DETERMINATION OF HEALTH IMPACTS IN URBAN REGIONS EXPOSED TO ATMOSPHERIC POLLUTANTS

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Abstract

A simple method for relating urban health responses to ambient air pollution levels is outlined. The method requires daily values of concentrations for the most common atmospheric irritant and respiratory complaint statistics from an adjacent medical clinic. The data need to be quality controlled and of sufficient length to be statistically screened using various thresholds. The method is limited in scope, so historical evidence is needed to guide the survey to the most relevant time of year and most exposed place. In the example given for Richards Bay - South Africa, health responses achieve maximum variance (27.4 %) with respect to peak values of SO_2 on the same day over a 40 day period in the winter of 1998. The correlation function for various thresholds indicates that 30 ppb is a critical health sensitivity level. The economic implications are computed and interpretations address how the results can be used to modify town planning efforts.

1. INTRODUCTION

Air quality is a concern in urban areas, and the rising global population has led to increasing emissions for O_3, NO_x, CO_2, etc in many parts of the world. The multiplier effect of urbanisation means that effluents will overflow city boundaries, requiring new technologies to maintain the integrity of town plans. For example in Harare, Zimbabwe annual SO_2 concentrations in the late-1990s increased above 30 ppb (Mathee 1998). Energy dependence is generally on fossil fuels and potentially unhealthy conditions are likely for residents of affected urban areas. (McCormick 1991). Many cities require regulatory agencies and industries to monitor the levels of key pollutants to ensure public health. Air quality is often assessed using national or World Health Organisation (WHO) guidelines (Matooane, 1999), and it has long been assumed that high doses would have to be sustained over long time periods before any discernable health impacts would result. The most stringent WHO standards for SO_2 applied at different averaging times are: 175 ppb: 1 minute, 110 ppb: 1 hour, 45 ppb: 1 day, and 15 ppb as an annual average. The South African guidelines are typically a factor of 2 - 3 higher, hence more lenient toward industry to create incentives for profitable business. Air pollution standards are designed to reduce the risk of death, not to ensure a reasonable quality of health. It is therefore necessary to evaluate the urban air pollution burden in the context of health impacts, not on the basis of exceedance or environmental carrying capacity.

There are various types of health impact studies, the one most used looks at spatial variations amongst a population directly exposed to industrial air pollutants in comparison with a population with similar demographic properties who are well removed from most air pollution sources. In a French study conducted over 20 years on 17 802 people, it was found that a 8.9 - 10.5% increase in deaths could be ascribed to annual mean SO_2 exposures of 10 - 15 ppb, following careful accounting for differences in age, habits, education, etc (Baldi et al, 1998). Most of deaths were attributable to respiratory failure and related pulmonary disfunction. In another study in eastern Europe a 6 - 7 % increase in acute respiratory infections, particularly for those prone to asthma, could be attributed to a mixture of atmospheric pollutants, which made a significant 24% contribution to local cases of morbidity (Naumenko et al, 1998a).

Matkovic et al (1998) found that residents living directly exposed to air polluting industries had significantly lower lung function efficiency than those living in non-polluted areas. Forced respiratory volume was reduced by 20% for those living in exposed areas, out of a sample of 386 non-smoking respondents of average age 45. A statistical significance of $p < .01$ was claimed in that study. A further east European health survey of children aged 10 - 14 found reductions in weight and lung function in the exposed group. Reported sicknesses were about 10-times higher than for unexposed children in 9 surveys conducted over 8 years in Romania (Vasilov et al 1998). The study by Naumenko et al (1998b) suggests that in the adult population, a number of confounding factors can occur: smoking, alcohol use, low-income accommodation, workplace hazard, etc, hence the use of children in health surveys is advisable.

Temporal changes in pollutant exposure are another important method to be considered in explaining variations in human health. Koffler et al (1998) found varying sensitivities to short term SO_2 exposure. 23% of individuals in their study were prone to respiratory impacts with a 2.2 second exposure to a 10^3 ppb dose. In studies conducted near Johannesburg, South Africa emission inventories, air quality standards, atmospheric dispersion, and impacts on biota and human health have been assessed (Held et al 1996). Winter periods show higher concentrations for SO_2 and particulate matter, followed by acid rain events which impact soils, food production and water resources. A comprehensive health survey revealed that exposed children aged 8 - 12 had a 21 - 103 % higher prevalence of respiratory illness than a control group (Terblanche et al 1992). These health impacts could be attributable to indoor sources in communities using coal for heating and cooking. This result stems from a history of poor infrastructure delivery in South Africa. Internal pollution exposure is not the focus here, rather it is the impacts of external air quality. The paper begins with a description of the scenario to be analysed, the atmospheric dispersion conditions, and the temporal methodology employed to determine health impacts. The results are presented and discussed and recommendations for further studies are given.

1.1 Study Area: Richards Bay

Richards Bay (pop. ~ 5 10^4) is typical of a small city near the tropics, located along the south-eastern coast of Africa at 29°S, 32°E. The warm Agulhas Current flows along its seashore ensuring a pleasant, humid climate most of the year. It serves as a hub for infrastructure development and its large port handles about 50% of South Africa's maritime cargo. In the early days it was a fishing village. During its expansion in the early 1970s, a number of heavy industries were located there to generate export revenue, creating potential environmental consequences. For example sea discharges exceed 10^8 kg day^{-1}, a level comparable to some of largest cities in the world (CSIR 1986). Although mainly industrial, Richards Bay's future economic growth could include a service (tourism) component, providing that the town plan is well informed.

In a random survey in the main shopping centre of the central business district (CBD) during 1997, 84% of respondents agreed that poor air quality during winter was related to respiratory illness (Mhlongo 1997). The public perceptions indicate possible environmental effects of industrial pollution. The combined air pollution output in Richards Bay is of order 10^5 kg day^{-1} (Boegman 1985), 6.6 10^4 kg day^{-1} of which is SO_2 and 6.3 10^3 kg day^{-1} is fluoride (EEU 1993, CSIR 1998). Pollutant dispersion can be estimated from the gaussian equation: [$X = Q / \pi \sigma_y \sigma_z u$] using typical values for horizontal and vertical plume spread (σ_y = 150 m, σ_z = 50 m) ~ 3 km downstream in stable (E class) conditions, a wind speed of 4 m s^{-1} (u) and a 1 % sector coverage to account for plume meander. Hence, deposition rates of 1 g day^{-1} are likely for the surrounding residential areas. Considering respiratory volume, it is estimated that an urban resident inhales ~ 1 mg day^{-1} of air pollution when situated in the downwind sector. This could lead to cumulative health impacts, particularly for young children (Moore, 1997).

Thus a study of health impacts and related air pollution dispersion patterns is useful for planning mitigation strategies at the municipal level.

1.2 Background: Extent and seasonality of air pollution

To determine the optimum time and place to conduct a limited effort survey, historical evidence was consulted. An assessment conducted by the CSIR for the expansion of a factory in Richards Bay, a dose mapping was done using local meteorological data input to the Calpuff atmospheric dispersion model (CSIR 1998). The Calpuff model is a set of equations used to simulate how puffs of pollution become transported and diluted under time- and space-varying weather conditions. The model has been validated using observed data and found to be accurate for cumulative dose (CSIR 1998). A numerical simulation of dose based on a comprehensive emission inventory can establish the spatial extent of air pollutants better than a few monitoring stations. Figure 1 shows the 24-hour maximum SO_2 dose map using meteorological data for the 1997-1998 period.

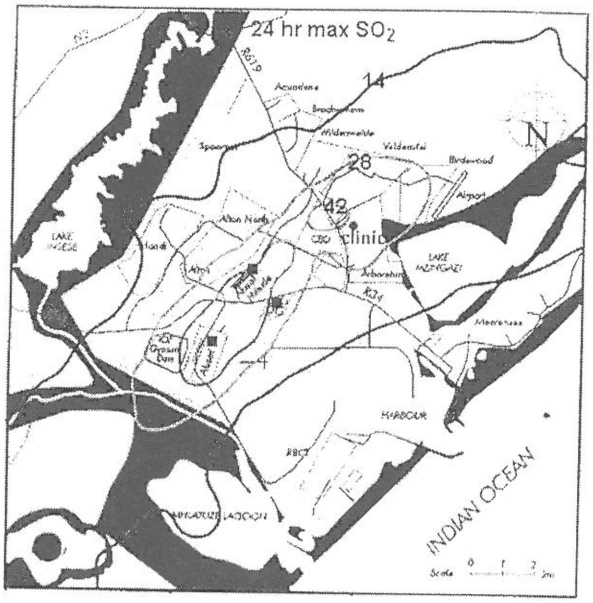

Figure 1. Maximum 24 hour SO_2 dose map of Richards Bay area, showing concentration isopleths in ppb, and position of the doctor's clinic and SO_2 monitoring station (adapted from CSIR 1998).

The main plume axis is NW-SE along the prevailing winds. Interestingly the distribution is quite symmetrical about the sources, even though the wind from NE blows two-thirds of the time, the stability during the SW wind regime makes up the difference. Previous advice to the town planners of Richards Bay suggested that the industries could be situated in close proximity to residential areas because of the asymmetry of wind flows, however the dose mapping refutes this hypothesis. The doctor's clinic used in the health survey is shown in figure 1. It lies near the maximum dose, and is next to the SO_2 gas analyser station (Aboretum).

Further confirmation of the spatial extent of atmospheric pollutants can be sought in biomonitoring results using rye grass sensitivity to fluoride, which most industries in Richards Bay emit. The biotic response is used to map deposition in the surrounding environment (Boschoff 1996). The fluoride distribution in 1995 (not shown) conforms to the dose map with high values over the industrial area which spill over onto the residential area of Arboretum and the CBD where schools, hospitals and shopping centres are located. The fluoride biomonitoring results were discontinued following commissioning of the new Hillside aluminium smelter, whose outputs would lead to an eastward extension of the affected area (EEU 1993).

Monthly averages of fluoride reveal a peak during the early winter (figure 2).

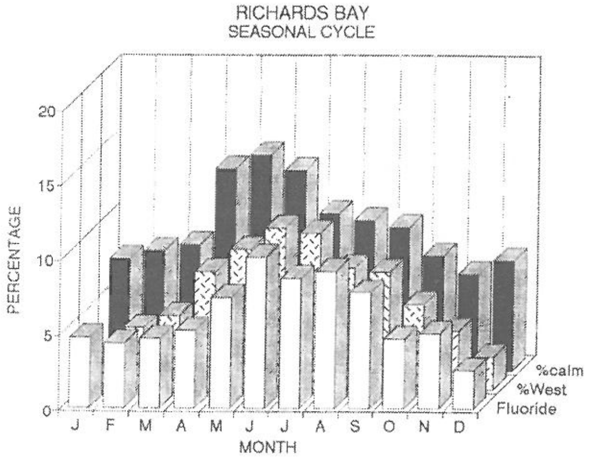

Figure 2. Seasonal cycle of historical weather data compared with fluoride deposition for residential; sectors (Boshoff 1996). Percentage westerly winds and calm conditions increase during early winter months, hence the time of greatest health risk.

The seasonal cycle is driven by the presence of westerly winds and nocturnal cooling. Calm conditions < 1 m s^{-1} occur ~ 15 % of the time during winter. Thermal inversions are typically 500 m deep with a strength of 5 - 8°C, and wind directions are often sheared counterclockwise from the surface to plume level (~ 100 m) according to intensive balloon sounding campaigns (CSIR 1978). The boundary layer mixing depth varies from 200 – 700 m in winter to 300 – 1000 m in summer (D'Abreton et al 1998). The gradual eastward movement of pollution from sources in Richards Bay is prevalent in the winter season because the large-scale westerly circulation to the west is slightly dominant over the north-easterly flow over the ocean to the east (figure 3).

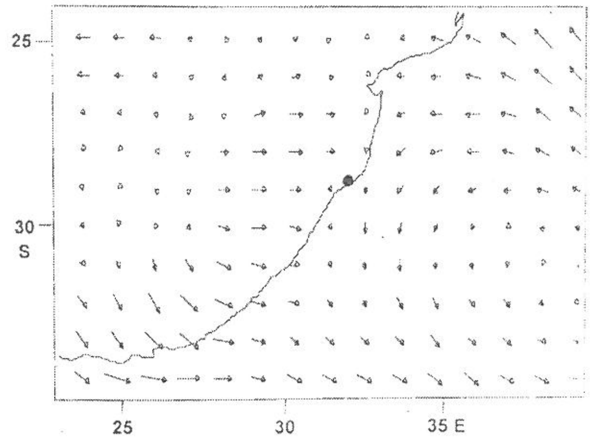

Figure 3. Average large-scale surface winds at night during winter season from ECMWF weather data. Dot illustrates Richards Bay.

The temporal nature of air pollution episodes is characterised from local information on air pollution and weather conditions from a network of five SO$_2$ gas analysers and four automatic meteorological stations maintained by the Richards Bay Clean Air Association (RBCAA 1998). Prominent features of episodes are outlined in Jury (1998) based on a 24 hour averaged SO$_2$ value > 30 ppb maintained for at least two days. Episodes occur a few times each month during winter. Wind speeds are typically 3 - 4 m s^{-1} with little diurnal variation and wind directions gradually shift from southerly to westerly. Thus the Arboretum suburb lying to the NE is most affected. SO$_2$ values are highest in the early morning, and decline as winds shift to north-easterly. According to nearby radiosonde data, inversion conditions coincide with pollution episodes and limit the vertical depth of mixing. The climatological evidence suggests that pollution exposure in the Arboretum suburb is high from April to July, hence the months chosen for the health impact study. The hypothesis is that fluctuations of daily averaged values of SO$_2$ contribute to increased respiratory complaints in local doctor's clinics on the following day.

2. HEALTH SURVEY METHODOLOGY

To collect unbiased information regarding respiratory complaints, a busy local doctor's clinic was identified in the exposed area, within 500 m of a regularly serviced and calibrated SO$_2$ pollution monitoring point (Hurt et al 1998). The clinic serves a suburban population of ~ 4 000 people within a 1 km radius. Doctors attending the clinic were briefed on the need for information on the number of patients presenting illnesses. The doctors expressed an unwillingness to report the total number of cases, owing to potential tax implications, so it was agreed only to report respiratory complaints. The survey commenced on 15 April 1998, but a misunderstanding became apparent when cases were not summarised into daily values. Additionally chronic respiratory complaints in older patients were included, and it was felt that these should be withdrawn. Finally the survey results started flowing in on a weekly basis from 1 May 1998. Eventually by 15 June a sample of 958 cases over a period of 45 days was available for analysis and the survey ceased. By that stage winds from the NE had commenced and exposure to high concentrations of ambient air pollution became infrequent.

The doctors reported that there was not much additional work involved in keeping tabular results on the daily number of patients with 1st time respiratory complaints. No additional information was taken on the patient's details, however the doctors reported that over two-thirds of cases were school-going children 5 - 15 years of age in the middle income class (family after-tax earnings > R 5 000 ~ $ 800 per month). Following diagnosis, most of the patients were given prescriptions for nose spray, anti-histamine syrup, antibiotic pills, or referred to a physiologist for nebulising treatment to relieve constricted breathing.
Given the young age of the patients, it was realised that a visit to the doctor's clinic would require two human responses. The first – the child's symptoms being sufficient to trigger the need for medical attention, and the second – a mother's response to the child's symptoms and a willingness to alleviate the health problem. The cost of each clinic visit is estimated at R 500 per visit for 1 hour of time lost, and fees for transport, the doctor's diagnosis and medicines. Only after the survey was completed, was the doctor informed that the results were to be associated with observed air pollution levels. The survey costs amounted to very little; the effort of the data analyst and the doctors were quite limited in scope; and the overall efficiency of the project is therefore high. In addition a statistically robust sample was obtained with a degrees of freedom of 44.

Correlation between SO_2 daily average and peak values, and respiratory complaints were calculated and scatterplot functions were analysed. A correlation of 0.24 reaches the 90% confidence limit, a nominal reference for studies of human health responses. To establish the threshold at which maximum variance is found, data were screened in 10 ppb (28.7 ug m^{-3}) intervals. Correlations were considered for all data, then only comparisons were done above 10 ppb, 20 ppb, and so on. The shape of the correlation function is used to describe responses to varying pollutant exposure levels.

During the following winter of 1999, a health impact assessment was planned by the municipality. Here only meteorological and pollution data are considered in light of the earlier health survey, to enable further recommendations regarding siting of industries in the municipal plan.

3. RESULTS

3.1 Health survey in 1998

Relationships between fluctuations of daily averaged and daily peak values of SO_2 and the number of respiratory complaints in local doctor's clinics on the same day and following day were analysed. The only significant correlation (r = 0.34) was for daily peak (5 min. averaged) values of SO_2 and respiratory complaints the same day. Typically the SO_2 peak occurs in the morning following relaxation of the landbreeze, whilst patient visits increase in the afternoon as school ends for the day. It is surprising that peak values well below stringent WHO standards yield significant results. It is thought that the sparseness of the pollution sampling network contributes to this result.

Figure 4 illustrates the time series of SO_2 peak values and respiratory complaints. The first increase in respiratory complaints occurs without any pollution peak, probably related to the first wave of influenza virus to hit the area with the onset of cooler winter weather.

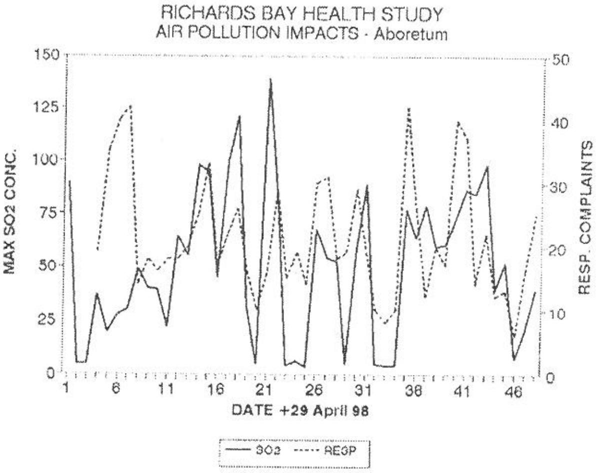

Figure 4. Time series comparison of peak SO_2 concentrations and respiratory complaints registered at the local doctor's clinic.

This likely pre-conditions children to be more susceptible to external irritants such as air pollution. If the first batch of sample is removed so the correlation is computed from day 8 onwards, the correlation is 0.52, significant at the 99.9% confidence limit. Hence 27.4 % of the variance in respiratory complaints is explained by peak values of the most common air pollutant. With 958 cases reported at an estimated R 500 direct cost per visit, if 27.4% of cases are attributable to external pollution, the economic drag induced by the health impact over the 45 day period is ~ R 131 000 or ~ $ 22 000.

The scatterplot of respiratory complaints versus peak SO_2 concentration indicates an incoherent response at low SO_2 values. This suggests a threshold analysis would be useful. In figure 5 the correlation function at different peak values is computed.

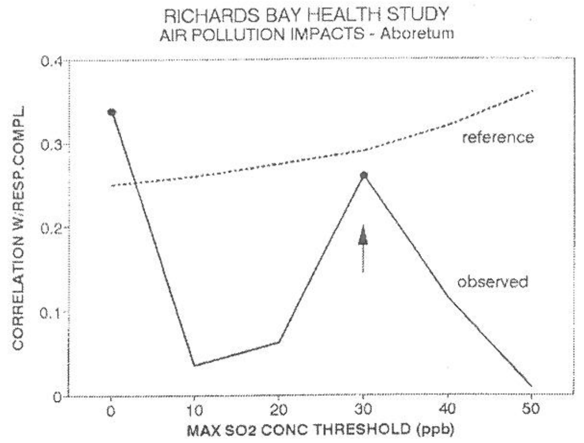

Figure 5. Correlation function at different thresholds (solid) based on comparison of peak SO_2 concentrations and respiratory complaints. Arrow points to critical health risk level. Dashed line is the reference 90% significance value.

Including all values to zero, the peak correlation is achieved. Hence less people visit the doctor's clinic on days when the air is 'clean'. At thresholds of 10 and 20 ppb low correlation are found, however at 30 ppb a sharp rise in the correlation function is observed. It is concluded that this level causes the strongest variation in human response to ambient air pollution in Richards Bay. Correlation decline above 30 ppb as air pollution levels become 'saturated' and patients more continuously visit the doctor's clinic, yielding little temporal variability in the sample.

3.2 Pollution episode survey in 1999

Having established the likely threshold of health impacts, a further survey was conducted in 1999 using SO_2 and meteorological information. The municipality planned to collect health statistics, but was unable to do so. Daily peak values of SO_2 exceeding 30 ppb were noted between 15 March and 10 July 1999. Table 1 indicates that peak SO_2 values > 30 ppb were recorded on 45 days or 38% of the time at Aboretum (next to the clinic). This station may be considered representative of the eastern CBD, Boardwalk shopping centre, Bay Hospital and numerous local schools, according to the aforementioned dose map (eg. figure 1). According to the wind direction data in scatterplot form in figure 6, it is the industries situated immediately to the south-west of Aboretum, which cause the peak values, eg. IOF for directions 220°, Bayside - 230°, and Hillside - 240°+.

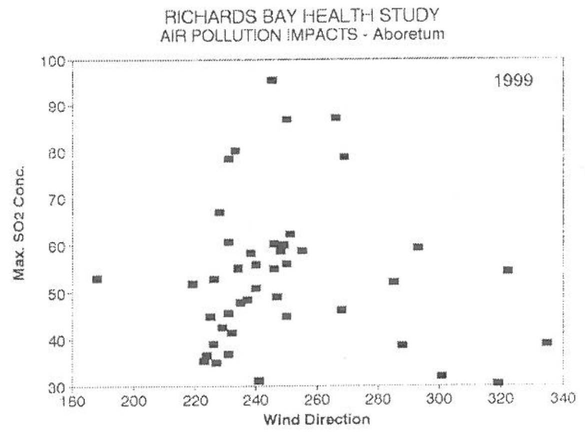

Figure 6. Scatterplot of wind direction versus peak SO_2 concentrations in March to July 1999 survey.

The time of day with highest probability for pollution exposure is in the morning (figure 7): 15 cases between 08h00 and 10h00 as children arrive at school and 7 cases between 04h00 and 05h00.

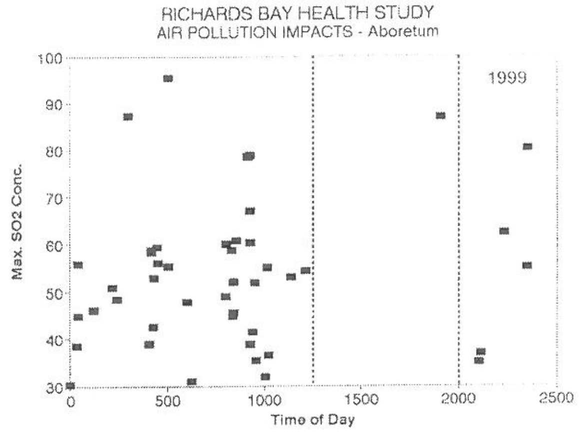

Figure 7. Scatterplot of time of day and peak SO_2 concentrations. Afternoon-evening pollution exposure is limited by convective seabreeze activity.

The relationship with wind speeds is incoherent and typically in the range 2 - 2.5 m s^{-1}. Highest SO_2 peaks occur at wind speeds from 2.5 to 4.5 m s^{-1} presumably as turbulence draws the elevated plumes toward the surface.

Table 1 : Daily maximum SO_2 pollution concentrations and comparative meteorological data, for cases > 30 ppb in the period 15 March and 10 July 1999.

Date	Time	SO_2	Dir	Spd
18-3	08h00	49.0	247	2.3
23-3	08h55	60.8	231	2.2
24-3	06h25	31.0	241	2.1
7-4	10h15	55.0	234	2.2
8-4	0h35	38.5	288	1.9
9-4	08h40	45.5	231	1.0

Date	Time	SO_2	Dir	Spd
11-4	04h35	52.8	226	4.4
18-4	06h00	47.8	235	1.0
19-4	22h30	62.3	251	1.1
16-4	04h05	39.0	226	1.0
20-4	08h30	58.8	255	2.4
21-4	21h05	35.0	227	5.2

26-4	0h40	44.8	225	2.6
24-4	05h05	55.3	234	3.4
5-5	23h50	80.3	233	3.0
3-5	09h40	41.3	232	4.1
4-5	09h25	60.3	246	2.5
6-5	04h45	59.3	293	1.9
10-5	0h00	30.3	319	0.8
11-5	09h55	35.3	223	2.6
13-5	02h15	50.8	240	2.7
14-5	10h05	32.0	301	0.5
15-5	12h15	54.3	322	1.4
16-5	04h25	42.5	229	3.0
17-5	09h25	38.8	335	1.6
20-5	08h05	60.0	249	1.9
23-5	01h20	46.0	268	2.0
24-5	08h40	52.0	285	1.1
25-5	11h40	53.0	188	0.9
27-5	02h40	48.3	237	3.1
28-5	09h25	78.8	269	2.2
30-5	08h35	44.8	250	2.6
1-6	23h45	55.0	246	1.9
2-6	0h40	55.8	240	2.3
6-6	09h15	78.5	231	2.4
7-6	19h10	87.0	250	4.4
8-6	04h15	58.3	238	4.1
9-6	04h50	56.0	250	1.9
15-6	03h00	87.3	266	2.6
20-6	05h05	95.5	245	3.4
24-6	21h15	36.8	231	2.3
25-6	09h25	67.0	228	3.4
26-6	10h25	36.5	224	1.0
30-6	09h50	51.8	219	2.0
2-7	04h15	58.8	248	2.6
total sample = 118 days.				

4. SUMMARY AND RECOMMENDATIONS

In this study, a simple method for determining health impacts in comparison with observed air pollution data has been outlined. Preliminary analysis of meteorological information suggested that the summer season, from August to March, is characterised by easterly winds, rainy weather, onshore seabreezes and a thermally convective boundary layer favourable to mixing and dispersion of air pollutants away from the residential areas of Richards Bay. During winter, April to July, light drainage flows draw pollutants eastward across residential areas. A dose map analysis determined the spatial extent of pollution levels and against this background, a preliminary health survey was devised. A busy doctor's clinic in the key exposed area recorded vital daily statistics on 1st time respiratory complaints. Most of the patients were school-aged children. Relationships between air pollution exposure and reported illnesses were investigated. A maximum correlation of 52% was determined considering daily peak values of SO_2, excluding the first couple of days of the survey when an influenza virus reportedly afflicted residents. Correlations were lower for daily averaged levels and at lags other than simultaneous. A threshold analysis determined that much of the correlation could be attributed to two factors: reduced health impacts on days with near-zero pollution concentrations (eg. winds from the NE), and a particular sensitivity (eg. higher variance) to peak SO_2 values ~ 30 ppb. This interpretation for a limited period during the winter of 1998 needs to be supported by further surveys of a similar nature.

Public perceptions support the view that the health impacts are real, not psychosomatic. It appears the town plan has been mis-informed, leading to some of the air pollution sources being sited inappropriately as highlighted in earlier reports (ENPRO 1997). Whilst maritime transport has a locally viable niche, further industrial expansion in Richards Bay should accommodate growth in the service (tourism) sector which is vital to the creation of jobs.

Air pollution monitoring efforts should be continued in conjunction with a substantially widened health survey in exposed urban areas. Although the simple method outlined here establishes the temporal character of health responses, the spatial context remains unanswered. Health results in conjunction with dose maps can be used to guide municipal decisions on compromises between industrial siting, environmental protection and health risk reduction.

5. ACKNOWLEDGEMENTS

Pollution concentration and meteorological data from the Richards Bay Clean Air Association are gratefully acknowledged. Dose maps were constructed by the CSIR under contract to IOF.

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ELECTROSTATIC PRECIPITATOR ENHANCEMENT THROUGH GAS AND DUST FLOW OPTIMISATION

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1. INTRODUCTION

The recent projects conducted by Eskom Technology Servises International in applying the electrostatic precipitator Skew Gas Flow Technology have demonstrated that significant reductions in emissions can be achieved by low cost flow modifications.