LONG–TERM TRENDS IN SMOKE AND SULPHUR DIOXIDE POLLUTION IN THE REPUBLIC OF SOUTH AFRICA

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SUMMARY:

Over the past 25 years a national survey on smoke and sulphur dioxide has been developed in the Republic of South Africa which at present collects data on smoke at 114 monitoring sites and on sulphur dioxide at 66 sites. The measurement procedure used is the South African filter paper method which, as far as sampling is concerned, is similar to the British method. The evaluation procedure for smoke, however, is different in order to minimize the influence of natural dust particles of light colour which are also suspended in the atmosphere due to the dry climate. The method evolved is specific for the dark smoke and carbonaceous particles.

The monitoring data, satistically evaluated by the Air Pollution Research Group, prove that *the air quality over urban areas has improved despite industrial development and expansion.*

Applying the long-term goals recommended by the World Health Organization, in absence of appropriate standards for the Republic of South Africa, it is evident that, *as far as sulphur dioxide is concerned, the goals of the World Health Organization are generally met.* For smoke and carbonaceous particulates this is not the case: a number of monitoring sites in the central and industrial areas of the major cities do not meet the limits of the World Health Organization, which appear to be low.

It can be expected that the smoke levels will continue to decrease in South Africa due to the strict control measures applied.

OPSOMMING:

Gedurende die afgelope 25 jaar is 'n nasionale meetprogram vir rook- en swaeldioksied ontwikkel wat tans uit 114 meetstasies vir rook en 66 stasies vir swaeldioksied bestaan. Die Suid-Afrikaanse filtreerpapiermetode word gevolg waarvan die monsterneming ooreenstem met die Britse metode. Die evalueringsproses vir rook verskil van die Britse metode om die invloed van natuurlike stofdeeltjies wat lig van kleur is en wat as gevolg van die droë klimaat ook in die lug gesuspendeer word, tot 'n minimum te beperk. Die metode word spesifiek toegepas op donker rook- en koolstofhoudendende deeltjies.

Die data, wat statisties deur die Lugbesoedelingnavorsingsgroep geëvalueer word, toon aan dat *die lugkwaliteit oor stedelike gebiede verbeter het ten spyte van nywerheidsontwikkeling en uitbreiding.*

In vergelyking met die standaarde wat deur die Wêreldgesondheidsorganisasie aanbeveel word (in die afwesigheid van neergelegde standaarde in Suid-Afrika) is dit *duidelik dat die grenswaarde van dié organisasie vir swaeldioksied bevredig word.* Sover dit rook- en koolstofdeeltjies aanbetref, is dit egter nie die geval nie: 'n aantal meetstasies in die sentrale en nywerheidsgebiede van die groot stede oorskrei die grenswaarde van die Wêreldgesondheidsorganisasie wat laag skyn te wees.

Daar kan egter verwag word dat die rookkonsentrasies steeds sal verminder in Suid-Afrika as gevolg van beheermaatreëls.

INTRODUCTION

Concern about the visible deterioration of the air quality over built-up urban areas lead to the first attempt to measure the concentrations of smoke and sulphur dioxide in the Republic of South Africa. The organisation responsible for finding suitable measurement methods was the National Physical Research Laboratory of the Council for Scientific and Industrial Research and the city where the first survey was introduced in 1955 was Pretoria, the home town of the CSIR. When the measurement programme proved successful, it was recommended to other cities. It was taken up immediately by Cape Town, Johannesburg and Durban which were more industrialized than Pretoria. Other major cities like East London, Germiston and Pietermaritzburg followed suit so that by 1965 when the Atmospheric Pollution Prevention Act came into force, the levels of smoke and sulphur dioxide pollution were known in many, and from the air pollution point of view, significant areas.

Between 1965 and 1970 the importance of monitoring smoke and SO_2 in urban atmospheres as a scientific means for studying the effectiveness of control measures became widely recognised and many towns, though not densely populated but housing one or more big industries within their boundaries, started with surveys. The greatest increase in the number of towns taking up monitoring work took place when the State Department of Health decided to grant subsidies to local authorities for the acquisition of the apparatus which was standardized to measure smoke and SO_2 in the Republic.

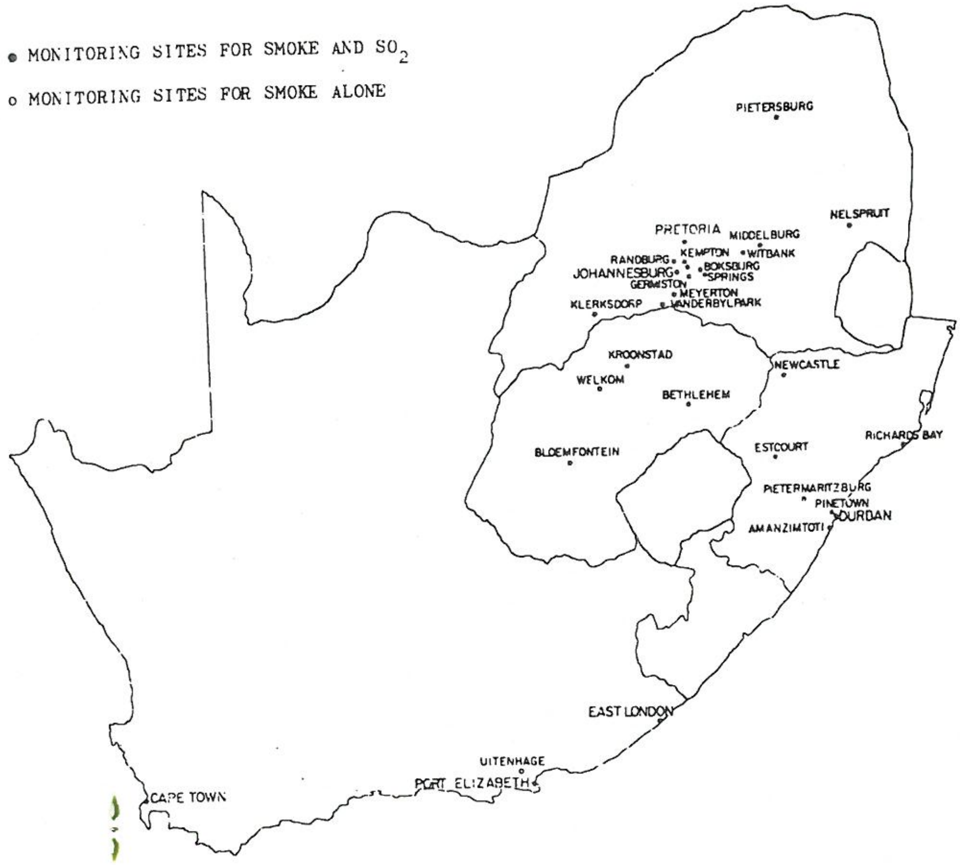

FIG 1 Monitoring sites in the Republic of South Africa

The Air Pollution Research Group which is the successor to the division in the NPRL which started the investigations into environmental pollution, continued its research activities, and by doing so achieved the role of scientific adviser to the local authorities on, what developed into a National Survey on smoke and SO_2. The Group continued the monitoring work in Pretoria until the end of 1977 when it was taken over by the City of Pretoria. The APRG analyses statistically the measurement results obtained by the National Survey and publishes at regular intervals some data of importance in air pollution control.

At the beginning of 1979 the National Survey comprised

- 30 cities and towns with 114 monitoring sites for smoke, and
- 16 cities and towns with 66 monitoring sites for sulphur dioxide.

The monitoring sites are spread over the whole country though the greatest number is to be found in the Johannesburg – Witwatersrand area which is the most densely populated and most industrialized area in the Republic of South Africa (Figure 1).

Over the years the National Survey Supplied valuable information on the levels of smoke and SO_2 and on their seasonal and spatial variations. The efforts made in the Republic of South Africa to improve the air quality over urban areas, however, are best shown by the long-term trends of smoke and SO_2.

SOUTH AFRICAN STANDARD METHOD FOR MONITORING SMOKE

Introduction of the soiling index

When the NPRL started its studies in 1955 neither standardized methods nor automatic recorders were commercially available. Because information on the pollution levels, which appeard to be high in South Africa was required without delay, the NPRL adopted the British filter paper method for the initial survey in Pretoria[1,2]. Experience gained during this investigation lead the research scientists in Pretoria to reconsider the British method which consisted of

1. collecting smoke particles on a filter paper, and measuring the light transmission (or reflection) of the stain, and

2. converting the photometric reading into the mass of smoke by means of a pre-established curve.

In Britain the conversion curve was found by taking two smoke samples in parallel, the one on the filter paper and the other on a medium which allowed the smoke mass to be weighed directly. Step two proved difficult in Pretoria because fine particles of natural dust were suspended in the atmosphere due to the dry climate and were collected together with the smoke particles. The dust problem, which probably was never encountered in England, lead the APRG to investigate a new concept of thinking which was proposed in the USA though motivatd by different reasons. There Hemeon *et al.*[3] suggested that the smoke concentrations be expressed in an arbitrary unit, based on the optical properties of the smoke particles, and not as a mass concentration, in order to avoid the determination of the conversion curve which was not only time consuming but had to be repeated frequently. Hemeon introduced the COH (Coefficient of Haze) unit which is generally used in the USA.

Experimental studies carried out in Pretoria revealed that the COH-unit did not apply to the South African filter paper apparatus because this manual apparatus did not work with constant volumes. Nevertheless, an arbitrary unit could be introduced for this sampler, but it had to be taken into account that between the concentration of smoke (K) and optical density (D) a relationship of the form

$$K = a \cdot D^{5/3} \text{ where a is a constant} \quad (1)$$

existed and not a linear one as assumed in the USA.[4]

Since October 1958 the smoke concentrations measured in the Republic of South Africa are expressed by a quantity called "Soiling Index"[5,6]. The indices were found to fluctuate between 0 and 100 in urban areas, a range small enough to be easily understood and well suited for statistical operations even at places where computers were not available.

Conversion of soiling index into mass concentration

The question of how the soiling index could be converted into a mass concentration in a practical way was studied in the centre of Pretoria between 1958 and 1961 using an electrostatic precipitator for obtaining weighable samples. Sampling intervals of three hours were chosen, the calibration tests starting either at 06h00, 09h00 and so on; a few tests were also carried out during the night. The study showed that it was possible to convert the soiling index into a mass concentration by multiplying it by a suitable conversion factor. These were found to fluctuate between 4,1 and 48,8 according to the time of the day and the season the calibration tests were carried out. The microscopic study gave the explanation: the samples collected in the electrostatic precipitator consisted of smoke and dust particles, mixed in varying ratios. By conducting a great number of calibration tests during winter mornings when the atmospheric conditions were stable and dust was not raised from the ground, the average conversion factor was found to be

$$b = 5{,}1 \quad (2)$$

The mass concentration of smoke, expressed in $\mu g/m^3$, is obtainable by means of the equation

$$y = 5{,}1 \times K \quad (3)$$

y being the mass concentration and K the soiling index.[7]

Calibration tests were also carried out in Durban, Johannesburg and Germiston with similar results and the conversion factor 5,1 was recommended to local authorities intending to use gravimetric units.

Re-assessment of the standard method for measuring smoke

During the last few years the South African standard method for smoke was re-assessed because of two reasons:

(i) the particles collected on the filter papers were no longer smoke produced by the combustion of coal as was the case in the years when the evaluation method was evolved, but were produced by a variety of sources, one of them being diesel engined vehicles whose numbers increased over the years,

(ii) in towns which were small in size but housed prominent specific industries, fine particulates which were not carbonaceous were collected together with the smoke particles and the basic relationship between concentration, light transmission and optical density may have been changed.

The study, carried out between 1975 and 1978, was similar to the one which supplied the equations (1) and (3), only the electrostatic precipitator was replaced by a membrane filter unit which was assembled by the APRG in such a way that it collected a size spectrum of particles similar to that collected on the filter papers of the standard sampler, i.e. particles smaller than 10 μm. The monitoring sites chosen for the study were situated

1. in the centre of Pretoria
2. on the Foreshore and in Green Point in Cape Town, and
3. in towns on the Witwatersrand and in the Transvaal.

Studies were also carried out in Johannesburg by the Chief Air Pollution Control Officer who made use of a Philips recorder for obtaining weighable particulate samples.

The three year study may be summarized as follows:

1. Equation (1) describing the relationship between smoke concentration and optical density is still applicable, even at monitoring sites where natural or industrial particles are suspended in the atmosphere

2. The evaluation process which is based on the measurement of light transmitted by the particles collected minimizes the interference by particles of light colour and favours dark, i.e. smoke and carbonaceous particles

3. The soiling index remains the correct unit for expressing the concentrations of smoke and carbonaceous matter in the Republic of South Africa, provided the South African sampling instrument is used

4. The mass concentrations of smoke and carbonaceous matter, expressed in $\mu g/m^3$, may be obtained by multiplying the soiling index by the conversion factor $b'' = 5,0$.

The conversion factor 5,0 was used for obtaining the mass concentrations of smoke and carbonaceous matter which appear in table 4.

THE SOUTH AFRICAN STANDARD METHOD FOR MONITORING SULPHUR DIOXIDE

For obtaining the concentrations of SO_2 the hydrogen peroxide method is used in the Republic of South Africa. The method consists of passing the air volume from which the smoke particles were filtered out through a dilute solution of hydrogen peroxide and of measuring the increase in the acidity by titration, the titrant being a sodium borate solution. The concentrations of SO_2 are expressed as $\mu g/m^3$.[8]

The standard method for SO_2 was validated during 1968 by means of SO_2 permeation tubes when the APRG participated in a study conducted by the Analytical Methods Evaluation Service of the National Centre for Air Pollution Control, USA. The SO_2 method was also checked against one of the sulphur dioxide recorders, manufactured by Gas Chromatography Ltd. in England, during 1969 when it was found that the SO_2 concentrations, supplied by the two measuring systems compared well.

CHANGES IN THE LEVELS OF SMOKE AND SO_2 POLLUTION

Annual variations

While the monitoring surveys were conducted in the major cities, the concentrations of smoke and SO_2 were found to fluctuate during the year in such a way that they were low and of similar order between October and March and that they increased, reached their maxima and decreased again between April and September. Only the SO_2 concentrations monitored in Cape Town did not follow this pattern; they decreased between April and September due to winter rains.

The annual fluctuations were found to be caused more by changes in the atmospheric conditions over the cities than by changes in the emission. This applied also to the pollution levels which ultimately were reached in the individual cities and resulted in Pretoria with its stable atmospheric conditions frequently having higher smoke and SO_2 concentrations at its monitoring sites than other cities at comparable sites.[9,10]

In the cities and towns which took up monitoring work during later years the annual variations of smoke and SO_2 turned out to be similar to those in the major cities and high and low pollution periods could also be distinguished. The highest concentrations of the year occur most frequently during the high pollution period. Because of the sampling periods being 48 and 72 hours, respectively, the maximum concentrations are not as significant as the other statistical data collected, though, as far as smoke is concerned, an equivalent concentration for a 24 hour period can be calculated from the concentration obtained during a 48 hour period.[11]

Long-term trends

Statistical evaluation

As far as air pollution control is concerned the high pollution period April to September which roughly coincides with the winter season in the Republic of South Africa is of greater importance than the second period of the year. For this reason the APRG decided to study the long-term trends from the average concentrations obtained for the period April to September and not from the annual averages as it is done in other countries. The long-term trends are represented by a linear regression. A trend indicates a decrease or increase if the probability that the respective tendency continues is higher than 90 %. If this is not the case, the trend is considered to be not significant. The annual rate of change, averaged over the whole monitoring period is calculated from the first and last concentration values on the regression line.

The evaluation of the monitoring data collected until the end of the winter season 1978 proves that there is a definite improvement in the air quality over urban areas in the Republic of South Africa. Of the 43 monitoring sites for which the long-term trends of smoke and of the 22 sites for which the trends of SO_2 could be calculated, 72% in each group show that the concentrations of both pollutants have the statistically proved tendency to decrease. No significant trends are shown by 26% of the smoke and by 18% of the SO_2 monitoring sites. The tendency to increase is shown by 2 and 9% of the monitoring sites, respectively.

A break-down of the figures for each city is given in Table 1.

TABLE 1 Long-term trends in South African cities and towns

City or town	SMOKE				SULPHUR DIOXIDE			
	No +)	D	I	O	No +)	D	I	O
Benoni	2	2	–	–	–	–	–	–
Bloemfontein	4	2	–	2	4	3	–	1
Boksburg	3	1	–	2	–	–	–	–
Cape Town	7	6	–	1	7	6	–	1
Durban	6	3	1	2	6	3	1	2
Germiston	2	1	–	1	–	–	–	–
Johannesburg	8	8	–	–	–	–	–	–
Kempton Park	1	–	–	1	–	–	–	–
Klerksdorp	1	–	–	1	–	–	–	–
Kroonstad	1	1	–	–	–	–	–	–
Pietermaritzburg	3	3	–	–	–	–	–	–
Pretoria	5	4	–	1	5	4	1	–
TOTAL	43	31	1	11	22	16	2	4
PERCENTAGE	–	72	2	26	–	73	9	18

+) Number of monitoring sites for which long-term trends can be calculated

D Decrease

I Increase

O No significant trend

Decrease

With regard to smoke, all the monitoring sites in the central and the purely industrial areas have decreasing trends, the average rate of decrease being 3 and 4 % per year for sites in operation for 20 or more years and 6 to 12% for sites in operations for 10 years or shorter. The introduction of the Atmospheric Pollution Prevention Act in 1965 and the stricter control measures introduced in compliance with the Act during the following years has a noticeable effect which also applies to SO_2.

The smoke levels which have been reached in the central areas of the various cities show some differences according to the geographical situation: in the coastal cities Cape Town and Durban the average winter concentrations in 1978 fluctuate between 30 and 50 $\mu g/m^3$, in Bloemfontein between 100 and 110 $\mu g/m^3$ and in Pretoria they fluctuate between 110 and 130 $\mu g/m^3$.

The long-term trends of smoke and SO_2 obtained in the central and main industrial areas are graphically presented in Figures 2 to 5. For Cape Town the long-term trends of SO_2 were also obtained from the summer averages which, as mentioned before, are slightly higher than those of the winter seasons. For the statistical evaluation, however, it is immaterial which average concentrations are used, the long-term trends are always decreasing and the rates of change are similar in both cases (see Figure 7).

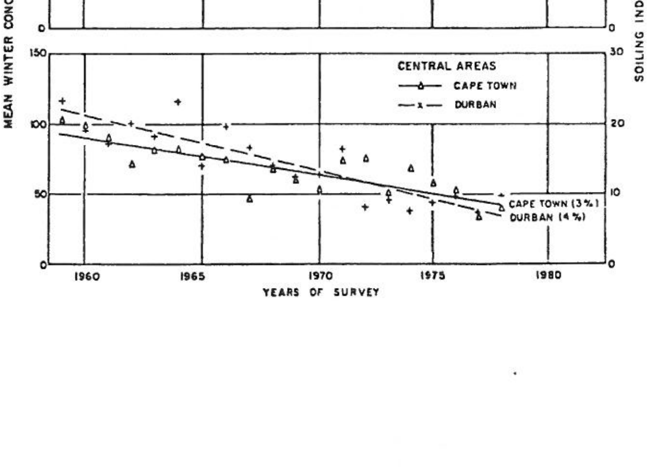

FIG 2 Long-term trends in smoke pollution

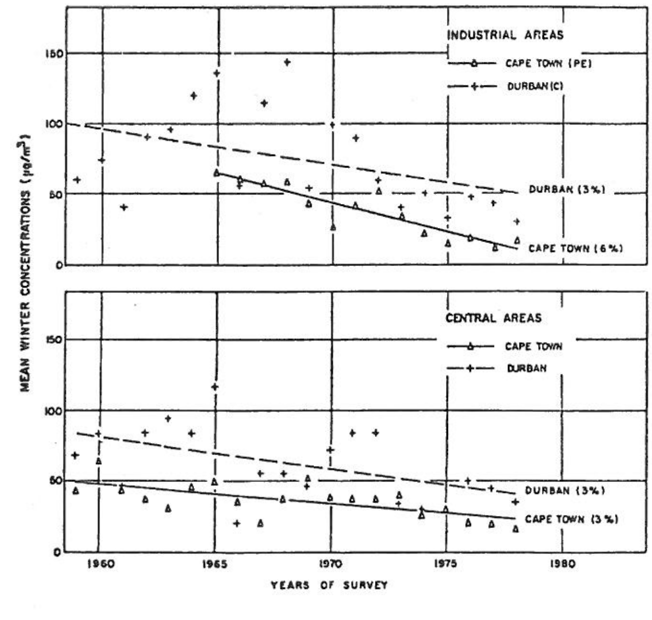

FIG 3 Long-term trends in SO_2 pollution in coastal cities

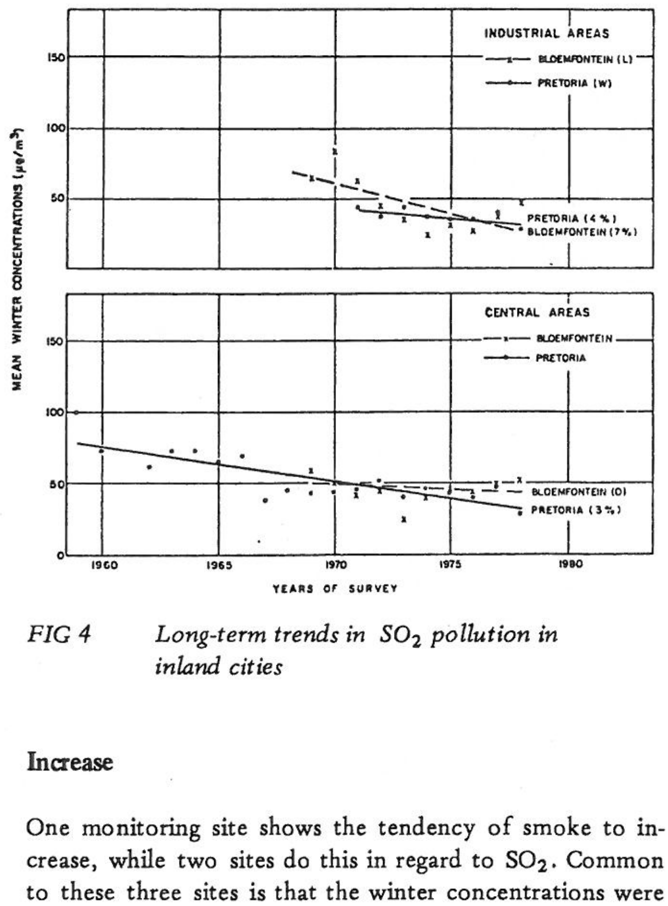

FIG 4 Long-term trends in SO_2 pollution in inland cities

Increase

One monitoring site shows the tendency of smoke to increase, while two sites do this in regard to SO_2. Common to these three sites is that the winter concentrations were very low when monitoring started and they are still low at present. One of the sites where the SO_2 concentrations tend to increase is situated in the grounds of the CSIR and was erected as a background station. In contrast to SO_2 the smoke concentrations, though they are low, have the tendency to decrease, especially during the past 5 years. An explanation for this behaviour may be that although the residential areas surrounding the CSIR grounds were de-

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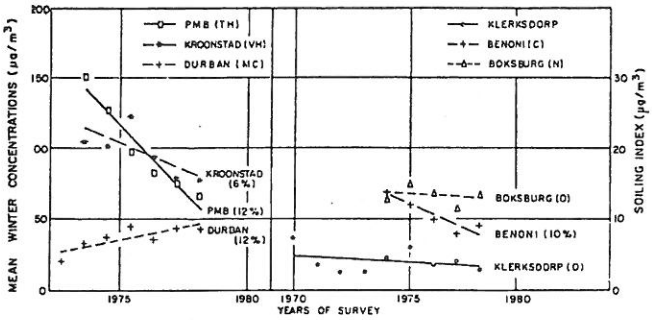

FIG 5 *Long-term trends in smoke pollution*

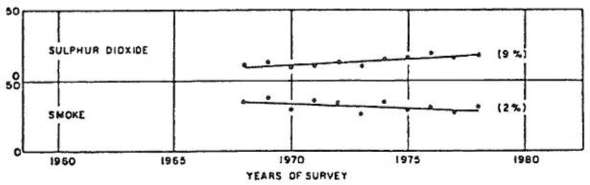

FIG 6 *Long-term trends in smoke and SO_2 pollution, Pretoria, Scientia*

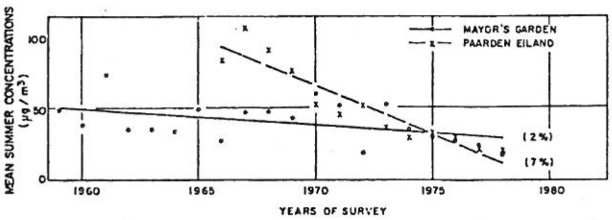

FIGURE 8: LONG-TERM TRENDS IN SO_2 POLLUTION, CAPE TOWN (SUMMER AVERAGES)

FIG 7 *Long term trends in SO_2 pollution, Cape Town (Summer averages)*

clared smoke free zones an industrial area at a distance of 4 km to the north of the CSIR is extending and growing. The emission of the industrial sources may have caused the winter concentrations of SO_2 to rise from 10 to 16 $\mu g/m^3$ within 11 years. The long-term trends of the CSIR monitoring site are graphically presented in Figure 6.

No significant trends

Many of the sites where the long-term trends are not significant at present showed a definite decrease at one time or another, followed by a period during which the concentrations fluctuated widely. At most of the sites the concentrations are low.

THE SOUTH AFRICAN SMOKE AND SO_2 LEVELS IN COMPARISON TO INTERNATIONAL STANDARDS

From the statistical point of view the measures to control smoke and SO_2 over the urban areas in the Republic of South Africa prove to be successful. The question to be considered is whether the improvements are sufficient from the point of view of public health, a question which can only be answered by looking at the standards recommended in other countries since in the Republic no criteria have been laid down.

In 1972 the World Health Organization recommended long-term goals for the more common urban air pollutants like SO_2, particulates, carbon monoxide and ozone which are set out in Table 2[12,13]. With regard to SO_2 and suspended particulates the recommendations are based on the British measurement method, i.e. the British filter paper method. This method was not strictly copied in the Republic of South Africa as far as particulate matter is concerned. The changes which have been made and which are discussed in paragraph 2, do not affect the size spectrum of the particles which are collected and in this critical aspect the British and the South African methods are similar. The long-term goals recommended by the World Health Organization are as applicable to the South African standard procedure as they are to the British standard procedure.

TABLE 2 *Long-term goals recommended by World Health Organization*[a] [12]

Pollutant and measurement method		Limiting level
Sulfur oxides[b] - British Standard Procedure	annual mean	60 $\mu g/m^3$
	98 % of observations[d] below	200 $\mu g/m^3$
Suspended particulates[b] - British Standard Procedure[c]	annual mean	10 $\mu g/m^3$
	98 % of observations[d] below	120 $\mu g/m^3$
Carbon monoxide - nondispersive infrared	8-hour average	10 mg/m^3
	1 hour maximum	49 mg/m^3
Photochemical - oxidant as measured by neutral buffered K ℓ method expressed as ozone	8-hour average	60 mg/m^3
	1 hour maximum	130 $\mu g/m^3$

[a] The Committee specifically urged that this table should not be sidered independently of the accompanying text.

[b] Values for sulfur oxides and suspended particulates apply only in conjunction with one another.

[c] Methods are not those necessarily recommended but indicate those on which these units have been based.
Where other methods are used an appropriate adjustment may be necessary.

[d] The permissible 2 % of observations over this limit may not fall on consecutive days.

In the USA ambient air quality standards were published and are in force at present which are set out in Table 3[14]. The American standards are based on the monitoring methods and recorders used in that country which are very different from the South African procedure. Judging from the literature the concentration of suspended particulate matter is determined by means of a high-volume sampler which collects particle sizes between 0,1 and 100 μm whereas the South African filter paper sampler collects particles smaller than 10 μm due to its low sampling speed and design of the air inlet. The American air quality standards for particulate matter can consequently not be used as a guide in the Republic of South Africa.

According to a report by Stichting Concawe,[15] dated March 1976, several countries have published recommended air quality standards for SO_2, but only a few have given targets for smoke and particulate concentrations. With regard to SO_2, the present target in Europe is a maximum monthly SO_2 concentration of 150 μg/m³ which is equivalent to an annual level of about 100 μg/m³.

TABLE 3 States ambient air quality objectives and United standards[14]

Contaminant		United States Air quality standards: Secondary	Primary
Sulphur dioxide	(Annual)		80 μg/m³ (,03 ppm)
	(24 hr)		365 μg/m³ (,14 ppm)[c]
	(1 hr)	1 300 μg/m³ (,5 ppm)[b]	
Suspended particulate matter	(Annual)	60 μg/m³	75 μg/m³
	(24 hr)	150 μg/m³[c]	260 μg/m³[c]

[a]Proposed.

[b]3 hour concentration. Not to be exceeded more than once per year.

[c]Not to be exceeded more than once per year.

TABLE 4 Annual average concentrations of smoke and sulphur dioxide in South African cities and towns

City or town	SMOKE μg/m³ Centre	SMOKE Ind.	SMOKE Res.	SULPHUR DIOXIDE μg/m³ Centre	SULPHUR DIOXIDE Ind.	SULPHUR DIOXIDE Res.
Benoni	32	63	–	–	–	–
Boksburg	60	–	47	–	–	–
Bloemfontein	75	85	32	33	29	9
Cape Town	34	67	35	22	20	15
Durban	34	52	22	33	39	11
Germiston	52	65	35	–	–	–
Klerksdorp	14	–	–	–	–	–
Kroonstad	62	67	–	–	20	–
Pietermaritzburg	55	51	40	–	–	–
Pietersburg	10	23	–	–	–	–
Port Elizabeth	37	75	26	20	20	19
Pretoria	96	84	39	30	24	19
Randburg	–	–	25	–	–	–
Springs	111	61	–	39	36	–
Welkom	–	–	38	–	–	–

The ambient air quality standards are all based on the annual average concentrations. At the South African monitoring sites these average fluctuate from year to year because of atmospheric changes. In order to obtain statistically valid information on the question whether the present smoke and SO_2 levels in the Republic of South Africa would meet the goals set by the world Health Organization, the annual average concentrations were calculated for all the South African monitoring sites, not from the measurements of one year, but from the monthly concentrations obtained during the three year period October 1975 to September 1978.

Examining the annual averages set out in Table 4, it can be seen that as far as SO_2 is concerned, the long-term goals recommended by the WHO would be met by every monitoring site in the Republic. With regard to suspended particulates this is not the case because some industrial areas in the coastal cities would not meet the WHO targets at present and the same applies to some central and industrial areas in the inland cities.

The fact that European countries have raised the SO_2 targets recommended by the WHO from 60 to 100 $\mu g/m^3$ indicates that these are considered to be low. The same may apply to the targets for suspended particulates and be the reason why they are not applied in European countries. In the Republic of South Africa the efforts to improve the air quality will continue and because of this it is certain that the levels of smoke and suspended particulates will decrease further in the future.

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