Sonderdruck aus: GEORGII, H.-W. & J. PANKRATH (eds.):
Deposition of Atmospheric Pollutants.
Dordrecht, Holland, 1982, S.97-113.

INVESTIGATIONS ABOUT WET DEPOSITION OF POLLUTANTS IN AN URBAN ECOSYSTEM

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1. Problems

In view of an extensive investigation programm on geo-ecological problems studies of acid precipitation were begun in the Ruhr District and its periphery at the following collection stations: Geldern (Lower Rhine, in the periphery of the Ruhr District (RD), Lünen (in the eastern part of the RD, Bochum (in the central area of the RD, Wuppertal (in the Bergisches Land), Lüdenscheid (in the Bergisches Land), Obergurgl (Tirol, Austria)
While the measurements at the stations of Geldern, Lünen, Wuppertal, Lüdenscheid and Obergurgl have been in process since early or mid 1980, and are intended to end in 1982, the measurements at Bochum station (Botanical Garden of Ruhr University) have still in process since May 1978. At this station the investigations are intended to run after 1982.
Precipitation is collected 1.6m above ground in bulk samplers, made of polyethylene, exposed for a week.Every Monday the samples are analysed among others on the pollutant compounds of sulphate, calcium, chloride as well as nitrate and lead. Additionally the pH-value is determined and since April, 1981, even electric conductivity.
Since October, 1981, we analyse parallel to these investigations event-only rain samples in order to find out the enrichment factor of concentrations in bulk samples to concentrations in pure samples (see MOLDAN, 1980, as well as GEORGII and others, 1980). Samples which cannot be analysed on the same day are kept in a refrigerator at + 4°C.
The methods of analysis are conventional and are carried out with the help of photometry and titration.

On the one hand it is the aim of the research programm to determine the amount of different pollutants, and on the other hand to examine the effects of acidity on soil (buffering capacity).

Concerning this , extensive soil-dependent investigations will be carried out in early summer 1982 in the Ruhr District as well as in the remaining NRW in order to map soil sensitivity,similar to the investigations by ROOT and other (1980) in the frame of a survey for North America and by GLASS and others (1980) for the eastern coast of the United States as well as HUTTUNEN (1979) for Sweden. Extensive measurements concerning estimations of forest-ecosystems have been carried out in the Federal Republic of Germany, i.e. by ULRICH and others (1976) or GÜNTHER and others (1976).
In this report I'll present the first results from Bochum station for some selected pollutants, and that for calcium, chloride and sulphate as well as the pH-value during the period from May, 1978 to April, 1980.

2. Results

The frequency distribution of calcium concentrations at Bochum station shows(Fig.1) values ranging between 0.5 mg Ca/l and 6.5 mg Ca/l. The mean value is 3.2 mg Ca/l. Referring to this the average of winter months is lower by 18 p.c. while the summer values are higher by 11 p.c. . For Calcium is a significant component of dust and is used especially in the building and construction trade it becomes that the higher summer values can be interpreted as a result from the intense building activities during the summer months.
Turning to the chlorid concentrations (Fig.2) we could not find a visible seasonal difference during the period of our investigations. We found an average value of $\bar{x}$ = 4.4 mgCl/l. The frequency distribution of the measured values ranged between 1 and 15 mg Cl/l with a median value of 4.0 mg Cl/l.

The frequency distribution of the pH-values for the annual mean shows (Fig.3) values between 3.2 and 7.0 at Bochum station resulting in an average mean of 4.3. The seasonal variations which show a relatively low value in the winter period of pH = 4.0 with a summer value of pH = 4.5 can be compared to the investigations of KAYSER and others (1974) at "Schauinsland Station" in the Black Forest. This can be explained together with KAYSER (1974) and KLOKOW (1978) in the influence of the heating period.
Adequate to the importance of sulphur in our atmosphere I'll deal with this pollutant more in detail.
The sulphate concentrations (Fig.4) reached an average of $\bar{x}$ = 18.6 mg SO_4/l with a standard deviation of s = 6.3. The lowest concentrations in rainwater had been measured in July, 1979, with values between o.9 and 1.1 mg SO_4/l when the situation of a cyclonal western weather condition with maritime tropic air masses caused heavy rains and resulted in a low absorption of pollutants in the raindrops.

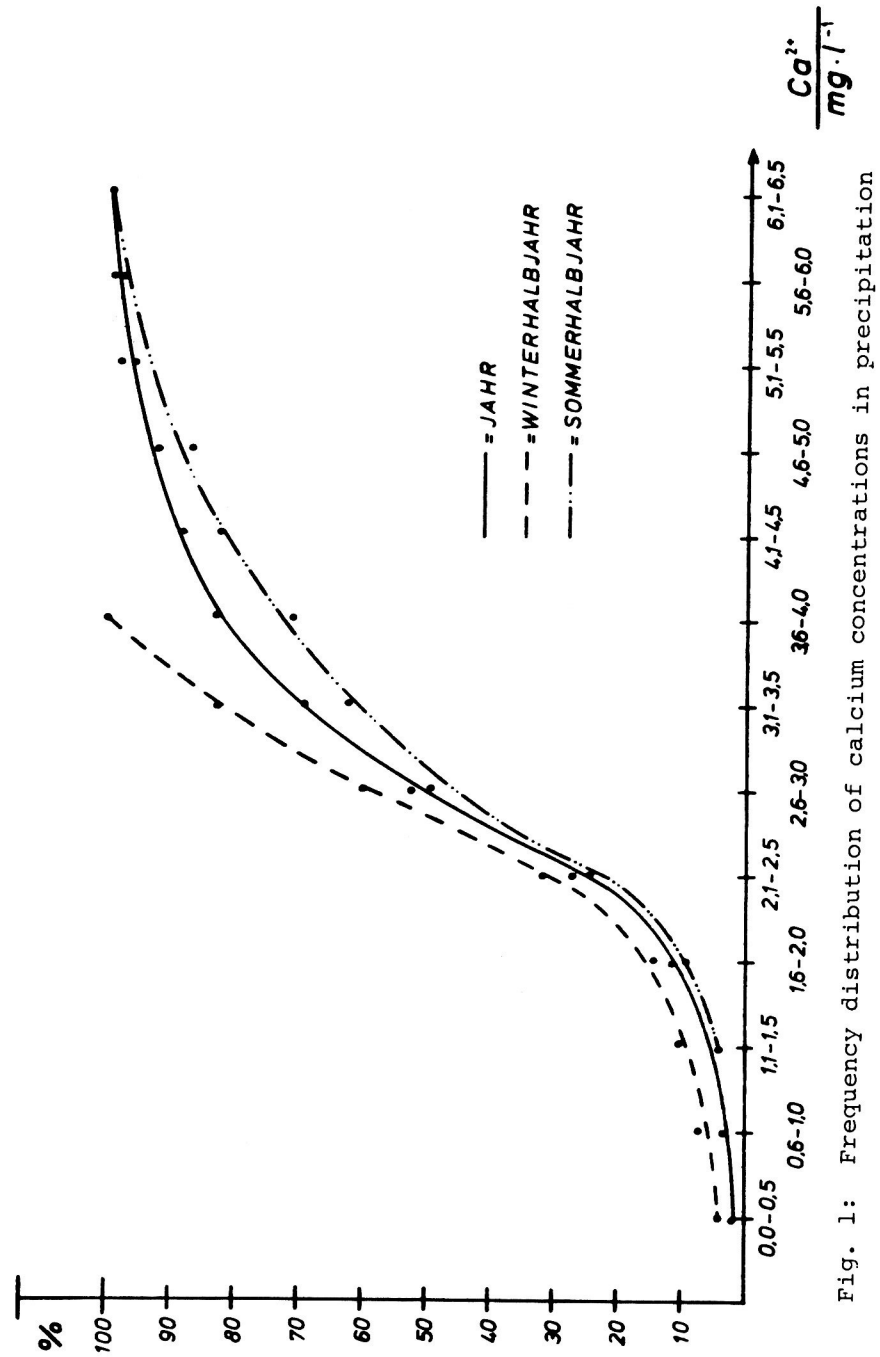


Fig. 1: Frequency distribution of calcium concentrations in precipitation

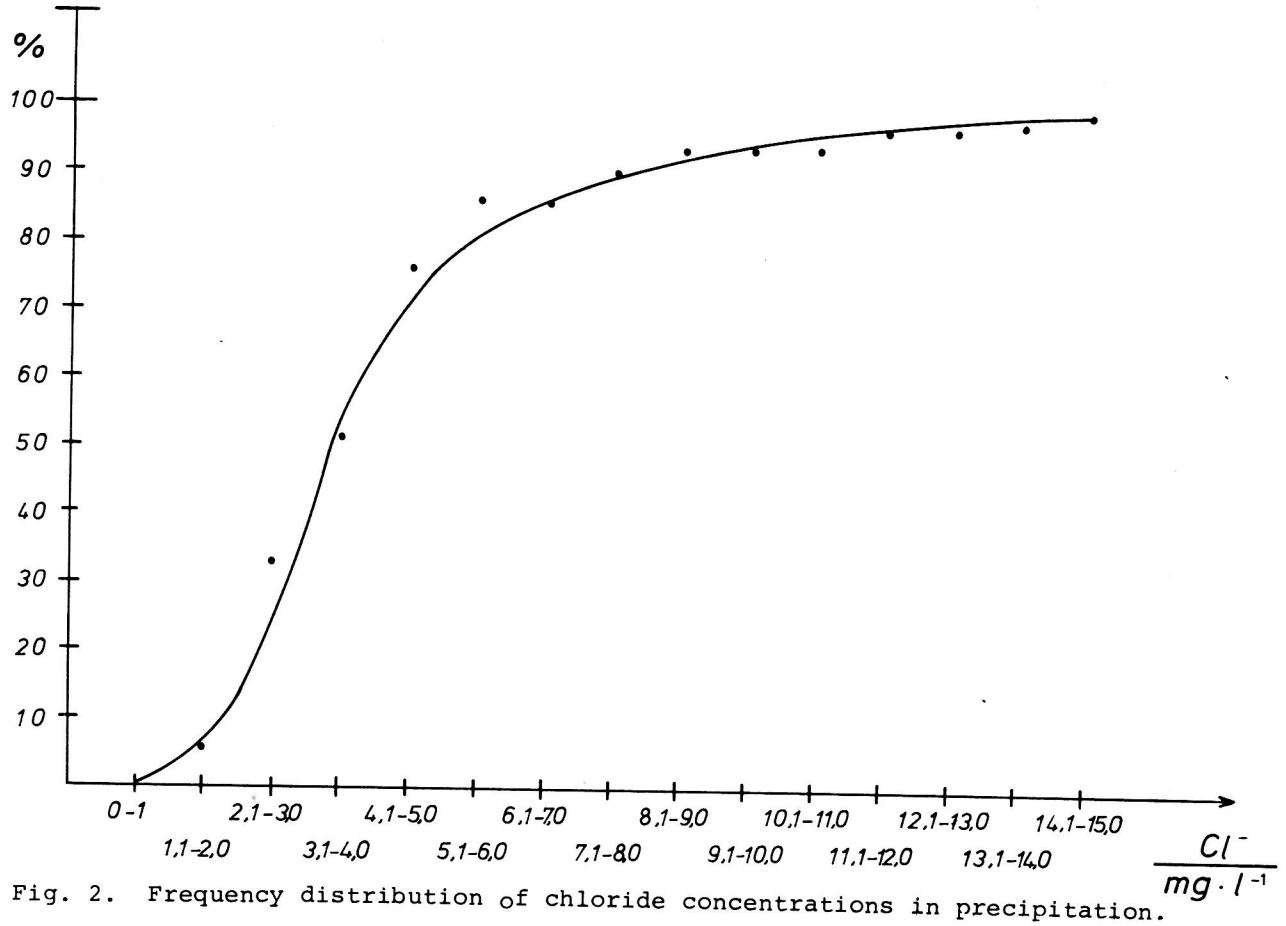


Fig. 2. Frequency distribution of chloride concentrations in precipitation.

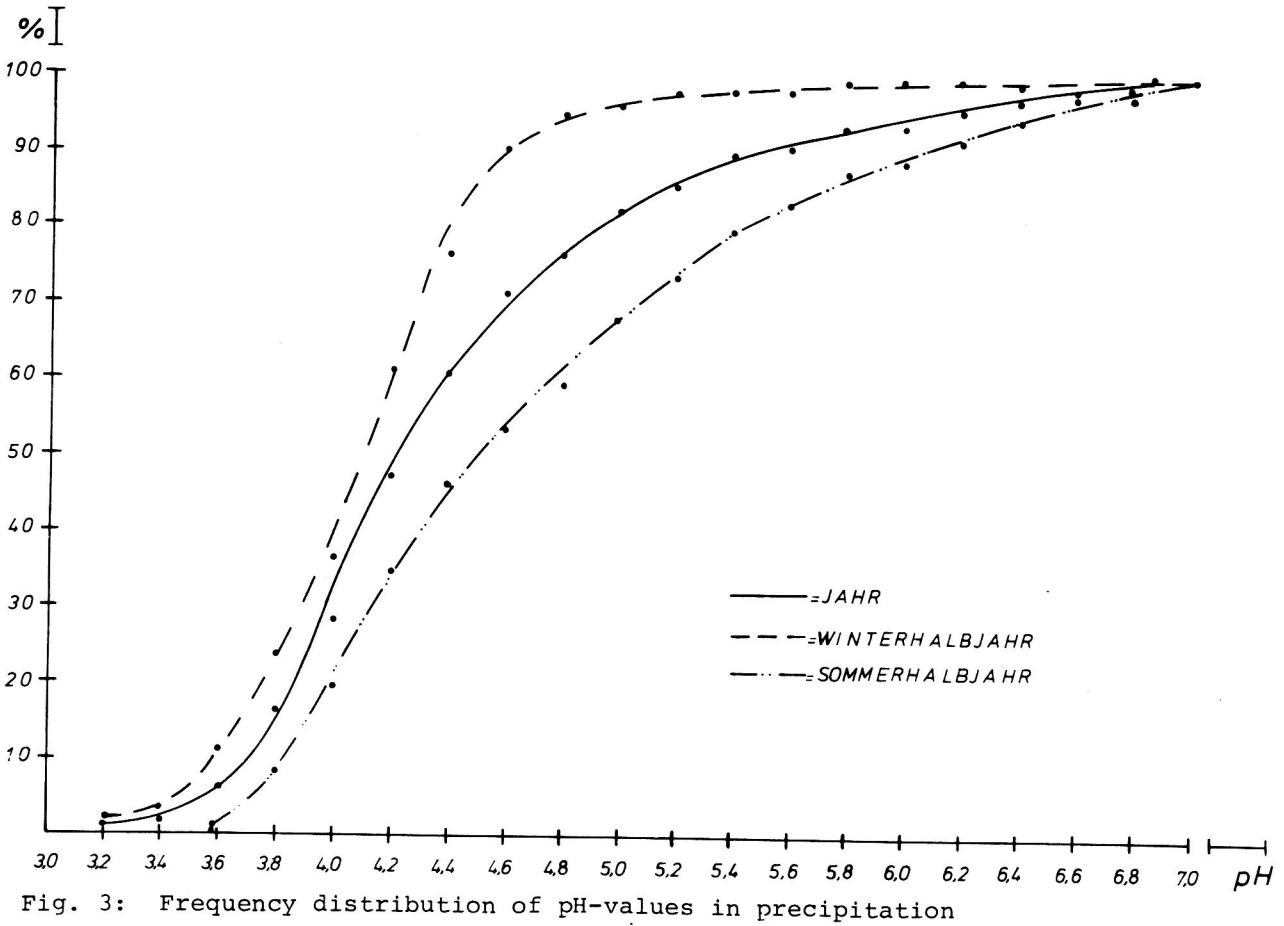


Fig. 3: Frequency distribution of pH-values in precipitation

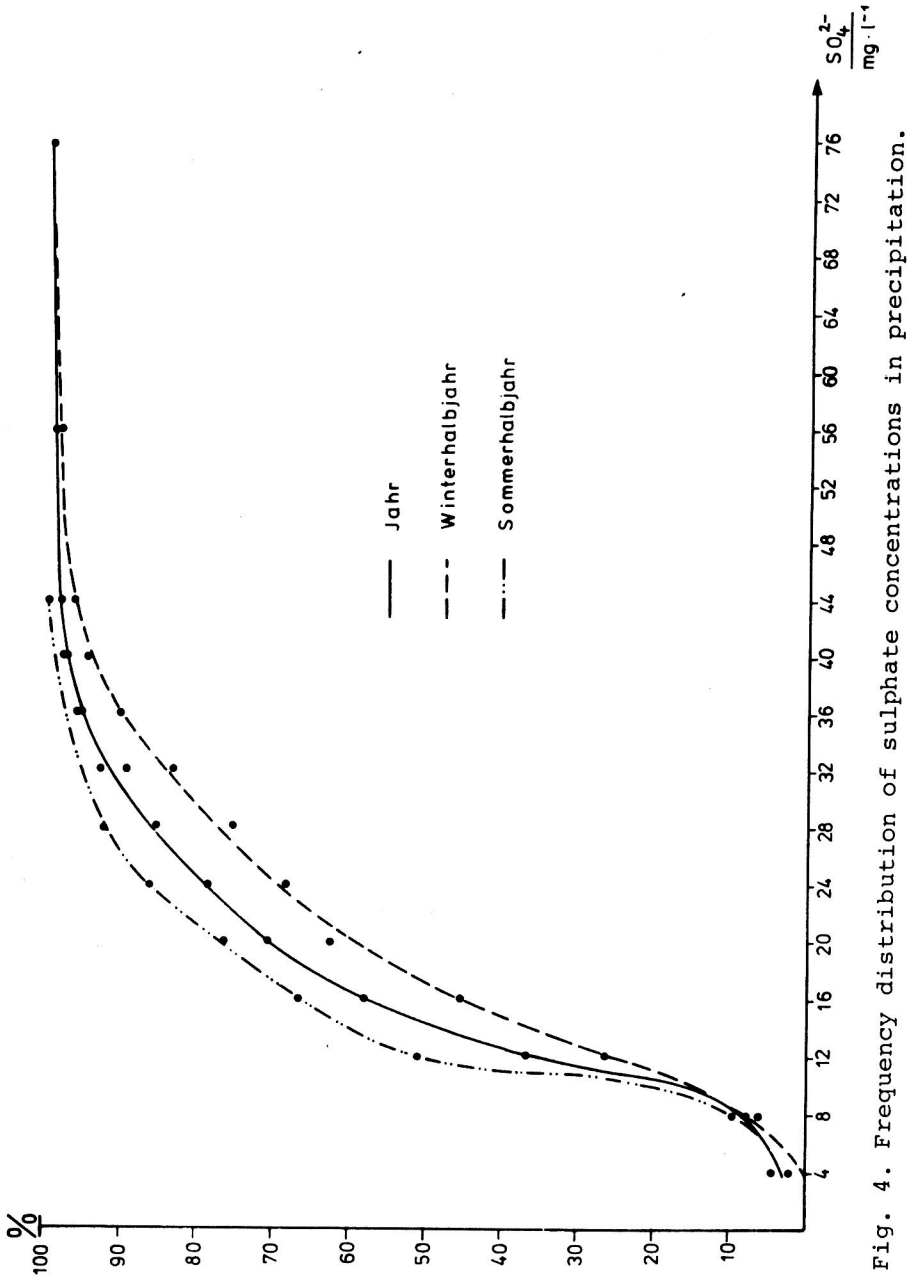


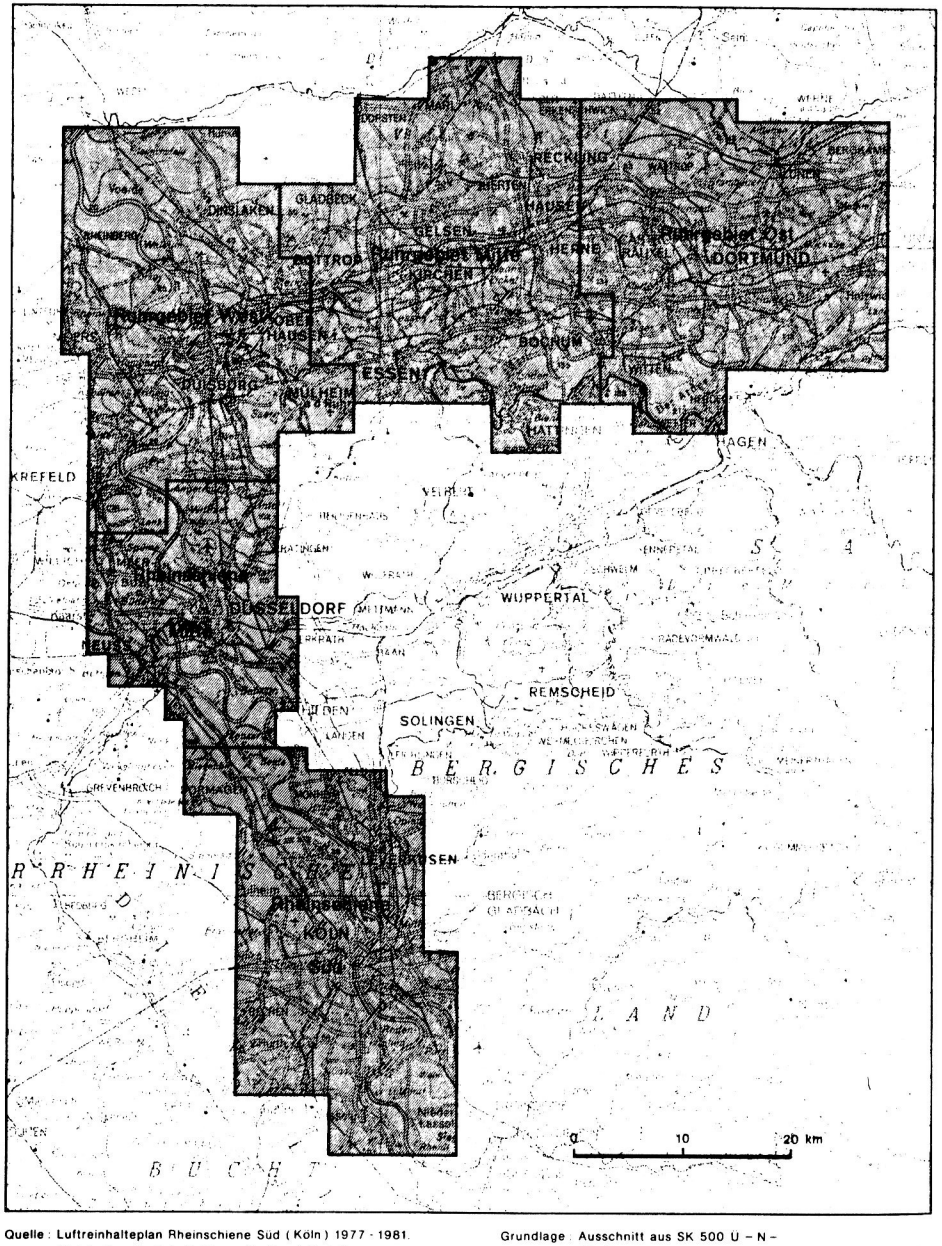
Fig. 4. Frequency distribution of sulphate concentrations in precipitation.

On the other hand the highest sulphate concentrations had been registered in January, 1979, with 75.1 mg SO_4/l in the first rain after anticyclonal weather conditions. During this stable weather condition the concentrations of the pollutant SO_2 had been high enough to develop a SO_2-Smog (KUTTLER 1979 a) which made it necessary for the first time in the history of air control in NRW to call out a smog-alarm in the Western Ruhr District.
The average values of sulphate concentrations calculated from the weekly values show-parallel to the seasonal differences of pH-values - high winter concentrations and lower summer values. The frequency distribution of sulphate concentrations (Fig.4) shows that the median value for the annual mean is x_{50} = 15 mg SO_4/l, the 10 p.c. value x_{10} = 9 mg SO_4/l and the 90 p.c. value x_{90} = 26 mg SO_4/l.

The average amount of pollutants, which reaches the soil per month and hectare, could calculated for calcium (1.75 kg) and for chloride (2.1kg).

Considering the pollutant sulphur I'll deal a bit more in detail with the load per unit area by wet and dry deposition for the investigated area Central Ruhr District (Fig.5). The geographical limits of the polluted area with space of 761 km^2 is given by the "Luftreinhalteplan Ruhrgebiet Mitte".
The total SO_2-pollution in the examinated area makes up about 312,000 tons per year, of which industry has a share of 94 p.c., domestic heating and small trade of about 5.6 p.c. and traffic of 0.4 p.c. . From the partly estimated concentrations of pollution it was possible to determine an average load of SO_2-pollution for all unit areas of one square kilometer of about 0.10 mg SO_2/m^3 in the investigated area for the year 1979.
This average per unit area for the Central Ruhr District of about 0.10 mg SO_2/m^3 can easily be compared with the annual mean value of 1979, which amounted to 0.11 mg SO_2/m^3 at Bochum station. The dry deposition values have been calculated from this measured mean air concentrations of sulphur dioxide.

For "it is difficult or impossible to measure the dry deposition directly, because of the influence of the specific surface qualities of a collecting funnel or measureing container in the measured values ... measurements of such an apparatus do not show values for the dry deposition of a real land surface " (translated from MAYER, 1978, p. 263).



Quelle: Luftreinhalteplan Rheinschiene Süd (Köln) 1977 - 1981. Ministerium für Arbeit, Gesundheit und Soziales des Landes NRW (Hrsg.) 1976

Grundlage: Ausschnitt aus SK 500 U - N - Mit Genehmigung des Landesvermessungsamtes NRW vom 12. 10. 1979, Kontrollnummer D 6351 vervielfältigt durch die Ruhr - Universität Bochum

Fig. 5. Polluted regions in Northrhine-Westfalia (KUTTLER 1979b)

The deposition velocity of SO_2 - which have been calculated for different surfaces - ranged considerably because of meteorological-, substratum- and plant-specific parameters (compare the list of PERSEKE and others 1980), so that it is difficult to come up with the demanded exactness for a heterogenous structure like the landscape of the investigation area.

Beside artificial and anorganic land surfaces especially vegetation has an immense influence on the deposition velocity, this show for example the calculated values by FOWLER (1980; see Fig. 6).
For closed stomata in vegetation he found a V_g for SO_2 of between o.2 and o.3 cm/s, independent of the height of the plants. For open stomata, so for proceeding photosynthesis, he could determine a doubling of deposition velocity from o.5 to 1.0 cm/s together with an increase of the height of the plants by factor 100. For wet leaf-surfaces he could even determine a boost of deposition velocity by the factor 19 with an increase of the height of the plants by the factor 100.

For it is impossible to determine a corresponding deposition velocity for every surface and meteorological situation, we took the generally used value V_g = o.8 cm/s for further calculations (see PERSEKE and others 1980). In these estimations it is impossible to consider the seasonal influence of the vegetation period. The result is shown in Fig. 7.

The wet deposition of sulphur has been calculated from the determined sulphate concentrations in the rainwater for Bochum station in consideration of the precipitation amount. The result is shown in Fig. 8.

The average monthly wet sulphur deposition amounts to making up o.29 g S/m^2 with an annual sum of about 3.4 gS/m^2. In order to be able to express the wet deposition of pollutants per area in the examinated area it was necessary to know the distribution of the precipitation in this region. Concerning this matter we made use of the values of 19 stations for precipitation measurement in the area of 761 square kilometers. The regional distribution of precipitation is shown in Fig. 9.
In this map we see a decrease of precipitation from southwest to northwest of about 1000 mm to 750 mm while it remains nearly unchanged in the direction southeast to northeast with low values in the Ruhr Valley between 750 mm and 850 mm.

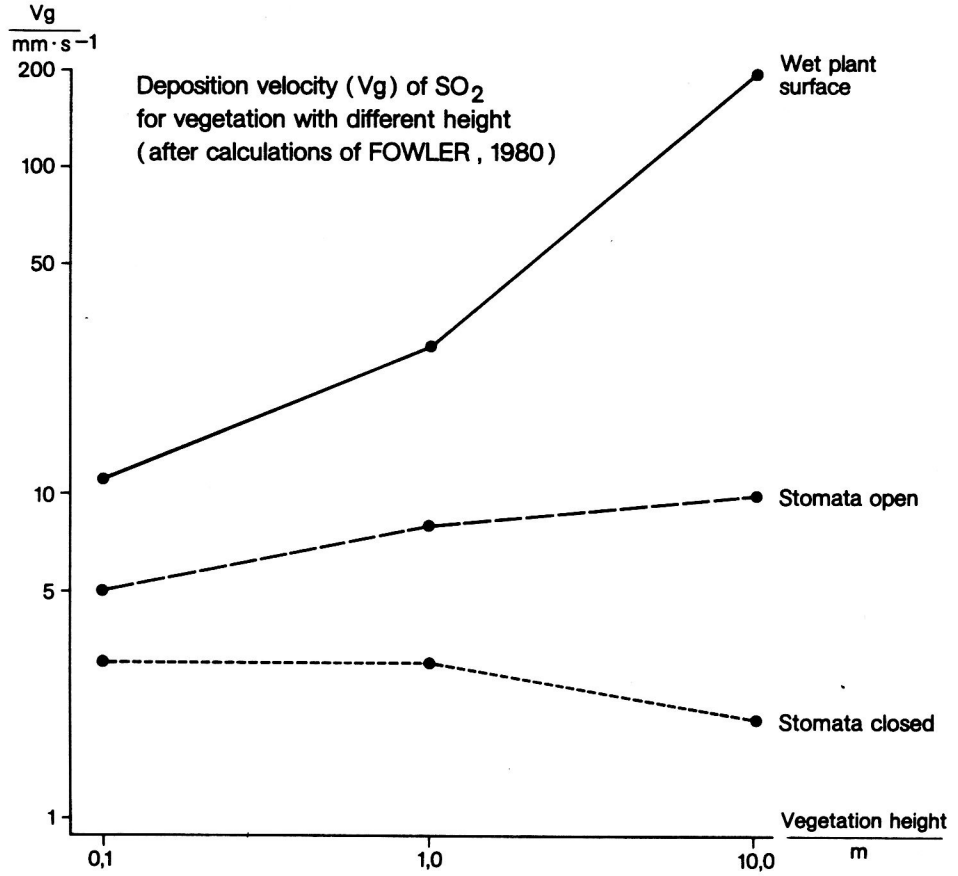


Fig. 6. Depostion velocity of SO_2 for vegetation with different height (after calculations of FOWLER 1980)

Fig. 7

Monthly mean values of sulphur dioxide concentrations and dry SO_2-S Deposition at Bochum station (KUTTLER 1981)

	Jan.	Feb.	März	Apr.	Mai	Juni	Juli	Aug.	Sept.	Okt.	Nov.	Dez.	Jahres-mittel bzw. Jahres-summe
SO_2 [mg·m^{-3}]	0,26	0,27	0,08	0,07	0,07	0,08	0,06	0,08	0,11	0,11	0,11	0,10	0,11
SO_2-S [mg·m^{-2}]	2785	2612	856	726	750	726	856	642	829	1178	1140	1071	14.171

Fig. 8

SO_4^{2-}-S concentrations in precipitation, monthly precipitation values (N) and monthly wet sulphur depositions (S_{wet}) at Bochum station (KUTTLER 1981)

	Jan.	Feb.	März	Apr.	Mai	Juni	Juli	Aug.	Sept.	Okt.	Nov.	Dez.	Jahres-summe bzw. Jahres-mittel
SO_4^{2-}-S [mg · l^{-1}]	14,0	8,3	5,3	4,0	4,0	5,7	2,7	2,7	4,0	7,3	4,7	3,3	5,5
N [mm]	26	37	131	47	72	47	63	85	34	16	72	102	732
S_{wet} [mg·m^{-2}]	364	307	694	188	288	268	170	229	136	117	338	337	3436

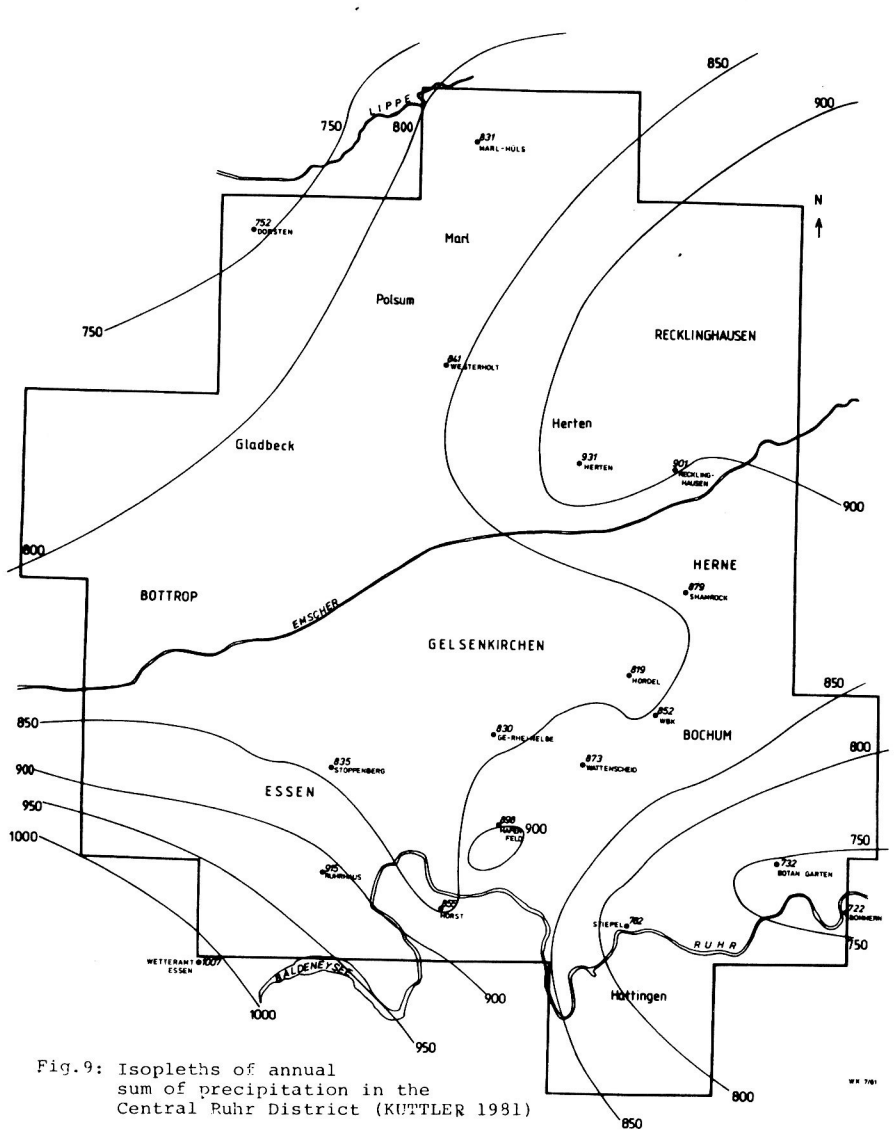


Fig.9: Isopleths of annual sum of precipitation in the Central Ruhr District (KUTTLER 1981)

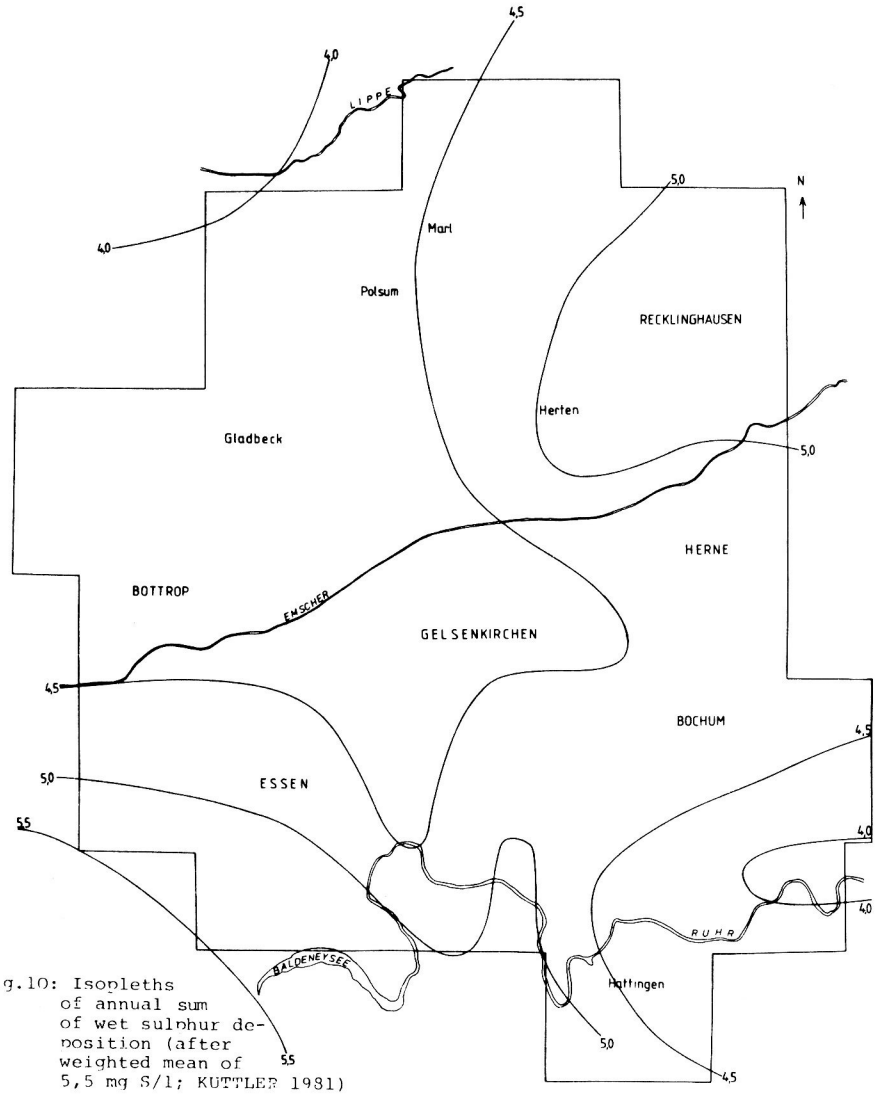


Fig.10: Isopleths of annual sum of wet sulphur deposition (after weighted mean of 5,5 mg S/l; KUTTLER 1981)

Fig. 11

Dry, wet and total sulphur deposition in 1979 at Bochum station (KUTTLER 1981)

	Jan.	Feb.	März	Apr.	Mai	Juni	Juli	Aug.	Sept.	Okt.	Nov.	Dez.	Jahres-summe
SO_2-S_{dry} [mg·m^{-2}]	2785	2612	856	726	750	726	856	642	829	1178	1140	1071	14.171
SO_4^{2-}-S_{wet} [mg·m^{-2}]	364	307	694	188	288	268	170	229	136	117	338	337	3.436
$\sum_{wet,\ dry}$ [mg·m^{-2}]	3149	2919	1550	914	1038	994	1026	871	965	1295	1478	1408	17.607
prozentualer Anteil dry	88	89	55	79	72	73	83	74	86	91	77	76	80
prozentualer Anteil wet	12	11	45	21	28	27	17	26	14	9	23	24	20

From the annual sums of precipitation of the stations and the knowledge of the sulphur concentrations in precipitation we prepared a further map of the annual sum of wet sulphur deposition. This map (Fig. 10) shows that the highest concentrations of pollutants have been deposited in the southwest with values of 5.5 g S/m^2 and year. The lowest depositions of pollutants are found in the northwest and southeast.

The following table (Fig. 11) serves a survey of the dry, wet and total sulphur deposition as well as the dry and wet deposition percentage of the total sulphur deposition in the Ruhr District.

Referring to the amount of SO_2 - S pollution of about 156,000 tons in the Central Ruhr District in 1979, about 9 p.c. of the sulphur is deposited within this region.

We plan to extend the investigations for the whole Ruhr District and its periphery when we'll have gained further results from the particular stations.

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Summary:

In this report the results of rainwater measurements of different pollutants (sulphur, calcium, chloride and the pH-value from the station Bochum, Central area of the Ruhr District, Northrhine-Westfalia) are discussed. For this area,moreover, calculations about wet and dry deposition are made for the pollutant sulphur. The results are presented in several figures and in a map.