
Vryheid	1985/1986	0,48	13,98	8,07	3,01
Ladysmith	1985/1986	0,40	10,69	5,35	3,49
Winterton	1986/1988	0,22	49,75	4,22	7,14

Table A1.7 *Wet deposition rates of various anions in the ETH and adjacent regions (kg/ha/yr) (Tyson et al,1988:62 and van Wyk,1990:11)*

Appendix 1.8

Determinant	Jonkershoek (Stellenbosch)	Dry deposition as % of total	Winterton (Cathedral Peak)	Sabie (D R de Wet)	Dry deposition as % of total
Na^+	23,6	8,1	12,7	14,3	7,8
K^+	4,9	10,2	8,6	4,1	15,0
Ca^{2+}	6,4	12,9	20,7	7,1	17,2
Mg^{2+}	2,5	14,5	4,5	0,2	43,5
NH_4^+	1,3	23,7	7,1	3,4	30,4
H^+	0,1	-	0,2	0,8	-
Cl^-	47,3	6,3	35,6	25,8	7,0
SO_4^-	29,5	3,0	49,8	32,9	2,7
NO_3^-	0,5	20,7	4,2	2,6	24,2
PO_4^{3-}	0,3	20,7	0,3	0,6	40,4
HCO_3^-	50,7	3,2	110,6	39,5	2,0
TP	0,5	71,7	1,0	4,1	8,2
KN	3,9	17,1	15,2	10,2	24,3
Si	4,5	2,3	15,2	3,7	5,1
F	0,3	15,1	0,7	0,4	11,7
TDS	197,9	5,7	297,1	162,5	7,0
pH	5,17		4,81	4,18	

TP = total phosphate
KN = total nitrogen
TDS = total dissolved solids

Table A1.8 *Mean mass atmospheric deposition (kg/ha/yr) at Jonkershoek, Winterton and Sabie (van Wyk,1990:11)*

Appendix 1.9

City/Town/Region	Maximum 48/72 hour average (1988/89) [µg/m³]	Range of monthly averages (1988/89) [µg/m³]	Range of annual averages (1988/89) [µg/m³]	Range of mean annual averages (1985 to 1989) [µg/m³]
Cape Town	44	1-24	4-13	3-11
Western Cape**	65	0-32	3-11	4-9
East London	109	0-49	2-28	3-12
Port Elizabeth	93	1-38	6-15	4-15
Uitenhage	-	-	10	-
Durban	322	2-141	15-76	15-63
Amanzimtoti	9	-	-	-
Estcourt	50	0-26	-	-
Newcastle	15	9-12	11-12	11-12
Pinetown	133	1-47	-	-
Pietermaritzburg	105	3-30	9-13	6-13
Richards Bay	78	2-53	-	60
Bethlehem	18	0-5	-	7-8
Bloemfontein	29	0-11	-	28-30
Kroonstad	46	5-24	-	-
Sasolburg	81	2-17	-	-
Welkom	46	1-22	-	-
Alberton	223	4-134	17-25	21-34
Bedfordview	-	-	-	-
Benoni	-	-	-	-
Boksburg	446	14-225	23-123	26-60
Edenvale	55	1-31	8-14	15-19
Germiston	-	-	-	-
Johannesburg	-	-	-	-
Kempton Park	-	-	-	-
Klerksdorp	-	-	-	-
Meyerton	-	-	-	-
Middelburg	76	2-35	16-28	7-10
Nelspruit	-	-	-	-
Pietersburg	20	2-11	5	-
Pretoria	113	1-85	8-46	10-25
Randburg	-	-	-	-
Roodepoort	-	-	-	-
Springs	496	5-144	18-50	33-47
Vanderbijlpark	58	1-33	8-14	10-21
Vereeniging	120	1-35	10-21	-
Witbank	125	1-66	7-40	14-20

- = insufficient or bad data

** = Bellville, Goodwood, Pinelands, Parow, Elsies River, Kayelitsha

Table A1.9 *SO_2 concentrations in various South African cities, towns and regions (1988/89) (Ellerbeck,1990)*

Appendix 1.10

City/Town area	Number of sites	SO_2 (1959 to 1989)				SO_2 (1985 to 1989)			
		I	O	D	*/-	I	O	D	*/-
Cape Town	4	-	3	1	1	-	3	-	1
Western Cape**	6	-	1	1	1	-	4	1	1
East London	3	-	-	-	-	-	2	-	1
Port Elizabeth	6	-	2	1	1	2	1	2	1
Uitenhage	-	-	-	-	-	-	-	-	-
Durban	14	-	2	3	3	-	9	1	4
Amanzimtoti	3	2	-	1	1	-	-	-	3
Estcourt	2	-	-	2	2	-	-	-	2
Newcastle	4	-	2	-	-	-	4	-	-
Pinetown	4	1	-	3	3	-	-	-	4
Pietermaritzburg	6	-	1	-	-	-	6	-	-
Richards Bay	6	-	-	-	-	-	-	-	6
Bethlehem	3	6	-	-	-	-	1	1	1
Bloemfontein	4	-	3	-	-	-	1	1	2
Kroonstad	2	-	2	-	-	-	-	-	2
Sasolburg	3	-	-	3	3	-	-	-	3
Welkom	3	-	-	3	3	-	-	-	3
Alberton	3	-	-	-	-	-	2	2	1
Bedfordview	1	1	-	1	1	-	-	-	1
Benoni	-	-	-	-	-	-	-	-	-
Boksburg	6	-	-	2	2	1	3	3	2
Edenvale	2	1	1	-	-	-	2	2	-
Germiston	-	-	-	-	-	-	-	-	-
Johannesburg	-	-	-	-	-	-	-	-	-
Kempton Park	-	-	-	-	-	-	-	-	-
Klerksdorp	-	-	-	-	-	-	-	-	-
Meyerton	-	-	-	-	-	-	-	-	-
Middelburg	3	-	-	-	-	-	3	3	-
Nelspruit	-	-	-	-	-	-	-	-	-
Pietersburg	2	-	-	2	2	-	-	-	2
Pretoria	6	-	4	-	-	-	6	6	-
Randburg	-	-	-	-	-	-	-	-	-
Roodepoort	-	-	-	-	-	-	-	-	-
Springs	5	-	1	3	3	-	2	2	3
Vanderbijlpark	6	-	1	1	1	-	4	4	1
Vereeniging	3	-	-	3	3	-	-	-	3
Witbank	4	1	-	1	1	-	3	2	1
Total	114	12	48	23	31	3	56	7	48

I = significant linear increase
O = no significant change
D = significant linear decrease
*/- = insufficient data
** = Bellville, Goodwood, Pinelands, Parow, Elsies River, Khayelitsha

Table A1.10 *Long term and short term trends in winter SO_2 concentrations (after Ellerbeck,1990)*

Appendix 1.11

City/Town/Region	Maximum 48/72 hour averages (1988/89) [S/m³]	Range of monthly averages (1988/89) [S/m³]	Range of annual averages (1988/89) [S/m³]	Range of mean annual concentrations (1985-1989) [S/m³]
Cape Town	29	3-11	5-7	6-8
Western Cape**	31	0-11	1-4	3-7
East London	9	0-5	1-3	1-5
Port Elizabeth	28	0-14	2-7	3-12
Uitenhage	21	3-7	-	4
Durban	42	0-24	3-13	4-19
Amanzimtoti	6	-	-	-
Estcourt	7	0-3	2	5
Newcastle	11	1-7	2-4	4-6
Pinetown	37	0-10	2-5	5-8
Pietermaritzburg	39	2-18	5-10	4-13
Richards Bay	32	0-5	-	2-3
Bethlehem	20	0-10	2-6	5-12
Bloemfontein	33	1-21	2-4	4-19
Kroonstad	50	2-23	4-9	9-20
Sasolburg	15	0-19	3-4	-
Welkom	52	1-21	-	3-13
Alberton	40	3-16	2-11	4-17
Bedfordview	30	1-26	9	11
Benoni	43	1-35	2-12	4-18
Boksburg	173	2-14	4-16	8-18
Edenvale	46	3-16	4-8	5-9
Germiston	30	4-24	4-10	5-10
Johannesburg	46	3-12	8-16	9-21
Kempton Park	27	1-8	-	6-8
Klerksdorp	23	1-18	3	4-5
Meyerton	29	2-10	5-7	8-10
Middelburg	20	0-8	-	7-9
Nelspruit	14	1-7	2-3	4
Pietersburg	12	1-23	4	4-5
Pretoria	75	1-7	2-14	4-19
Randburg	18	1-9	3-4	4-6
Roodepoort	18	1-8	3-5	7
Springs	34	2-17	5-9	9-14
Vanderbijlpark	27	2-16	5-8	8-12
Vereeniging	34	1-20	4-11	-
Witbank	22	1-12	2-7	4-7

- = insufficient or bad data

** = Bellville, Goodwood, Pinelands, Parow, Elsies River, Khayelitsha

Table A1.11 *Smoke concentrations in various South African cities, towns and regions (1988/89) (Ellerbeck,1990)*

Appendix 1.12

City/Town area	No of sites	Smoke (1959 to 1989)				Smoke (1985 to 1989)			
		I	O	D	*/-	I	O	D	*/-
Cape Town	4	-	-	3	1	1	2	-	1
Western Cape**	7	-	3	2	2	-	4	1	2
East London	3	-	2	1	-	1	2	-	-
Port Elizabeth	10	1	5	4	-	1	5	4	-
Uitenhage	1	-	1	-	-	-	1	-	-
Durban	14	-	7	4	3	-	10	-	4
Amanzimtoti	3	2	1	-	-	-	-	-	3
Estcourt	2	-	-	-	2	-	-	-	2
Newcastle	4	-	2	2	-	-	4	-	-
Pinetown	4	-	2	-	2	-	2	-	2
Pietermaritzburg	6	1	2	3	-	-	6	-	-
Richards Bay	6	3	3	-	-	-	-	-	6
Bethlehem	3	-	-	3	-	-	3	-	-
Bloemfontein	4	-	-	4	-	-	4	-	-
Kroonstad	3	-	-	3	-	-	2	1	-
Sasolburg	4	-	-	-	4	-	-	-	4
Welkom	3	-	2	1	-	-	2	1	-
Alberton	3	-	3	-	-	-	3	-	-
Bedfordview	1	-	1	-	-	-	1	-	-
Benoni	4	-	1	3	-	-	4	-	-
Boksburg	6	-	1	4	1	-	4	1	1
Edenvale	3	-	1	2	-	-	3	-	-
Germiston	4	-	1	3	-	1	3	-	-
Johannesburg	2	-	-	2	-	-	2	-	-
Kempton Park	2	-	1	1	-	-	2	-	-
Klerksdorp	2	-	2	-	-	-	2	-	-
Meyerton	3	1	1	-	1	1	1	-	1
Middelburg	3	-	3	-	-	1	2	-	-
Nelspruit	3	-	3	-	-	-	3	-	-
Pietersburg	2	1	1	-	-	-	2	-	-
Pretoria	6	-	2	4	-	-	6	-	-
Randburg	3	-	-	2	1	-	2	-	1
Roodepoort	4	-	2	-	2	-	2	-	2
Springs	5	-	1	1	3	-	2	-	3
Vanderbijlpark	6	-	5	-	1	-	5	-	1
Vereeniging	3	-	-	-	3	-	-	-	3
Witbank	4	-	2	1	1	-	3	-	1
Total	150	9	61	53	27	6	99	8	37

I = significant linear increase

O = no significant change

D = significant linear decrease

*/- = insufficient data

** = Bellville, Goodwood, Pinelands, Parow, Elsies River, Kayelitsha

Table A1.12 *Long term and short term trends in winter smoke concentrations (Ellerbeck et al,1990)*

Appendix 1.13

Pollutant	1984 [µg/m³]	1985 [µg/m³]	1986 [µg/m³]	1987 [µg/m³]	1988/89 [µg/m³]	1989/90 [µg/m³]
NO_x	229	180	199	215	196	238
NO	169	149	150	154	140	182
NO_2	58	55	47	60	55	57
O_3	-	-	9	16	13	9
HC	-	-	72	-	-	-

Table A1.13 *Annual mean levels of NO_x, NO, NO_2, O_3 and HC at Cape Town City Hall (1984-1989/90) (Cape Town Medical Officer of Health)*

Appendix 1.14

City	Period	24-hour average [ppb]	Maximum 24-hour average [ppb]
Pretoria	May/Aug 1986	0,355-0,656	0,849-1,623
	Dec/Feb 1987	0,180-0,301	0,393-0,814
Cape Town	May 1988	0,102-0,163	0,474-0,859
	Mar/Apr 1989	0,215-0,619	0,670-2,809
Johannesburg	Aug 1988	0,474-0,501	1,255-1,293

Table A1.14 *Monthly average daytime PAN (06h00 to 18h00) levels in Pretoria, Cape Town and Johannesburg (Grosser and Baunok,1989:230)*

Appendix 1.15

Site	1986 [µg/m³]	1987 [µg/m³]	1988/89 [µg/m³]	1989/90 [µg/m³]
City Hall	1,4	1,2	1,0	0,7
Epping Market	0,6	0,7	0,6	0,4
Paarden Eiland	0,8	0,9	0,8	1,1
Heerengracht	1,1	1,2	1,0	0,7
City Hospital	0,4	0,4	*	*
Camden Street	0,2	0,2	*	*
Drill Hall	0,6	0,7	0,6	0,4
Salt River	0,5	0,4	*	*

* indicates monitoring discontinued

Table A1.15 *Average of monthly means for lead concentrations at sites in Cape Town (Cape Town Medical Officer of Health,1986-1989/90)*

Appendix 1.16

Month/Year	Monthly average [µg/m³]	Instantaneous maximum [µg/m³]	one-hour maximum [µg/m³]	24-hour maximum [µg/m³]
June 1983	72	774	494	122
July	63	518	383	124
August	57	740	385	147
September	50	456	301	92
October	35	375	140	57
November	49	278	170	61
December	-	196	153	55
July 1984	59	890	421	128
August	36	401	293	80

Table A1.16 *Soweto NO_x concentrations (1983/1984) (After Turner et al,1984:9 and Rorich,1986:12)*

Appendix 1.17

Site	Date	Monitoring period	Concentration [µg/m³]
Tladi Clinic	July 1973	monthly	340
		24 hour	685
		1 hour	3940
	June 1982	monthly	520
		24 hour	1040
		1 hour	4520
Mofolo Clinic	June 1982	monthly	465
		24 hour	680
		1 hour	3270

Table A1.17 *Maximum smoke concentrations in Soweto (June 1972 to September 1973 and April to August 1982 (Kemeny et al,1988:155 to 157)*

Appendix 1.18

Element	Average concentration [µg/m³]	Maximum two-hour [µg/m³]	Maximum 24-hour [µg/m³]
Si	9,3	37,4	16,2
S	1,7	8,4	2,8
Fe	1,7	6,9	2,8
Br	0,1	1,5	0,3
Pb	0,3	3,1	0,8

Table A1.18 *Concentrations of various elements in aerosols from Soweto (after Annegarn et al,1981:437)*

APPENDIX TWO - CALCULATION OF POLLUTION EMISSIONS

Appendix 2.1 Coal use

Electricity generation

a) The emission factors in Table A2.1 were used and an average bituminous coal composition was assumed: sulphur 1%, ash 25% and carbon 55%.

b) Carbon dioxide emissions were calculated by assuming that all carbon present in the coal was oxidised to CO_2. The amount of carbon used in the formation of CO was not taken into account, but generally forms a relatively small part of the total carbon.

c) An average ESP efficiency of 99,7% was assumed.

Pollutant/Sector	Electricity generation [kg/tonne]	Industrial, metallurgical and mining [kg/tonne]	Commerce [kg/tonne]	Transport and domestic [kg/tonne]
SO_2	19S	19S	19S	19S
NO_x	9	7,5	3	1,5
Particulates	8A X (1-eff_{ESP})	6,5A X (1-eff)	1A	10
HC_x	0,15	0,5	1,5	10
CO	5	1	0,5	45

S = percentage sulphur in the fuel
A = percentage ash in the fuel
eff_{ESP} = ESP efficiency
eff = efficiency of pollution control equipment

Table A2.1 *Emission coefficients for bituminous coal usage in various sectors (Sittig,1975:245)*

Industrial, metallurgical and mining sectors

The industrial sector consumption includes the portion of coal in the merchants and domestic category that is used in small commercial and industrial operations (4,51 million tonnes), but is less the 0,7 Mt estimated to be used as a feedstock in chemical processes. The emissions for small commercial and industrial operations were calculated using emission coefficients which are more appropriate for smaller furnaces and boilers.

a) Average ash, sulphur and carbon contents of 20%, 1% and 60% were assumed for the coal used in this sector.

b) There is little information describing the type and prevalence of pollution control equipment fitted in South African industries. For these calculations it was assumed that the only pollution control equipment fitted to industrial equipment was particulate control equipment fitted to large scale boilers and furnaces. A further assumption was that this equipment had an average efficiency of 70%.

Transport and domestic sectors

The same average coal composition as used for the industrial sector was assumed, and emission factors for hand-fired boilers were used (Table A2.1). Coal consumption in domestic environments is probably far more inefficient and these estimates can be regarded as quite conservative.

Appendix 2.2 Petroleum fuel use

a) Emission coefficients for domestic oil (Sittig,1975:294) were employed for the use of paraffin (Table A2.2). No emission factors for jet fuel were available and so the same emissions factors were used. The specific gravities in Table A2.3 were used to calculate the volumes of fuel used.

b) For residual fuel and paraffin a sulphur content by weight of 0,5% was assumed.

c) Carbon dioxide emissions were calculated by assuming that all carbon present in the fuel was completely oxidised to CO_2. The amount of carbon used to form CO and hydrocarbons were assumed to be relatively small, and were not taken into account when calculating CO_2. The carbon content of the fuels appear in Table A2.3.

Pollutant	Residuals [kg/1000l]	Paraffin [kg/1000l]	Petrol [kg/1000l]	Diesel [kg/1000l]	LPG [kg/1000l]
SO_2	19S	17S	1,1	4,8	-
NO_x	7,2	1,5	13,6	26,6	1,3
Particulates	2,75	1,2	1,4	13,2	0,2
HC_x	0,35	0,35	24	16,3	0,1
CO	0,5	0,6	276	7,2	0,2

S = percentage sulphur in the fuel

Table A2.2 *Emission coefficients for the use of petroleum fuels (Sittig,1975:294 and Ledbetter,1972:37)*

Fuel	Specific gravity	Carbon content [%]
Residuals	0,86	86,5
Paraffin	0,85	86,5
Petrol	0,70	85,0
Diesel	0,88	86,5
LPG	0,56	82,0

Table A2.3 *Characteristics of petroleum fuels*

Appendix 2.3 Renewable fuels use

a) The same emission coefficients were used for the combustion of wood, wood-wastes and bagasse. It was assumed that combustion of biomass fuels occurred only in the domestic and industrial sectors. The emissions were broken down into sectors according to a 70:30 ratio of domestic to industrial use (in proportion to the mass of fuel used in each sector).

b) Emission coefficients for commercial wood waste combustion were used and are very approximate. Where a range of coefficients was given, an average value was taken (Table A2.4).

c) An average fixed carbon content of 40% was assumed. Char was taken as 15% of the mass of the fuels and to consist entirely of carbon. CO_2 emissions were calculated as if the full amount of carbon not remaining in the char was fully oxidised. The CO and HC_x emissions were calculated separately.

d) The pollutants produced during the manufacture of charcoal were included in the calculations (Table A2.4) but the pollutants produced by the final use of charcoal were not taken into account as these contributions were thought to be small.

Pollutant	Combustion [kg/tonne]	Charcoal manufacture [kg/tonne]
SO_2	0,75	-
NO_x	5	-
Particulates	15	200
HC_x	18	50
CO	16	160

Table A2.4 *Emission coefficients for biomass use (Sittig,1975:521)*

Appendix 2.4 Regional breakdown

Various statistics were used to provide an indication of the geographical distribution of sectorial emission sources, and the emissions from each sector were broken down proportionately. The emissions due to all sectorial sources situated in a region were then added to give the total emissions for that region.

The following criteria were used to break down the sectoral contribution of each region (1989 statistics were used where possible):

a) Emissions due to electricity generation were divided in proportion to the installed generating capacity of coal, gas turbine and diesel stations in each region (see Eskom (1990:12) and UMESA (1989:481)).

b) SASOL II and III are situated in region F. No data is available for emissions from SASOL I which is situated in region H.

c) Emissions due to industry and the emissions from ferrous and non-ferrous basic metals industries, were divided amongst regions in proportion to the regional gross value of the output of these sectors (as determined in the 1985 census) (see CSS (1990:12.44)).

d) Domestic and transport sectorial emissions were distributed amongst the regions in proportion to the regional population distribution (see Calitz (1990:11)).

e) Emissions from mining industries were broken down in proportion to the number of mines supplied with electricity in each region in 1990 (practically all mines are electrified) (see Eskom (1991:20)).

f) Emissions due to the use of fuel in the agricultural sector were broken down according to the proportion of the total area of cultivated and afforested land in each region (see LHA (1990:14)).