Trends in photochemical smog in the Cape Peninsula and the implications for health

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There has been growing public concern over reports of increasing air pollution in the Cape Peninsula. Attention has been focused on the 'brown haze' and on photochemical smog. Because of deficiencies in the monitoring equipment, information on trends in photochemical smog levels over the past decade is limited. Trends in oxides of nitrogen, one of the main precursors of photochemical smog, and therefore an indicator of the potential for its formation, were examined for the period 1984 - 1993. Meaningful data for determining trends were available from only a single site. Increases in mean monthly levels, peak hourly levels and the number of times guidelines were exceeded were demonstrated. Given the dynamics of formation of photochemical smog and the particular role of motor vehicles, it is argued that the trends measured at this site are probably an underestimate of the trends in other parts of the Cape Town metropolitan area. Some of the precursors of photochemical smog, notably nitrogen dioxide, and some of its components, notably ozone, have been shown to be detrimental to respiratory health at levels close to, or below, current recommended guidelines. A continuing increase in these pollutants will therefore result in more respiratory illness, particularly among susceptible groups. This calls for an upgrading of monitoring of air pollution in Cape Town and for appropriate steps to prevent its further increase.

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There is growing public concern over periodic reports of an increase in air pollution in the Cape Peninsula.[1-3] Attention has centred on the 'brown haze', a phenomenon familiar to the residents of Cape Town, and on reports of the increasing occurrence of photochemical smog.

Photochemical smog is the colloquial name for a blend of chemical compounds formed by the action of ultraviolet radiation on industrial and vehicular emissions.[4] The main components of the initiating reaction in the production of

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photochemical smog are the oxides of nitrogen and hydrocarbons (primary pollutants). The result of this reaction is a complex mix of organic and inorganic compounds (secondary pollutants), some of which are toxic to plants and animals. These include ozone and peroxyacetyl nitrate (PAN).[4]

The relationship of the 'brown haze' to photochemical smog is unclear. A study has recently been commissioned by the National Association for Clean Air to investigate the composition of the haze (Cape Town City Council — personal communication). However, photochemical smog has been noted in the Cape Peninsula.[5]

There are two principal reasons for the belief that levels of photochemical smog may be rising. Firstly, the frequency with which the national guidelines for oxides of nitrogen are exceeded, as detected by the monitor in the central business district (CBD), has been increasing.[6] Secondly, levels are likely to rise with the growth in traffic volume associated with expansion and urbanisation in the greater Cape Town area.[7]

A major difficulty in assessing the problem of photochemical smog in Cape Town is that the indicators available for monitoring this type of pollution have, to date, been deficient.

Indicators of photochemical smog

Although ozone is one of the main components of photochemical smog, it is a poor indicator of its extent.[5] This unsuitability arises because ambient ozone levels at any point are strongly dependent on the ratio of nitric oxide (NO) to nitrogen dioxide (NO_2). However, this ratio does not necessarily correlate well with photochemical smog levels. For example, in areas of heavy traffic flow, ozone is rapidly consumed in a reaction with NO. In such areas concentrations of ozone may be fairly low. In areas away from heavy traffic flow, where the concentration of NO is lower, the reaction is reversed. A secondary pollutant such as ozone may thus be at its highest concentration in an area some distance from the point at which the primary pollutants are produced. In suburban (or even rural) areas which may be distant from major pollution sources, ozone concentrations may be very high.[8,9] This finding has been confirmed by Dutkiewicz *et al.*[10] in a survey of ozone levels at various locations in the Cape Peninsula.

A more useful indicator of photochemical smog is PAN, which is less dependent on the ratio of NO to NO_2.[5] The Cape Town City Council recently installed the first PAN-monitoring equipment in South Africa. However, until this equipment is functioning effectively, alternative indicators of the potential for photochemical smog formation have to be used.

In order to examine long-term trends we examined routinely collected data on one of the precursors of photochemical smog, the oxides of nitrogen. These are predominantly NO and NO_2, the sum of which measures is referred to as NOx.[3]

Oxides of nitrogen levels have been routinely measured at two fixed points in the Cape Peninsula: by the City Council at a monitor at the City Hall since 1984, and by the Western Cape Regional Services Council (RSC) at a mobile monitor in Labiance (Bellville) since February 1990. The measurement is done on a continuous basis, with measurements expressed as hourly means.

The RSC monitor has been in place for too short a period to discern meaningful longer-term trends. Therefore, indications of such trends are limited to measurements obtained from the City Council monitor at the City Hall.

Fig. 1 displays two measures calculated from the data produced by this monitor: (*i*) the 12-month moving average of the hourly NOx readings from 1 January 1984 to 30 November 1993; and (*ii*) the 12-month moving average for the peak hourly level of NOx in each month over the same period.

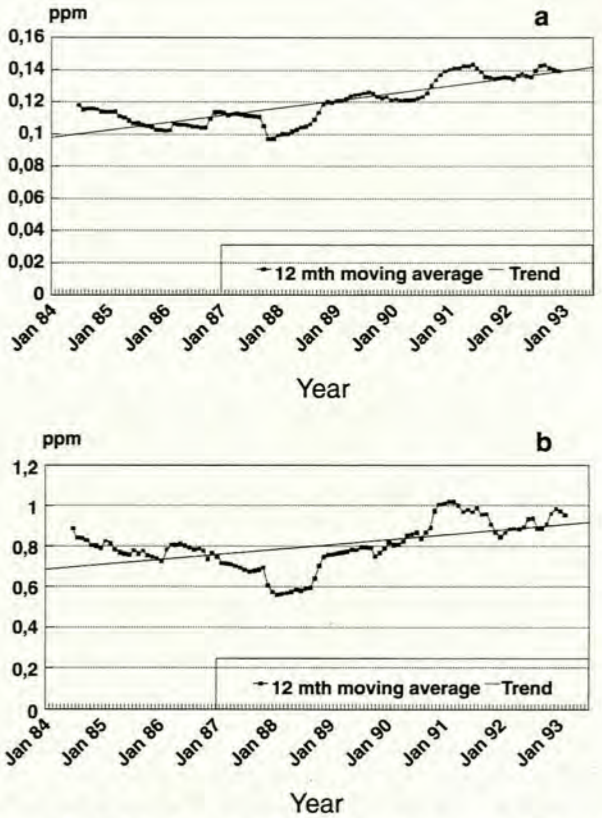


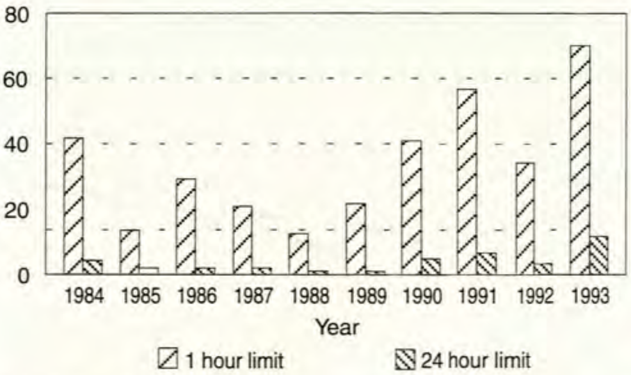
Fig. 1. NOx in Cape Town, 1984-1993: a) monthly mean; b) highest hourly mean per month.

The 12-month moving average of hourly measures, reflecting prolonged exposure, shows a downward or static trend over the first 4 years. However, there is a stronger upward trend over the following 6 years, which is responsible for a slight upward trend overall. The readings remain well below the national maximum allowable concentration guideline of 0,3 parts per million (ppm) (Table I). The peak hourly value per month reflects the highest short-term exposure in each month. The 12-month moving average for this measure also shows a slight upward trend, and exceeds the national maximum allowable concentration guideline for short-term exposure of 0,8 ppm continually for the last 3 years of the study period. The apparently increasing trend is also reflected in the increasing frequency in the number of times 1-hour and 24-hour guidelines have been exceeded (Fig. 2).

Table I. Air pollution guidelines — recommended levels not to be exceeded*

Pollutant	Hourly mean	Monthly mean
NOx	0,8	0,3
NO_2	0,2	0,08
Ozone	0,12	0,03

* Department of National Health and Population Development.



Source: Cape Town City Council

Fig. 2. Number of times guidelines are exceeded per year.

The 12-month moving average smoothes the seasonal variation in the levels of NOx in Cape Town. Increased levels typically occur during the calmer winter months.[11,12] This reflects the dispersing action of the wind which is prevalent in Cape Town during the summer. The major meteorological factors associated with high NOx are low wind speed and the presence of an inversion layer — a cold layer of air at ground level covered by a layer of warmer air.[9,13] There is also geographical variation: for example, the city bowl, which is flanked on three sides by mountains, provides favourable topographical conditions for the accumulation of pollutants.

The trends described for NOx provide suggestive, but not strong, evidence that photochemical smog may be increasing. However, given the limited information supplied by routine monitoring over the past decade, this may be the best available indication of long-term trends. As this is a descriptive review of the problem which did not employ complex modelling techniques, the possibility that chance was responsible for the observed increase cannot be excluded. Nonetheless, these observations point to the need for a critical evaluation of current monitoring.

Limitations of current monitoring in Cape Town

There are at present only three monitors in the Cape Peninsula which can measure pollutants and may be used as indicators of photochemical smog. The PAN monitor situated in Oranjezicht (a suburb on the slopes of Table Mountain, above and close to the city centre) is potentially the most accurate of these, but is experiencing problems in its run-in phase, and is not yet producing reliable information (Cape Town City Council — personal communication). The mobile monitor which was recently stationed in Labiance (a residential area in Bellville) is moved every 2 - 3 years to satisfy the needs of the various municipalities which co-own the monitor, and is therefore of limited use in monitoring long-term trends. The third monitor is situated in an area of heavy traffic flow at the City Hall in the centre of Cape Town, and is the only monitor which has been producing data on indicators of photochemical smog more or less continuously for several years. There are thus a number of significant constraints on the ability of these monitors to provide meaningful data on long-term trends:

1. Each monitor is representative of a restricted area.[14,15] Thus, for much of the area outside the CBD there are no data available on indicators which may be used to assess long-term trends in photochemical smog.

2. For reasons described above, the positioning of the monitors may not be appropriate to detect secondary pollutants such as ozone at their highest concentrations. This inappropriateness is borne out by early results from the new monitor in Oranjezicht, compared with simultaneous readings from the City Hall monitor. The monitor at Oranjezicht has shown significantly higher levels of ozone than that at the City Hall (Cape Town City Council — personal communication). Thus, in some areas people are exposed to levels of pollutants which may be considerably higher than those shown by the monitors.

3. In those areas where pollution is likely to be increasing most rapidly there has been no monitoring, or the monitor has been moved too frequently to discern meaningful trends. Although it may be appropriate for two of the three monitors which measure indicators of photochemical smog to be placed in the city bowl, the area where the highest absolute levels of pollution occur, the *rate of increase* in levels of photochemical smog in other suburban and commercial/industrial areas may be much greater. This is suggested by patterns of increase in motor vehicle traffic. As motor vehicles account for by far the greatest production of NOx in the Cape Peninsula,[4,11,12] trends in the volume of motor vehicle traffic may be used to predict trends in the levels of NOx.

Total vehicle registrations in the greater Cape Town area increased by 32% during the period 1983 - 1990.[7] This percentage includes a 52% increase in commercial vehicles which are likely to burn more fuel because they are, on average, larger and spend more time on the road than private cars. The air pollution produced by motor vehicles in the greater Cape Town area may therefore have increased by more than 32%. This increase is in turn 2 - 3 times that of the estimated 10 - 15% increase in inbound traffic to the CBD over the same period.[7] Thus, although current monitoring shows the highest levels of NOx to be in the CBD, the rate of increase in photochemical smog precursors measured in the CBD is probably a marked underestimate of the rate of increase in other parts of the greater Cape Town area.

A further problem, which is important in assessing effects on human health, is that fixed-point monitors do not represent accurate exposure of individuals as they go about their everyday activities. Great variability is likely to occur in different environments, particularly indoors, where levels of pollutants may be far in excess of national guidelines, depending on the type of fuel used, quality of ventilation and proximity to outdoor sources.[8] This variability is of particular importance in townships and informal settlements.

Implications of rising photochemical smog for human health

The evidence for the adverse effects on human health of various components of photochemical smog is based on laboratory studies on animals and human volunteers, and on epidemiological studies. Laboratory studies allow the quantification of effects of exposure to specific pollutants. However, animal studies are limited by the difficulties of extrapolation of effects to humans,[16] while laboratory studies of humans can investigate only short-term exposure.

Epidemiological studies also present a number of problems. These problems include the difficulty in assessing effects of a single pollutant, given exposure to multiple pollutants, the impact of which may be additive or synergistic. There may be numerous factors confounding any observed association between air pollution and symptoms, including attitudinal, socio-economic and meteorological factors which may be difficult to quantify, as well as indoor air pollution which frequently remains unmeasured. The complexity introduced by multiple and correlated aetiological factors is exacerbated by the heterogeneous manifestations of respiratory illness.

In addition, most epidemiological studies conducted in the past have relied on fixed monitors which may not accurately reflect the exposure of individuals. It is only recently that researchers have used personal monitors which measure an individual's exposure more accurately, and are able to reflect exposure to both outdoor and indoor pollution. Because of the difficulties inherent in epidemiological studies, safe exposure guidelines for the usual indicators of photochemical smog have been based largely on laboratory studies.[8,17]

Studies of ozone and PAN

These pollutants are both oxidising agents. Their effects are similar, but ozone is more potent than PAN, and is therefore of greater concern. Concentrations of ozone of 0,1 ppm or less, particularly in susceptible populations, may be experienced as eye, nose and throat irritation, coughing, nausea, and headaches.[9,16,17] Several studies suggest no threshold for an observed ozone effect.[16,17]

Apparently reversible effects that have followed acute exposures to ozone lasting from 5 minutes to 6 hours include changes in lung capacity, flow resistance, epithelial permeability and reactivity to broncho-active challenges, leading to an increase in respiratory symptoms and decreased athletic performance. Such effects have been reported after single exposures of healthy non-smoking young adults at concentrations in the range of 0,08 to 0,20 ppm (i.e. partly below current hourly exposure guidelines of 0,12 ppm). The effects may persist for hours or days after exposure has ceased, and repetitive exposure, prolonged exposure, or exposure during exercise may prolong or exacerbate the effects. Exposure to similar concentrations of ozone in ambient air has been shown to produce more severe effects, possibly due to concurrent or prior exposure to other pollutants.[9,16-18]

Studies of the effect on humans of long-term exposure to ozone suffer from a lack of accurate exposure monitoring, but suggest that there may be premature age-related structural changes in the lung in those living in communities where there are persistently elevated ambient ozone levels. This suggestion is supported by evidence from animal studies, which show that exposure in the range of 0,08 to 0,20 ppm potentiates bacterial lung infections, and produces morphological and biochemical changes in the lung.[9,16-18]

Oxides of nitrogen

In addition to their contribution to photochemical smog, the pollutant oxides of nitrogen in the form of NO and NO_2 are of direct concern to human health. The health risks of NOx have been investigated in a number of studies internationally. A review of these studies formed the basis of NO_2 guidelines published by the World Health Organisation in 1983.[8] Animal studies demonstrate the potential for subchronic and chronic exposure to low levels of NO_2 to cause a variety of effects, including alterations of lung metabolism, structure and function, increased susceptibility to pulmonary infections and emphysema-like effects.[16]

In humans, clinical laboratory studies have produced conflicting results as to the threshold exposure which affects pulmonary function. The lowest level observed to affect pulmonary function reported from more than one laboratory was a 30-minute exposure, with intermittent exercise, to a NO_2 concentration of 0,3 ppm. These studies included mild asthmatics, who appear to be particularly sensitive to air pollution, but for ethical reasons could not include moderate or severe asthmatics.[16]

The contradictory findings of various studies are also evident in a recent review of ambient air pollution and respiratory disease by Abramson and Voigt.[19] Those laboratory studies with positive findings show a variety of effects. These include reduced vital capacity, a dose-dependent decline in airway resistance, potentiation of exercise-induced bronchospasm and nonspecific bronchial hyperreactivity, decreased baseline lung function in chronic obstructive airways disease sufferers, increased parental reporting of lower respiratory symptoms in children, and increased duration of symptoms. Epidemiological studies were reported to show an association between elevated ambient NO_2 and acute respiratory symptoms, and impaired lung function.[8,19-21] A recent study in the Cape Peninsula has shown a significant positive association between NOx levels and hospital admissions of children for acute respiratory tract infections and asthma.[22]

Conclusion

The evidence suggests that the levels of precursors of photochemical smog in the Peninsula, and therefore the potential for the development of photochemical smog, may be increasing. In certain areas away from the CBD this increase may be occurring at a more rapid rate than the trends for NOx obtained from the CCC monitor indicate. If these trends continue it is likely that the frequency with which current guidelines are exceeded will increase.

The increasing frequency with which these guidelines are currently exceeded at the sites of the monitors should be cause for concern. Firstly, the two fixed-point monitors do not represent exposure of people over the wide geographical area. Exposure of some individuals or groups may be considerably higher. Secondly, current guideline levels for pollutants may not be sufficiently stringent, as has been demonstrated for ozone. Thirdly, the dose-response relationship of air pollutants and respiratory effects indicates that effects may occur in susceptible individuals even at relatively low levels of pollution, which have been regarded as 'safe' for the general population. As epidemiological techniques for determining the health effects of air pollution improve, it may become possible to demonstrate effects at very low levels, particularly in these susceptible people (e.g. those that suffer from asthma or chronic obstructive airways disease).

It can thus be predicted that as the levels of pollutants increase, the severity and frequency of symptoms reported by residents of the Cape Peninsula will increase, and/or the proportion of people affected will grow. This predicted increase has obvious implications for the quality of life and productivity of people living in the area, for the health services which will face increasing demands for care, and for the local and state authorities responsible for controlling air pollution.

The efforts of the City Council to improve monitoring of photochemical smog and determine the major contributors to the 'brown haze' are positive moves. However, monitoring needs to be conducted on a wider basis, and in such a way that long-term trends can be determined. Specifically, this requires monitors to be positioned at points which are indicated by modelling and experience to be points at which high levels of pollutants (primary or secondary) are likely to occur, and which are representative of areas where significant numbers of people may be exposed. These monitors will need to be maintained in the same position in order to define long-term trends. Ideally, the network of monitors should be expanded, but this is unlikely to receive priority, given the constraints on resources. Efforts to combat the known causes of air pollution are more important than simply continuing monitoring of the increasing levels.

With the relatively small amount of industry in Cape Town, the prime contributor to the problem of photochemical smog is motor vehicle traffic. Emissions from motor vehicles may be reduced in two ways: fewer vehicles on the road and cleaner-running vehicles. Strategies introduced to reduce traffic volume will need to be backed up by a good public transport system. Reduction of emissions of NOx and hydrocarbons, the two principal contributors to photochemical smog, may be facilitated by the introduction of lead-free petrol. However, unless this is accompanied by the widespread installation of catalytic converters, it may lead to an increase in air pollution, caused by additives introduced to replace lead (R. K. Dutkiewicz — personal communication).

The problem of air pollution in the Cape Peninsula is complex, and requires a mix of responses. While there is a need to improve monitoring and surveillance, and to conduct further research into the components and principal sources of air pollution locally, experiences of urbanisation elsewhere suggest that protection of the health of the residents of the Cape Peninsula in the long term requires immediate action to limit the production of primary pollutants such as NOx.

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