Environmental Health Perspectives
Vol. 79, pp. 89–99, 1989

Health Effects During a Smog Episode in West Germany in 1985

by H. E. Wichmann,* W. Mueller,† P. Allhoff,‡ M. Beckmann,* N. Bocter,† M. J. Csicsaky,* M. Jung,§ B. Molik,* and G. Schoeneberg*

In January 1985 a smog period occurred for 5 days in parts of West Germany, including the Rhur District. Mortality (24,000 death certificates), morbidity in hospitals (13,000 hospital admissions, 5400 outpatients, 1500 ambulance transports) and consultations in doctors' offices (1,250,000 contacts) were studied for a 6-week period including the smog episode and a time interval before and thereafter. The study region was the State of North Rhine-Westfalia (16 million inhabitants), but the analysis is restricted to the comparison of the polluted area and a control area (6 million inhabitants each).

During the smog period, mortality and morbidity in hospitals increased in the polluted area, but there was no substantial increase in the control area. The increases were for the total number of deaths 8 vs. 2% (polluted area vs. control area), for hospital admissions 15 vs. 3%, for outpatients 12 vs. 5% and for deliveries by ambulance to hospitals 28% in the polluted area (not investigated in the control area). The effects were more pronounced for cardiovascular diseases than for respiratory diseases. The consultations in doctors' offices show a slight decrease (–2 vs. –4%).

Regression analysis shows a moderate influence of temperature, but a strong influence of ambient air pollution. The maxima of the ambient concentrations are more important on the same day, whereas the influence of the daily averages is more pronounced after a delay of 2 days.

The results are discussed considering other possible confounders such as indoor pollution and psychogenic influences of the alarm situation. In total, the study suggests moderate health effects due to increased air pollution during the smog episode.

Introduction

In January 1985 a smog episode took place in parts of North Rhine-Westfalia (West Germany). In the Ruhr District, a smog alarm was given for 5 days. In the western part of the Ruhr District, air pollution reached the emergency level, with the consequence of a total stop of traffic and reduced production in certain plants. An extended investigation of the health effects during this period was performed, supported by the Ministry of Work, Health and Social Care of North Rhine-Westfalia (*1*), the essentials of which shall be presented here.

*Medizinisches Institut für Umwelthygiene, Auf'm Hennekamp 50, D-4000 Düsseldorf 1, Federal Republic of Germany.
†Akademie für Öffentliches Gesundheitswesen, Düsseldorf, Federal Republic of Germany.
‡Zentralinstitut für die Kassenärztliche Versorgung, Köln, Federal Republic of Germany.
§Deutscher Wetterdienst Essen, Federal Republic of Germany.

Materials and Methods

Data on morbidity, mortality, ambient air pollution, and meteorologic variables were collected retrospectively for the period from January 1 to February 15, 1985, but the analysis is restricted to the 6 complete weeks between January 3 and February 13. In the following discussion, we shall refer to the week from January 17 to 23 as the smog period. This week includes the period of smog alarm (Thursday, January 17 to Monday, January 21) and the following 2 days. The rationale for this definition is the experience from earlier smog episodes, that health effects might follow with a delay of 1 to 2 days after the smog. The other 5 weeks (January 3–16, January 24–February 13) are referred to as control period while the whole time interval (January 3–February 13) will be denoted as the period of observation. Due to a shorter time interval for data collection, the period of observation for ambulance transports is restricted to January 3–February 6.

To allow for a comparison between areas with different degrees of pollution, the study was extended to the state of North-rhine Westfalia with about 16 million inhabitants, 6 million of them living in the polluted area, 4 million in an area with an intermediate degree of air pollution, and 6 million in the control area, which has a low degree of air pollution. Only data from the polluted area and the control area will be analyzed. The polluted area is highly industrialized and urban, with different types of industry (primarily metal industry, coal mining, chemical, petroleum refining, etc.): the control area is primarily rural, with some medium-sized cities and some minor local industries (furniture, textile, manufacturing). The age structure of the population in both areas is similar.

Meteorologic Variables

Meteorologic information about temperature, wind velocity, humidity, and biotropy was available from 11 stations of the German Weather Service. (Biotropy describes weather conditions with potential relevance to health, using the scale: 0 = no, 1 = weak, 2 = intermediate, 3 = strong biotropy. It is determined four times a day by the central weather station in Essen, on the basis of complex meteorologic information.)

Ambient Air Pollution

Ambient concentrations [30-min averages and 24-hr averages of sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and carbon monoxide (CO), 3-hr averages and 24-hr averages of suspended particulates, (SP)] have been measured at 42 permanent stations in the whole state run by the Landesanstalt für Immissionsschutz, Essen, and several data from further stations have been available. In the following analysis, only data from the 36 stations in the polluted area and one station in the control area will be presented.

Mortality Data

Mortality data were collected by the Public Health Administrations of all communities and counties in North Rhine-Westfalia and coded on the basis of the International Classification of Diseases (ICD). In addition, deaths by respiratory or cardiovascular diseases were coded separately if these diagnoses were either denoted as cause of death or as consecutive disease. Therefore, the latter numbers are higher than in the official mortality statistics, especially for deaths related to respiratory diseases. Furthermore age, sex, last place of residence and place of death were extracted from the death certificates. In total, data from 24,000 deaths (94% of all) were available.

Hospital Admissions

The data on hospital admissions were requested by questionnaires, which had been sent to all hospitals for internal medicine and pediatrics in North Rhine-Westfalia; 186 hospitals (45% of all) participated in the study. Individual information about the day of admission, the clinical diagnosis, the severity of the symptoms, age, sex, and anamnestic information were collected for about 13,000 patients with respiratory or cardiovascular diseases.

Ambulance Transports

The data about patients delivered by ambulance to the hospitals were collected in two steps. First all potentially relevant transports were extracted from the records in the ambulance control centers, then the diagnoses of these patients were completed from their hospital records. Thus, for seven big cities (Duisburg, Oberhausen, Essen, Dortmund, Gelsenkirchen, Düsseldorf, Köln), individual data from 1500 patients with respiratory or cardiovascular diseases delivered to 78 hospitals (58% of all transports under study) were collected. These data included day of admission, age, sex, diagnosis, and severity of symptoms. Furthermore, aggregated data about all ambulance transports and emergency transports were available on a daily basis.

Outpatients

One hundred nine hospitals also filled in questionnaires about visits of outpatients in their emergency rooms, but only in aggregated form. These ambulances are mainly consulted by the patient's own decision rather than by doctor's advice. In total, aggregated data of 5400 outpatients with respiratory or cardiovascular diseases could be collected giving the number of consultations in the clinic per day with, without, and with uncertain clinical verification of the complaints.

Consultations in Doctor's Office

A 10% random sample of all internists, pediatricians, and general practitioners in the polluted area and in parts of the control area was selected to participate in the study. From the insurance claim forms for the 3 month period, January–March 1985, the daily numbers of consultations (respiratory, cardiovascular, and other diseases, broken down by age and sex) were extracted. Thus, aggregated information about 1,250,000 consultations in 615 doctors' offices (93% of the random sample) was collected. These data do not represent the causes of consultation on that specific day, but the consultations of persons categorized into the given diagnostic groups.

Statistical Analysis

For the epidemiologic data day-of-week influences had to be eliminated. This was achieved by calculating the difference between the data of the specific day and

the average of the same days of week during the period of observation (e.g., difference between hospital admissions on January 17, which is a Thursday, and the average of hospital admissions on January 3, 10, 17, 24, 31, and February 7, which are all Thursdays of the period of observation). To obtain data adjusted for the day of week, the overall average is added.

$$Y_{ij} = X_{ij} - X_{\cdot j}/6 + X_{..}/42$$

X_{ij} original data, Y_{ij} day-of-week adjusted data; dots denote summation over the corresponding index; $i = 1, \ldots, 6$ weeks, $j = 1, \ldots, 7$ days of week.

The day-of-week adjusted morbidity is compared with the daily averages or daily maxima of the ambient concentrations and the meteorologic parameters of the closest station using linear regression analysis. A conservative test strategy is applied, in which the effects of potential confounders (i.e., weather variables) are considered in the first place. Thereafter, the additional contribution of the pollution variables expressed as partial R^2 is determined. To account for a possible time delay, the dependent variables at time t are compared with the independent variables either at time t or at time t–2. The pollutants are separately included in the regression analysis, in addition to temperature and biotropy, because SO_2, suspended particulates (SP), NO_2, and CO are closely correlated (the coefficients of correlation of their daily averages range from 0.80 to 0.95).

In Table 1 and Figure 1, for the number of patients, the smog period is compared with the pre- and post-smog period to quantify excess morbidity. For the number of deaths the smog period is compared with the total period of observation to quantify premature mortality rather than excess mortality (t-test, one-sided).

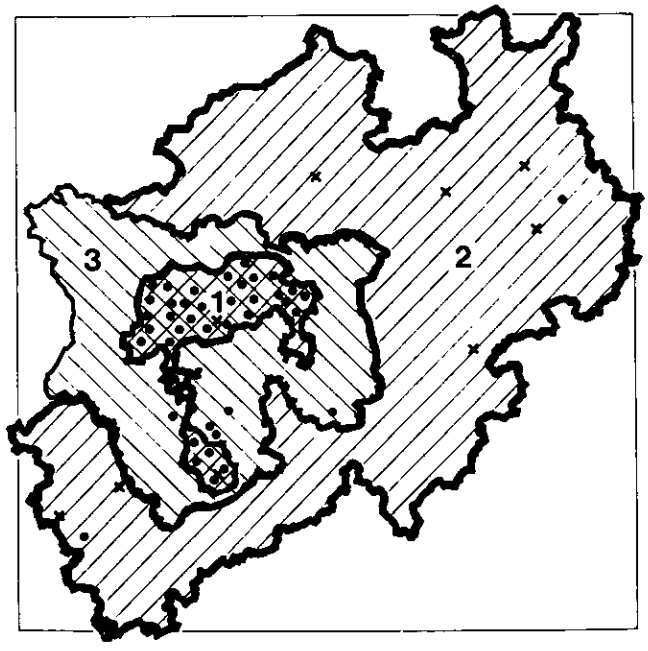

FIGURE 1. State of North Rhine-Westfalia, FRG. (1) Polluted area: Ruhr District (northern part of the polluted area 4.4 million inhabitants), Düsseldorf (south of Ruhr District, 0.5 million inhabitants), and Köln (south of Düsseldorf, 1 million inhabitants). (2) Control area: eastern and southern parts of North Rhine-Westfalia (6 million inhabitants). (3) Intermediate area (4 million inhabitants, not considered here). (•) Pollution control stations; (x) weather stations.

Results

Figure 2 shows the study area and the permanent stations measuring the ambient air pollution and the weather variables.

Table 1. Maximum concentrations for suspended particulates, sulfate, SO_2, NO_2, and CO during the smog period.

	Polluted area		Control area
Pollutant	Maximum 24-hr average, mg/m³ [a]	Pooled 24-hr average, mg/m³ [b]	Maximum 24-hr average, mg/m³ [c]
Suspended particulates[d]	0.60 (Jan 20)[e]	0.44 (Jan 20)	0.19 (Jan 19)
Sulfate[f]	0.123 (Jan 17)		
SO_2	0.83 (Jan 17)	0.62 (Jan 17)	0.32 (Jan 15)
NO_2	0.23 (Jan 17)	0.17 (Jan 17)	0.12 (Jan 19)
CO	8.00 (Jan 18)	5.90 (Jan 18)	–

[a]Highest individual 24-hr average reached at 1 of the 36 stations in the polluted area.
[b]Highest pooled 24-hr average of the 36 stations in the polluted area.
[c]Highest 24-hr average reached at one station (Eifel) in the control area.
[d]Beta attenuation particle sampler (*17*).
[e]Day the maximum was reached.
[f]Highest individual 24-hr average on Jan 17 at 1 of 10 stations (*18*).

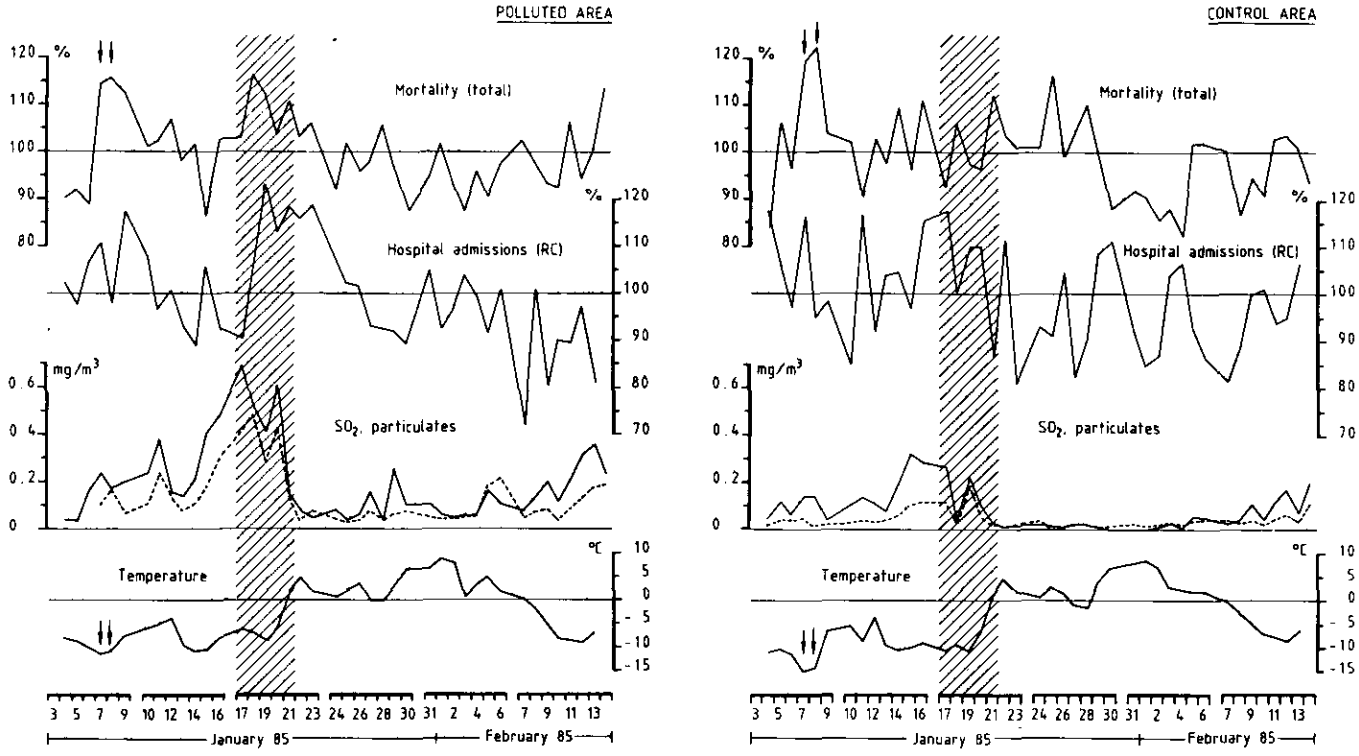

FIGURE 2. Top: Total mortality (deaths per day) and hospital admissions, patients per day with respiratory or cardiovascular diseases (RC), day-of-week adjusted. Bottom: SO_2 (—) suspended particulates (- - -) and temperature (24-hr averages) at representative stations in the polluted area (Duisburg, Essen) and the control area. (Eifel, Münster). Arrows: Two very cold days in the presmog period. Shaded area: period of smog alarm.

Meteorologic Situation

The smog episode was caused by an inversion of vertical temperature gradient from January 16 to 20 with a wind velocity below 1.5 m/sec. During this time pollutants accumulated, especially in the Ruhr District. Due to the wind from east and southeast pollutants were also imported from East Germany and Czechoslovakia (*2*). Inversion stopped on January 21, and fresh wind came up. During the first part of the smog period (January 17–20) it was cold, with temperatures between −4°C and −12°C (daily average). Temperature increased steeply on January 21. Humidity was high during the whole period. Biotropy was weak from January 17 to 20 and became strong on January 21.

In the control period the wind mainly blew fresh from changing directions. Only on January 10 to 11 and at the beginning of February, wind velocity also became low and in some areas an inversion without important accumulation of pollutants occurred. The temperatures were very low in the pre-smog period and the coldest days were January 7 to 8 with average temperatures of −17°C to −12°C. After the smog period, temperatures were much higher for 2 weeks and the weather was mild with much rain. Humidity was between 80 and 95% during the control period and decreased only on February 4 to 5 to 20 to 60%. Biotropy was weak before the smog and was elevated for 2 weeks after the smog episode.

In total, the weather was characterized by unusually low temperatures from the beginning of January until the end of the smog episode, where weather changed significantly (on January 21). Therefore, at the end of the smog period, combined influences from pollution and weather must be expected.

Ambient Air Pollution

In Table 2, the maximum concentrations for SO_2, suspended particulates (SP), NO_2, and CO (daily averages) are given for the polluted area and the control area. However, they can only be compared qualitatively due to the different number of stations in the areas. For the control area the station in the western part (Eifel) is considered, because the measurements at the eastern station, located on a mountain 150 km from the border to East Germany, are mainly determined by pollutants transported from the east (*3*).

The smog episode was characterized by elevated levels of SO_2 and SP. In the polluted area for SO_2 a daily average of 0.83 mg/m^3 and a daily maximum (30-min value) of 2.17 mg/m^3 was reached. For SP, the corresponding concentrations were 0.6 mg/m^3 (daily average) and 0.85 mg/m^3 (3-hr value).

Table 2. Health effects in the polluted area during the smog episode: Regression analysis of the number of patients or deaths.

Source of variation	M[b]	H	A	O	C
	Partial R^2 (t)[a]				
Temperature[c]	0.06	0.08	0.02	0.00	0.47†
Biotropy	0.03	0.00	0.00	0.01	0.02
Temperature and biotropy	0.06	0.12	0.05	0.01	0.60†
SP (daily maxima)[d]	0.13*	0.09*	0.33†	0.18†	0.02
SO_2 (daily maxima)[d]	0.09	0.03	0.24†	0.19†	0.00
NO_2 (daily maxima)[d]	0.12*	0.06	0.29†	0.07	0.03
CO (daily maxima)[d]	0.04	0.07	0.26†	0.06	0.05
All pollutants	0.20	0.13	0.34*	0.35†	0.12
Whole model	0.27	0.25	0.38*	0.36*	0.72†
	Partial R^2 $(t-2)$[a]				
Temperature[c]	0.18†	0.05	0.10	0.01	0.51†
Biotropy	0.03	0.02	0.00	0.08	0.10
Temperature and biotropy	0.19*	0.15*	0.18*	0.08	0.51†
SP (daily average)[d]	0.16†	0.28†	0.23†	0.35†	0.00
SO_2 (daily average)[d]	0.17†	0.20†	0.22†	0.30†	0.00
NO_2 (daily average)[d]	0.17†	0.26†	0.14*	0.28†	0.00
CO (daily average)[d]	0.19†	0.25*	0.15*	0.31†	0.00
All pollutants	0.21*	0.31†	0.28*	0.37†	0.02
Whole model	0.40†	0.46†	0.47†	0.46†	0.53†

[a]Variables for weather and pollution concentrations on the same day ($R^2(t)$) or 2 days earlier ($R^2(t-2)$) than health variables.
[b]M, mortality (all causes); H, hospital admission (RC), day-of-week adjusted; A, ambulance transports (RC), day-of-week adjusted; O, outpatients (RC, visits in emergency rooms) without Jan 4, day-of-week adjusted; C, consultations in doctors' offices (all causes) without Saturdays and Sundays, day-of-week adjusted; RC, respiratory or cardiovascular diseases.
[c]The correlation between temperature and M, H, A, O is negative and between temperature and C positive.
[d]At the station closest to the place of residence (M), location of hospital (H, A, O) or doctor's office (C). The pollutants are separately included in the regression analysis, in addition to temperature and biotropy. The correlation between pollutants and morbidity or mortality data is positive.
*$p < 0.05$.
†$p < 0.01$.

Health Effects

In Figure 3, the time courses of total mortality and hospital admissions are shown. In the polluted area, an increase of both the number of admitted patients and the number of deaths is observed, which is parallel to the increase of the pollutants. The maxima of mortality and hospital admissions are reached 1 to 2 days after the onset of the smog episode. No similar pattern is found in the control area, where the pollutant concentrations were lower.

There are fluctuations in the data that are similar in both areas. Most pronounced is a peak of the number of deaths in the presmog period (January 7 and 8), which coincides with very low temperatures. The regression analysis identifies a considerable contribution of air pollution to the explanation of the medical observations (exception: consultations in doctor's offices) in the polluted area. The contribution is highly significant for the maxima of ambient concentrations of the same day or their daily averages with a delay of 2 days (Table 3). For the control area no regression analysis was possible because of the small number of stations.

If one compares the smog period to the average of the other weeks, one finds a significant increase for total mortality, hospital admissions, outpatients, and ambulance transports of patients with respiratory or cardiovascular diseases in the polluted area (Fig. 1). This behavior is also reflected in the parallel increase of the smoothened time courses during the episode and the parallel decrease thereafter (Fig. 1). In contrast, for the control area no similar pattern is observed.

A more specific analysis of the diagnoses shows as a general feature that cardiovascular diseases increased more pronounced than respiratory diseases (Table 1). This will be discussed below in more detail.

Mortality

If the smog period is compared with the period of observation, one finds a significant increase of the number of deaths per day by 8% in the polluted area but only by 2% in the control area (Table 1). Looking at diagnostic groups, a clear increase for death by cardiovascular diseases is observed, which is similar in both areas (6 vs. 8% for polluted vs. control area), while for respiratory diseases only a small elevation is found in the polluted area and a reduction in the control area (3 vs. −5%). The most pronounced increase in the polluted area is found for combined respiratory and cardiovascular diseases (9 vs. 2%) and for other causes of death (11 vs. −6%).

Looking at single diagnoses, for death by heart insufficiency (19 vs. 15%), cardiac infarct (9 vs. −1%), cerebral circulation failure (5 vs. 1%), chronic bron-

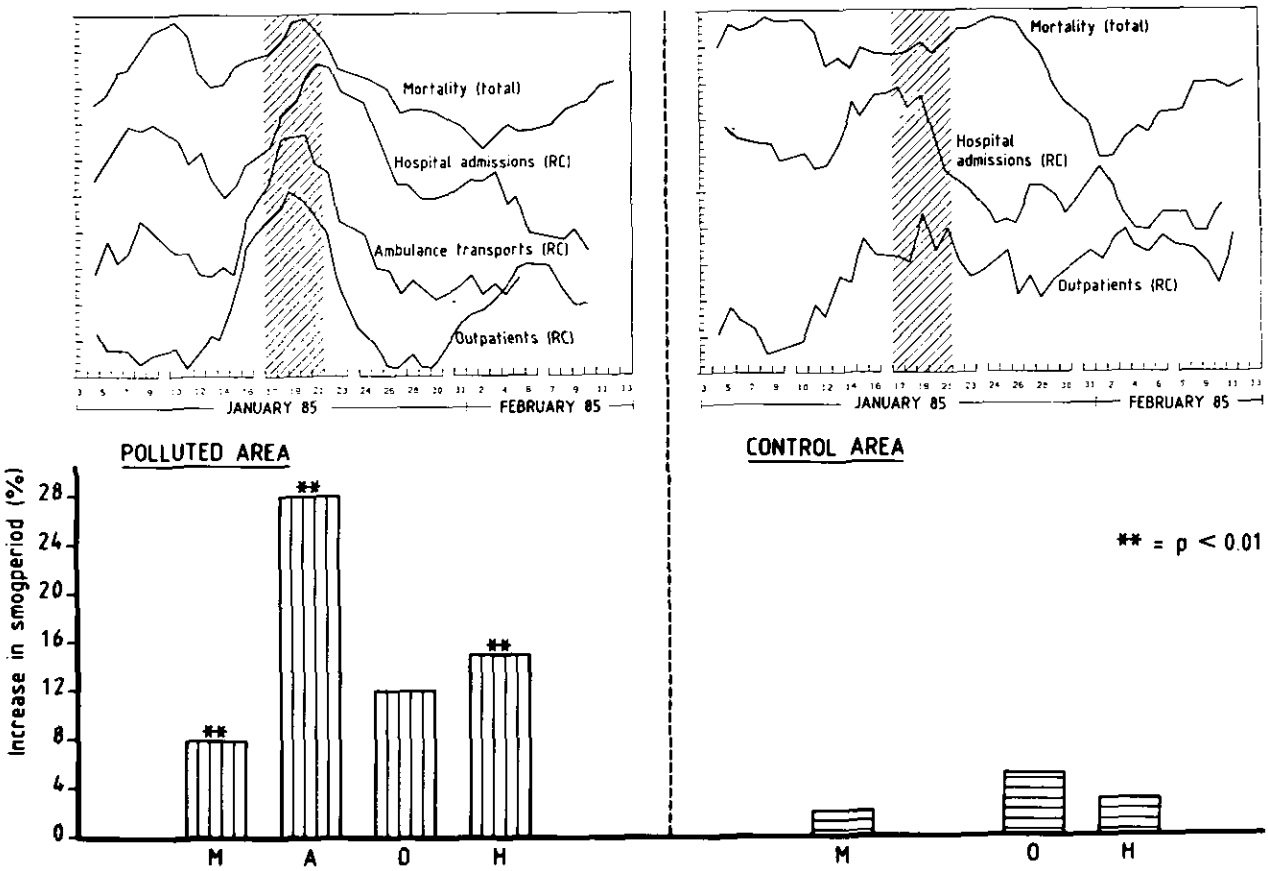

FIGURE 3. Top: smoothened time courses (7-day moving average) of ambulance transports (*A*): outpatients (*O*): and hospital admissions (H) for patients with respiratory or cardiovascular diseases and of total mortality (M). Bottom: Increase during the smog period compared with the other weeks.

chitis (12 vs. −8%), and lung cancer (20 vs. −2%), an increase is found in the polluted area, which is less pronounced or missing in the control area. However, these increases during the smog period are not significant (except for heart insufficiency).

Hospital Admissions

From Table 1, one finds that hospital admissions increase significantly by 15% in the polluted area and only slightly by 3% in the control area, if the smog period is compared to the control period. The increase is more pronounced for cardiovascular diseases (19 vs. 5%) than for respiratory diseases (7 vs. 0%).

The most pronounced effects are found for cerebral circulation failure (57 vs. 0%, but small numbers), heart arrhythmia (49 vs. −8%), chronic bronchitis (39 vs. 6%), and coronary insufficiency (30 vs. 3%), which all are significant in the polluted but not in the control area. However, for some diseases, a decrease during the smog period is observed, e.g., for bronchial asthma (−14 vs. −4%).

Ambulance Transports

The number of patients with respiratory or cardiovascular diseases, which were transported by ambulances into hospitals in the polluted area during the smog episode, shows the strongest increase of all parameters considered in this study. During the smog period, 28% of the patients of this diagnostic group were transported in excess (Table 3). The increase was stronger for patients with respiratory diseases (36%) than for those with cardiovascular diseases (25%). Transports by all causes, of which in our data only 10 to 15% were patients with validated respiratory or cardiovascular diseases, showed a smaller increase (6%).

Outpatients

The number of the recorded outpatients increased during the smog period by 12% in the polluted area and by 5% in the control area. Since these data are only available in aggregated form, an analysis within subgroups is not possible. In addition, the respiratory and cardiovascular symptoms have only been validated for approximately 50% of these patients.

Consultations in Doctors' Office

The number of consultations in doctors' offices (Table 1) shows no relevant changes for patients with

Table 3. Number of patients and number of deaths during the smog period and the control period in the polluted area and the control area.

		Polluted area			Control area		
		Smog period	Control period		Smog period	Control period	
Diagnosis		x̄ (s)[a]	x̄ (s)	Change, %[b]	x̄ (s)	x̄ (s)	Change, %[b]
Cardiovascular diseases (total)	M[c]	115.3 (11.6)	108.8 (12.2)	6	109.7 (11.5)	101.8 (11.4)	8
	H	87.6 (12.5)	73.7 (9.1)	19†	56.1 (11.1)	53.5 (7.7)	5
	A	35.1 (7.1)	28.4 (4.9)	25†			
	C	12262 (574)	12539 (780)	−2	2648 (85)	2730 (170)	−3
Heart insufficiency	M	22.1 (4.7)	18.5 (4.6)	19*	24.1 (3.0)	21.0 (4.1)	15*
	H	41.3 (7.5)	36.2 (7.7)	14	26.2 (6.4)	22.1 (5.0)	19†
Coronary insufficiency	H	24.0 (8.2)	18.4 (6.9)	30*	11.2 (3.8)	10.9 (5.1)	3
Heart arrhythmia	H	7.6 (3.1)	5.1 (1.9)	49†	4.7 (2.4)	5.1 (2.3)	−8
Cardiac infarct	M	22.1 (3.8)	20.3 (5.5)	9	20.9 (4.1)	21.2 (4.0)	−1
	H	18.6 (4.9)	16.9 (3.7)	10	11.7 (3.5)	11.5 (5.1)	2
Hypertonus	H	4.6 (2.7)	4.1 (1.8)	12	3.1 (2.6)	3.2 (1.6)	−3
Cerebral circulation failure	M	16.1 (4.5)	15.3 (4.6)	5	17.6 (5.4)	17.5 (5.0)	1
	H	3.6 (1.0)	2.3 (1.2)	57†	2.7 (2.1)	2.7 (1.5)	0
Respiratory diseases (total)	M	19.3 (3.8)	18.9 (3.7)	3	16.9 (2.9)	17.6 (3.9)	−5
	H	50.7 (5.1)	47.3 (6.6)	7	36.0 (3.9)	35.9 (7.0)	0
	A	13.6 (3.1)	10.0 (3.2)	36†			
	C	9706 (535)	9780 (836)	−1	2258 (73)	2347 (128)	−4
Obstructive bronchitis	H[d]	6.0 (1.8)	5.3 (2.0)	13			
Croup syndrome	H[d]	6.5 (1.8)	4.7 (2.8)	38			
Pneumonia	H	10.3 (3.1)	10.5 (3.8)	−2	6.7 (4.5)	7.3 (4.5)	−8
Chronic bronchitis	M	4.6 (1.5)	4.1 (1.6)	12	3.4 (1.9)	3.7 (1.8)	−8
	H	5.7 (1.8)	4.1 (1.6)	39*	7.0 (3.7)	6.6 (4.7)	6
Bronchial asthma	H	6.0 (1.7)	7.0 (2.0)	−14	6.7 (1.3)	7.0 (1.8)	−4
Lung cancer	M	11.3 (3.5)	9.4 (3.3)	20	6.0 (4.3)	6.1 (3.0)	−2
Combined respiratory and cardiovascular diseases	M	11.7 (2.8)	10.7 (3.3)	9	9.7 (2.6)	9.5 (3.1)	2
	H	6.4 (0.5)	5.8 (2.4)	10	6.3 (2.0)	5.2 (2.1)	21
	A	3.6 (1.8)	3.2 (1.7)	13			
	C	4048 (219)	4062 (263)	0	941 (52)	961 (59)	−2
Respiratory or cardiovascular diseases	M	122.9 (9.6)	117.0 (12.3)	5	116.9 (11.5)	110.0 (11.2)	6
	H	137.0	119.2	15†	88.7	86.0	3

(Continued on next page)

Table 3. (*Continued*).

Diagnosis		Polluted area: Smog period x̄ (s)[a]	Polluted area: Control period x̄ (s)	Change, %[b]	Control area: Smog period x̄ (s)	Control area: Control period x̄ (s)	Change, %[b]
		(13.5)	(11.7)		(11.8)	(9.8)	
	A	45.1	35.1	28†			
		(6.7)	(5.5)				
	O	64.1	55.7	15	31.1	29.7	5
		(12.6)	(15.6)		(7.1)	(5.1)	
	C	17919	18258	−1	3964	4116	−4
		(2631)	(2347)		(609)	(538)	
Other causes	M	109.0	97.9	.11*	70.3	74.4	−6
		(10.2)	(11.6)		(6.4)	(8.3)	
	C	5911	5879	1	1479	1475	0
		(153)	(232)		(36)	(45)	
All causes	M	231.9	214.9	8†	187.1	184.3	2
		(11.0)	(16.9)		(12.1)	(16.7)	
	A	821.4	774.8	6*			
		(76.1)	(54.9)				
	C	23831	24136	−1	5443	5590	−2
		(639)	(1240)		(128)	(229)	

[a]Average number and standard deviation of cases per day (only diagnoses with more than two cases per day are presented).
[b]Percent changes of the smog period compared with the control period in the same area.
[c]M, mortality (comparison of the smog period with the whole period of observation); H, hospital admissions; A, ambulance transports; O, outpatients (visits in emergency rooms); C, consultations in doctors' offices (without Saturdays and Sundays).
[d]Including data from pediatricians in Köln and Duisburg.
*$p < 0.05$.
†$p < 0.01$.

cardiovascular diseases (−2 vs. −3%), respiratory diseases (−1 vs. −4%), or combined cardiopulmonary symptoms (0 vs. −2%), or other complaints (1 vs. 0%). Furthermore, a strong positive correlation is found with temperature, but no correlation with air pollution (Table 3). These data show that the consultations in the doctors' offices are dominated by other influences, especially weather conditions. The number of consultations is reduced significantly on cold days or days with bad weather (*1*).

Comparison with Earlier Smog Episodes

If one considers the available information about smog episodes in the Ruhr District, one finds the results given in Table 4. The most important episode was in 1962 and lasted for 5 days. The pollutants reached 5 mg SO_2/m^3 and 2.4 mg SP/m^3 (24 hr averages) (*4*). During this episode the number of deaths increased by 15% if the week from the begin-

Table 4. Smog episodes in the Ruhr District.

Episode, duration	Dec. 1962 (*4,5*) (5 days)	Jan. 1979 (*6,7*) (1 day)	Jan. 1982[a] (*8*) (6 days)	Jan. 1985 (*1*) (5 days)
SO_2, mg/m^3				
30-min value		1.4	1.1	2.2
3-hr value		1.1	0.9	1.6
24-hr value	5.0	0.6	0.6	0.8
SP, mg/m^3				
3-hr value		0.5	0.6	0.8
24-hr value	2.4[b]		0.5	0.6
Increase of total mortality	15%[c] (19%)[d]	none	none[e]	6%[c] (8%)[f]

[a]The smog episode was restricted to a small area in the center of the Ruhr District.
[b]Different technique of measurement compared to later episodes.
[c]Recalculation to make 1962 and 1985 comparable: smog period (= week from the beginning of smog) compared with period of observation, only Ruhr District.
[d]Original calculation in Steiger and Brockhaus (*5*): 2 weeks from the beginning of smog compared with average of 4 weeks before and 2 weeks after this period, polluted area including Ruhr District.
[e]Wichmann and Molik, unpublished data.
[f]Polluted area including Ruhr District (see Table 1).

ning of the smog is compared to the period of observation (*5*; Wichmann and Molik, unpublished data).

In 1979, during a 1-day smog episode, concentrations of 0.6 mg SO_2/m^3 (24-hr average) and 0.5 mg SP/m^3 (3-hr average) were reached (*6*), but no increase in mortality could be found (*7*). In 1982, a local smog episode of 6 days was reported in the center of the Ruhr District, where 0.6 mg SO_2/m^3 and 0.5 mg SP/m^3 (24-hr average) also with high concentrations of NO_2 and CO were reached (*8*). The analysis of the mortality data of this small area did not show an observable effect (Wichmann and Molik, unpublished data).

The smog situation in January 1985 was extended over large parts of central Europe and lasted for 5 days. In the Ruhr District, SO_2 concentrations up to 0.8 mg/m^3 were measured, and suspended particulates reached concentrations of 0.6 mg/m^3 (24-hr average). During this episode an increase of the total number of deaths by 6% was found in the Ruhr District if the week from the beginning of the smog episode is compared with the period of observation (*1*).

Discussion

The analysis of earlier smog episodes in most cases was restricted on mortality data. Typical time courses showed a rise in the number of deaths that occurred within 24 hr after the rise in pollution, occasionally with a delay of 1 day (*9*). The number of deaths decreased on the termination of the incident with a consecutive minimum some days to 2 weeks after the maximum (*5,9,10*). Low temperatures lead to excess mortality (*11*), and epidemics of influenza were responsible for high peaks in mortality and effects of air pollution were aggravated during such epidemics (*10*).

In the present study, the number of deaths rise immediately when the pollutants increase (on January 16) (Fig. 2) and reach the maximum 2 days later. They decrease after the smog episode, and a minimum is found about 2 weeks after the maximum. (The minimum is difficult to identify from Figure 3, but becomes evident from the moving average curves in Figure 1.) This rebound is very similar in time and magnitude to that one observed during the smog episode of 1962 in the Ruhr District (*5*).

In the episode described here, temperature has also a significant contribution to mortality, as can be seen from regression analysis. The most convincing effect of temperature is observed on January 7 and 8, two extremely cold days (daily averages below −10°C), when mortality increases strongly both in the polluted and the control area. There is no indication that influenza may have played any role during the smog episode. However, approximately 6 weeks later, an epidemic of Influenza A occurred, resulting in a peak mortality higher than during the cold presmog phase and during the smog episode (*1*).

If one looks at the causes of death in the polluted area, one finds a stronger increase for cardiovascular or combined cardiopulmonary causes than for respiratory causes. Already in earlier smog episodes (*9,10*), it became evident that respiratory diseases are only in part responsible for the increase of mortality and that cardiovascular and combined cardiopulmonary conditions played an important role (*9*). The correlation of air pollution with total mortality was higher than with bronchitis (*9*) and highest for combined respiratory and cardiovascular conditions in elderly men (*10*). However, in the analysis of causes of death rather than in the analysis of total mortality, the problem of the limited validity of diagnoses on death certificates (*12*) has to be kept in mind for earlier studies as well as for the present one.

In total, the smog episode of 1985 shows moderate effects on mortality, which are less pronounced than in earlier episodes. This had to be expected due to the significant reduction of air pollution over the last decades.

Morbidity has been analyzed in several earlier smog situations (*10,13,14*). Hospital admissions in London (*10*) showed a significant correlation for respiratory or cardiovascular conditions with smoke and SO_2. However, the effects were not so sudden as for mortality. The degree of illness in patients with bronchitis keeping personal diaries was closely related to daily values of air pollution (*14*). The lowest concentrations leading to a significant response in these patients were about 0.5 mg/m^3 of SO_2 together with 0.25 mg/m^3 of smoke (24-hr averages). No evidence was found that these pollutants would, by themselves, produce the same response (*14*). Smaller peaks in the degree of illness were identified, which coincided with falls in temperature (*10,14*).

In the present study, an increase of hospital admissions, outpatients, and ambulance transports of patients with respiratory and cardiovascular diseases is observed if one compares the smog period with the control period. The time course of these data is very similar to the observations for mortality: Despite fluctuations, the curves show a parallel increase at the beginning of the smog period and a common decrease thereafter in the polluted area. In the control area, no similar pattern is found, as shown in Figure 3.

Since the admissions to the 186 cooperating hospitals are well documented and the diagnoses are confirmed, these data can be used for a more detailed analysis. One finds, similar to mortality, that patients with cardiovascular diseases are more strongly affected than those with respiratory diseases. Significant increases in admissions are found for patients with cerebral circulation failure, heart arrhythmia, coronary insufficiency, or chronic bronchitis, but only in the polluted area. A delay of 2 days between increase of the pollutants and the admissions is observed.

Patients delivered by ambulances to hospitals are a subgroup of hospital admissions for which, on the average, more acute or more severe symptoms have to be assumed. This subgroup shows the strongest in-

crease during the smog period, and here respiratory diseases are more important. Furthermore, there is a more direct relation of ambulance transports and maxima of pollutants measured on the same day. It has to be discussed whether the restrictions of motor traffic might be responsible for a more frequent use of ambulance transports. However, motor traffic was limited or reduced only for 2.5 days and only in the centers of some cities in the Ruhr District. Furthermore, the increase of all transports [of which the patients with respiratory or cardiovascular diseases are only approximately 10–15% (*1*)] was much smaller.

Also, for outpatients, a steep increase during the smog period is found with a similar pattern in time as for ambulance transports. The analysis of subgroups is not possible, due to the fact that only aggregated data are available.

Increase is observed for consultations in doctors' offices. A strong positive correlation is found with temperature, but no correlation with air pollution. We explain this by the fact that severely affected persons would rather go to a hospital. Consultations in doctors' offices allows for some flexibility with respect to the time and may be postponed from days with snow, slippery ice, or smog to days with more agreeable weather.

In total, the collected data base is broad and comprises information from different sources. Except for consultations in the doctors' offices a small but consistent increase of mortality and morbidity during the smog period has been shown. It is also consistent with the data from children in the Netherlands (*15*), which showed a significant reduction of their lung function values during the smog episode (January 18, 1985) compared with baseline measurements. Furthermore, the results are supported by morphological and functional analysis of cells from the respiratory system of rats, which lived outdoors in the Ruhr District during the smog period (*16*).

An epidemiologic study of the type presented here can only show relations between variables and does not allow for causal interpretation. At most, consistency can be reached, and therefore it is important to discuss the limitations of the data. The data are (except for mortality) not complete for the whole study area. Therefore, no direct comparison of the crude morbidity data in the polluted area and the control area is possible. However, due to the method of collection, the data are complete for the period of observation. This makes possible an unbiased comparison of the smog period with the control period. Furthermore, it allows a comparison of the profiles of the time courses in the polluted and the control area.

The validity of the diagnoses in part is limited, especially for diagnoses from death certificates and records of the primary doctors. However, by aggregation of the data, this becomes of minor importance. In the most aggregated form, namely, daily mortality and daily consultations, validation problems obviously do not occur.

Meteorological influences have to be discussed. Temperature and biotropy, wind velocity, and humidity have been considered, but only an important influence of temperature has been found. It cannot be excluded that at the end of the smog period, because of the change of weather, further synergistic influences of meteorology and pollutants occurred. On the other hand, the general meteorologic situation was the same in the polluted area and in the control area. Thus, the differences in health effects in these areas are difficult to understand by meteorological arguments alone.

Indoor measurements are missing, and it cannot be ruled out that people left their homes during the smog episode less frequently than usual. Higher exposure to indoor pollutants (tobacco smoke, reduced ventilation, more heating because of low temperatures) could have played a role. Again, this argument is at least in part also valid for the control area.

Psychogenic effects of the alarm situation could have occurred. This argument might be supported by the strong increase of hospital admissions of patients with coronary insufficiency, cerebral circulation failure, or heart arrhythmia, for which possible psychogenic effects have to be discussed. On the other hand, asthma bronchiale, which also has a strong psychogenic component, shows no increase, but a decrease. Furthermore, treatment in hospitals and mortality have increased, but not contacts to doctors' offices. The latter might have been expected if minor symptoms due to psychogenic influences of the smog alarm had played an important role in the study. In total, it seems less probable that the observed health effects can be explained independently from the increased air pollution during the smog episode.

NOTE ADDED IN PROOF: Meanwhile a more detailed analysis of the data set has been performed (*19*). The most important results are:

- If one considers not only the polluted and the control area but also the area with an intermediate degree of air pollution (area 3 in Fig. 2), one finds during the smog episode an increase in total mortality of 8 vs. 5 vs. 2% (polluted vs. intermediate vs. control area) and in hospital admissions of 15 vs. 7 vs. 4% (patients with respiratory or cardiovascular diseases).
- Within the big cities mortality increased during smog in the more industrialized areas.
- Additional information from the data records of hospital admissions (severity of the symptoms, age, sex, anamnestic knowledge) has been analyzed: The smog effect is most pronounced for patients with minor or severe symptoms; in the polluted area the admissions increase with increasing age; no sex difference is observed; the strongest increase of admissions during the smog episode was found for patients with preexisting respiratory problems.
- A bioclimatic classification of the study area has been performed. For both total mortality and hospital admissions of patients with respiratory or cardiovascular diseases, the increase in the smog

period is mainly restricted to areas with stressing bioclimate.

• The data show evidence for the hypothesis that the smog effect was less pronounced in areas with high mortality during the very cold period 10 days before smog. Furthermore, mortality increased in a dose-dependent way with decreasing temperature during these cold presmog days, and during the smog episode mortality increased in areas with sudden decreases in temperature.

In total, the additional analysis (*19*) shows that the pollution effects remain consistent if the intermediate area and local subunits are considered. On the other hand, the strong influence of meteorology on health during inversion—independent of air pollution—has to be emphasized.

We are obliged to the following institutions for allowing us to use their data or to extract data from their records: the cooperating hospitals for internal medicine and pediatrics in North Rhine-Westfalia (hospital admissions, outpatients, deliveries by ambulance); the control centers for ambulance transports in Duisburg, Oberhausen, Essen, Dortmund, Düsseldorf, Köln (deliveries by ambulance); the Public Health Administrations in the cities and counties of North Rhine-Westfalia (mortality); the Kassenärztliche Vereinigungen Nordrhein and Westfalen-Lippe (consultations in doctors' offices); the Landesanstalt für Immissionsschutz, Essen (pollution data); The Deutscher Wetterdienst, Essen (meteorologic data). Furthermore, the coding and processing of the data by many co-workers in the Medical Institute for Environmental Hygiene and the Academy of Public Health, Düsseldorf have to be acknowledged. This study was supported by the Ministry of Labour, Health and Social Affairs of the State of North Rhine-Westfalia, FRG.

REFERENCES

1. Wichmann, H. E., Mueller, W., Allhoff, P., Beckmann, M., Bocter, N., Csicsaky, M. J., Jung, M., Molik, B., and Schoeneberg, G. Investigation of Health Effects during the Smog-situation in January 1985 in North-rhine Westfalia, in German. Report to the Ministry of Labour, Health and Social Affairs of the State of North Rhine-Westfalia, FRG. Düsseldorf, 1985.
2. Kuelske, S., Giebel, J., Pfeffer, H. U., and Beier, R. Analysis of the Smog Episode from January 16 to 21, 1985, in the Rhine-Ruhr-District (in German). LIS-Berichte, Landesanstalt für Immissionsschutz Essen 55: 1–74 (1985).
3. Perkuhn, J., Puls, K. E., and Otte, U. Meteorologic Situation during the Smog Episode in the Ruhr District in January 1985 (in German). Report of the Wetteramt Essen, 1985, pp. 1–35.
4. Schmitt, O. A. Smog episodes in the Ruhr District since 1980 (in German). In: Smog Episodes (G. Von Nieding and K. Jander, Eds.), G. Fischer Verlag, Stuttgart, 1986, pp. 119–128.
5. Steiger, H., and Brockhaus, A. Investigations on mortality in North-rhine Westfalia during the inversion-weather situation in December 1962. Staub-Rein. Luft 31: 190–192 (1971).
6. Giebel, J., and Bach, R. W. Analysis of the causes of the high emission during the smog episode on Jan. 1, 1979 (in German). Schriftenr. Landesanstalt Immissionsschutz Essen 47: 60–73 (1979).
7. Steiger, H. Investigation on mortality during the smog period in the Western Ruhr District on January, 17th, 1979 (in German). Zentralbl. Bakteriol. Hyg. I. Abt. Orig. B 171: 445–447 (1980).
8. Kuelske, S. Analysis of the period of very high local emission in the Ruhr District from January 15 to 20, 1982 (in German). LIS-Berichte, Landesanstalt für Immissionsschutz Essen 24: (1982).
9. Martin, A. E., and Bradley, D. M. Mortality, fog and atmospheric pollution—an investigation during the winter of 1958–59. Mon. Bull. Minist. Health. Public Health Lab. Serv. 19: 56–75 (1960).
10. Martin, E. Mortality and morbidity statistics and air pollution. Proc. R. Soc. Med. 57: 969–975 (1964).
11. Brezowsky, H. Seasonal differences in the influence of the weather and different causes of death (in German). Med. Welt 14: 722–731 (1961).
12. Heasman, M. A., and Lipworth, L. Accuracy of Certification of Cause of Death. Her Majesty's Stationery Office, London 1968.
13. Lawther, P. J. Climate, air pollution and chronic bronchitis. Proc. R. Soc. Med. 51: 6–18 (1958).
14. Lawther, P. J., Waller, R. E., and Henderson, M. Air pollution and exacerbations of bronchitis. Thorax 25: 525–539 (1970).
15. Dassen, W., Brunekreef, B., Hoek, G., Hofschreuder, P., Staatsen, B., de Groot, H., Schouten, E., and Biersteker, K. Decline in children's pulmonary function during an air pollution episode. J. Air Pollut. Control Assoc. 36: 1223–1227 (1986).
16. Behrendt, H., Seemayer, N. H., Rosenbauer, K., and Brockhaus, A. Animal experiments during the smog episode. Preliminary morphological and functional results in rat lungs (in German). Conference on Health Effects of the Smog Episode in January 1985, December 5, 1985, Düsseldorf.
17. Pfeffer, H. U. The telemetric realtime multiple component recording system TEMES for emission control in Northrhine-Westfalia (in German). Staub-Rein. Luft 42: 233–236 (1982).
18. Buck, M. Sources, emissions and trends of ambient air pollution in the Ruhr District (in German). In: Smog Episodes (G. von Nieding and K. Jander, Eds.), Schriftenreihe des Vereins fuer Wasser-Boden-und Lufthygiene Berlin, Gustav Fischer Verlag, Stuttgart, 1986, pp. 25–54.
19. Wichmann, H. E., Spix, C., and Muecke, G. Analysis of Local Effects During the Smog-Situation in January 1985 Considering Meteorologic Influences (in German). Report to the Ministry of Labour, Health and Social Affairs of the State of North Rhine-Westfalia, FRG. Düsseldorf, 1987.