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Peripheral Clean Air Areas near Industrial Regions during Smog Weather Conditions – Contribution to Planning of Industrial Nearby Clean Air Areas

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1. INTRODUCTION

On the subject of air hygiene, industrial agglomerations show the following similarities because of the intense regional complexity of a high density of population and polluting industries: the lower atmospheric layers of peplosphere (urban boundary layer [13]) are, on the one hand, the assimilator and carrier of pollutants and, on the other hand, provide vital, and thus, clean air. As long as certain concentrations are not exceeded, the different altitudes of emissions (traffic, domestic heating, trade and industry) lead to a certain concentration which makes up — by transport and deposition (wet + dry) — a characteristic basic pollution of a certain region.

Worrying or noxious situations for the population will only occur when the exchange mechanism of the lower atmospheric levels is extremely disturbed so that a significant increase of pollutants in the air can be expected. Accumulations of non-air particles caused by low-exchange weather conditions have often been registered as smog episodes in industrial agglomerations [22].

Low-exchange weather conditions, which can occur in summer as well as in winter, mostly show a comparably characteristic structure. A polluted cold air ground layer which tends to fog in winter is separated at an altitude of some hundreds of meters above the ground by a temperature inversion acting as a stable thermic barrier towards the dry and clean warm air layer with clear views above.

Such autochthone weather conditions develop under the influence of low-gradient, and thus, low-wind anticyclones which often reach a horizontal area of a whole continent. When we have such weather conditions in a region with a very differing relief, upper regions are frequently separated by an inversion and are situated in an area of clean warm air masses. We should attach special importance to those regions in view of a potential recreation area for the population. These regions will be of special importance if they are situated near an industrial agglomeration and can thus be reached within a short time during a low-exchange weather condition.

This aspect will be examined exemplarily for the Rhine–Ruhr region — the largest industrial region in Central Europe — and the highlands of the Sauerland situated in its eastern vicinity for cases of low-exchange inversion periods (Fig. 1 shows the field of work).

2. POLLUTANTS IN THE ATMOSPHERE OF AN INDUSTRIAL REGION

Gas and polluting particles are defined according to the *TA-Luft 1974* [29] as "alteration of the natural compound of air, especially by smoke, soot, dust, gases, aerosols, steam or odorous substances". The majority of emissions derive from processes of combustion which cause the formation of approximately 300 different chemical compounds. These are, for example, sulphur, nitrogen, carbon monoxide, halogens and halogen compounds, inorganic dusts, soot and oxidizers as well as hydrocarbon substances. Among the indicators for air pollution which occur frequently, we have to mention sulphur dioxide resulting from primary processes of combustion and ozone originating secondarily from photochemical transformation. I'll deal with them exemplarily because of their special importance and value as an indicator for air pollution.

Sulphur dioxide

The distribution and concentration of sulphur dioxide depends on local, temporal

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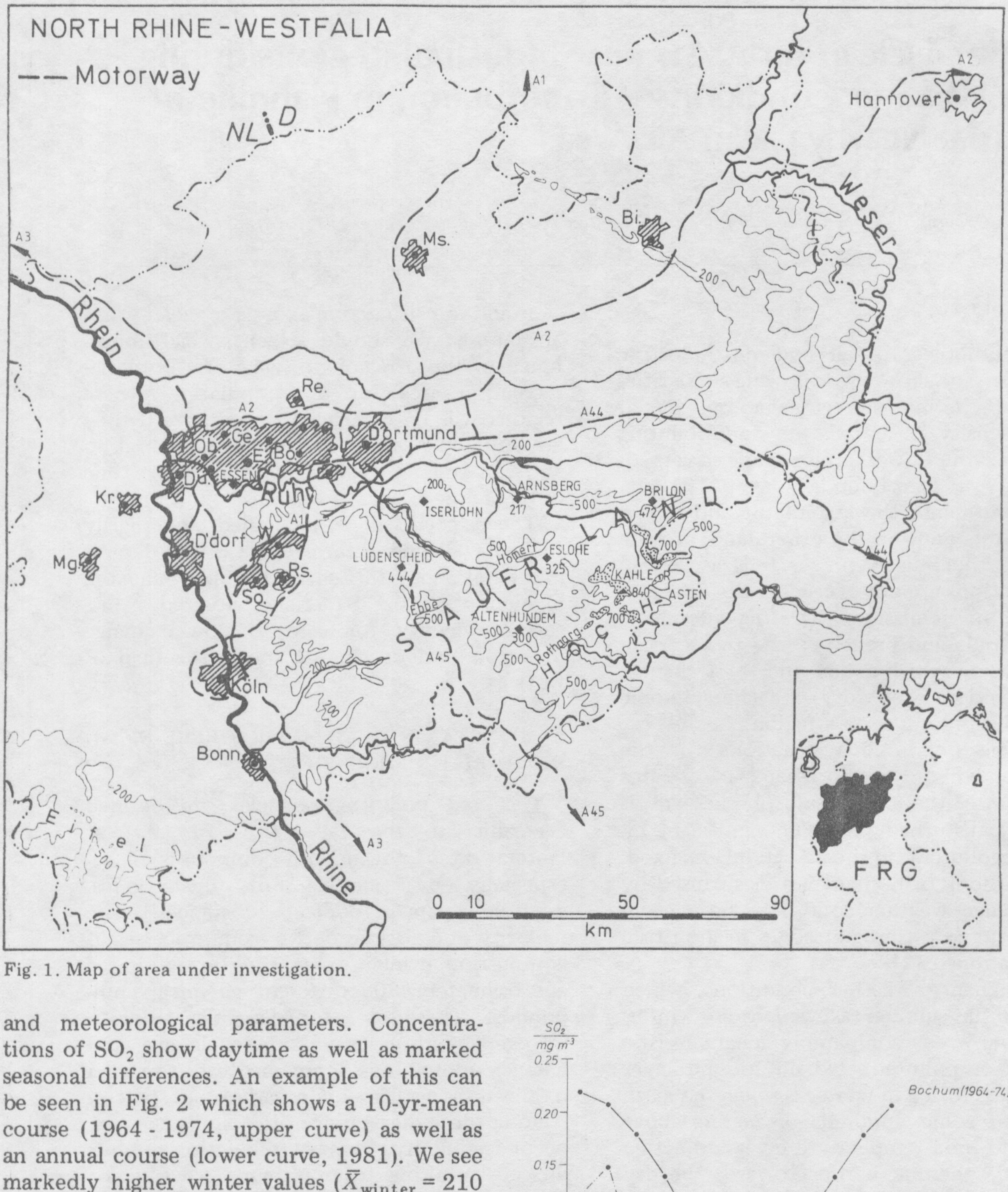

Fig. 1. Map of area under investigation.

and meteorological parameters. Concentrations of SO_2 show daytime as well as marked seasonal differences. An example of this can be seen in Fig. 2 which shows a 10-yr-mean course (1964 - 1974, upper curve) as well as an annual course (lower curve, 1981). We see markedly higher winter values ($\bar{X}_{winter} = 210$ $\mu g\ m^{-3}$) and lower values for the summer months ($\bar{X}_{summer} = 110\ \mu g\ m^{-3}$). Compared to the upper curve the lower curve reveals that SO_2 pollution has decreased in the period from 1964 to 1981) ($\bar{X}_{w\,81} = 86\ \mu g\ m^{-3}$) ($\bar{X}_{s\,81} = 45\ \mu g\ m^{-3}$). Furthermore, both curves show asymmetrical courses which are caused by the annual time lag of air temperature to the seasonal position of the sun, for the SO_2

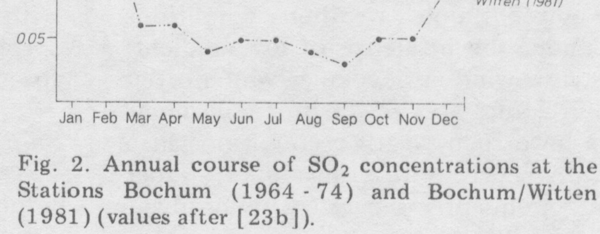

Fig. 2. Annual course of SO_2 concentrations at the Stations Bochum (1964 - 74) and Bochum/Witten (1981) (values after [23b]).

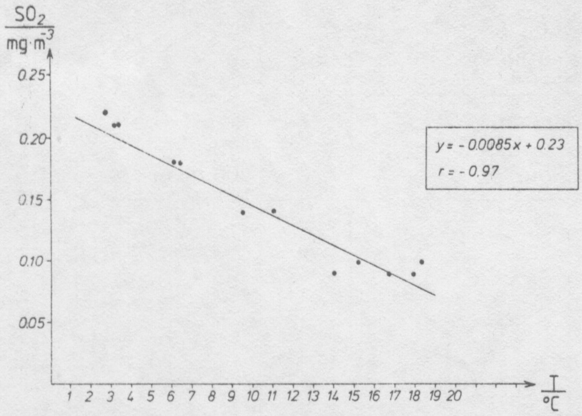

Fig. 3. Correlation between monthly values of SO_2 concentrations and monthly mean values of temperature at Bochum Station (after [23a]).

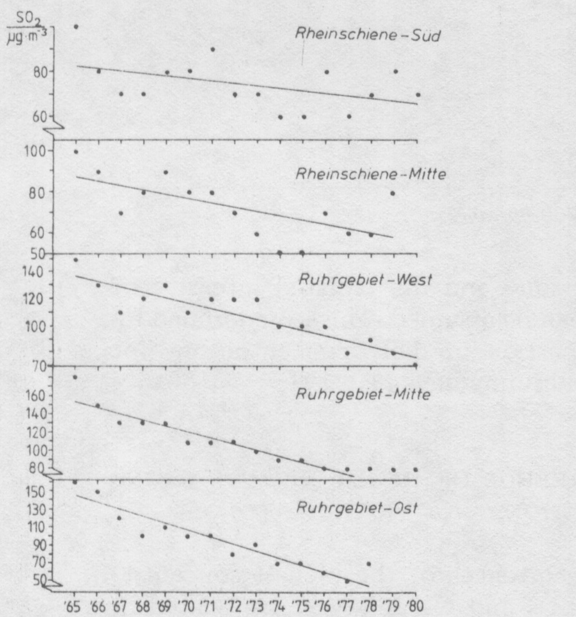

Fig. 4. Trends of SO_2 concentrations in the five polluted areas of the Rhine–Ruhr region (values after [26]).

concentration depends mainly on domestic heating and thus on the outside temperature.

This is underlined by Fig. 3 showing the correlation between air temperature and the SO_2 concentration which is inversely proportional to the temperature. The amount of decreasing pollution during the last two decades is shown in Fig. 4.

However, the decrease of pollution cannot be explained by a decrease of SO_2 emissions, as is shown in Table 1: as the SO_2 emissions in the Federal Republic of Germany have not been reduced, other parameters have to be seen as complex factors for the decrease, such as the construction of higher smoke-stacks and thus changed meteorological conditions [21, 27].

TABLE 1

SO_2 emissions in the F.R.G. between 1966 and 1978 in 10^6 tonnes sulfur (after [15])

1966	1970	1974	1978
3.58	3.97	3.78	3.58

Ozone

The high absorbing power of nitrogen dioxide leads to photolysis of molecules ($NO_2 \rightarrow NO + O$) during intensive radiation in the photochemical range of the sun spectrum (λ = 290 - 420 nm). Beside nitrogen monoxide, oxygen is released and reacts within a short time with the air's oxygen so that the chemically aggressive ozone is formed. This is only a simplified explanation of the process, which in reality needs a different mechanism to react [6, 11, 12, 14, 25]. Ozone, a precursor gas, is formed primarily from nitrogen oxides which have — unlike the pollutant SO_2 — increased in the last decades. They rapidly increased in the period from 1966 to 1978 as is shown in Table 2.

TABLE 2

NO_X emissions in the F.R.G. between 1966 and 1978 in 10^6 tonnes nitrogen (after [15])

1966	1970	1974	1978
1.98	2.39	2.62	3.09

On account of the high radiation needed, the formation of ozone has long been limited to regions with a high intensity of radiation in summer, i.e., cities in the latitudes of the 'subtropical anticyclones' such as Los Angeles where this kind of secondary pollution had first been observed.

In the summer months of 1965, the supposition was confirmed in the regions of the Randstad in the Netherlands that photochemically formed oxidizers damaged vegetation in the surroundings of agglomerations in Central Europe [18]. Today we suppose that ozone and its concomitant phenomena also cause damage in the vegetation of woodlands far away from industrial regions [3, 26].

TABLE 3

Measured ozone concentrations in various cities (according to different authors)

	Period of measurement	Maximum concentration per hour	No. of days with 200 $\mu g\ m^{-3}$*
Federal Republic of Germany			
Frankfurt a.M.	1973 - 1974	340	8
Karlsruhe	1974	460	—
Köln	1975	300	—
Bonn (city)	1976	368	—
Netherlands			
Delft	1969 - 1972	500	12
Eindhoven	1973 - 1974	440	16
Amsterdam	—	400	—
Great Britain			
London	1973 - 1974	360	10
Harwell	1973 - 1974	280	7
Norway			
Oslo	1976	240	—
USA			
Los Angeles	1976	720 - 1160	—

*Irritation of the eyes is frequently observed above concentrations of 200 $\mu g\ m^{-3}$.

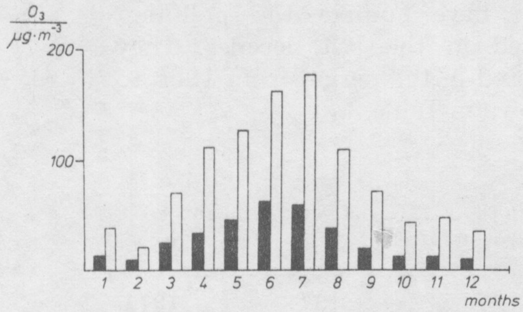

Fig. 5. Monthly mean values and 95% frequency distribution of O_3 concentration at the station Köln-Godorf in 1976 (after [9]).

These are the reasons why this new kind of air pollution has become the subject of intensive research.

It was shown that (see examples in Table 3) these formations of higher ozone concentrations didn't only occur in the industrial regions of the Netherlands during summer days with intense radiation but also in other European agglomerations [8, 16]. Measurements at a station between Cologne and Bonn showed a marked seasonal course of O_3 concentration with high summer values (see Fig. 5).

The comparatively high values of July reveal that a direct dependence of the formation of ozone and the radiated intensity of sunlight can be assumed. This is underlined by the comparison of daily concentrations for cloudy and sunny days [10, 12].

3. OCCURRENCE OF HIGH CONCENTRATIONS OF POLLUTION

The occurrences of the highest concentrations of SO_2 and O_3 pollution are related to low-exchange weather conditions which lead, according to the season, to the formation of O_3 smog in summer or SO_2 smog in the winter months. In addition to low winds, temperature inversions cause a considerable reduction of the mixing layer, the space between the sub-level of the inversion and the ground. Table 4 shows a comparison of the characteristic elements of the photochemically formed summer smog and the primarily formed winter smog.

Although the ozone values showed varying concentrations in the Rhine–Ruhr region in the previous years and have become the subject of public interest for several reasons, injuries to health or even deaths (as are connected with the sulphuric SO_2 smog) have not been observed in the region. How-

TABLE 4

Comparison of the characteristic features and effects of the ozone smog and sulphur dioxide smog (after [23])

Features/effects	Ozone smog	Sulphur dioxide smog
Air temperature	25 - 35 °C	−3 °C to 5 °C
Relative humidity	Below 70%	Below 80%
Wind speed	Below 2 m/sec	Below 2 m/sec
Visibility	800 - 1600 m	0 - 30 m
Necessary radiation conditions	Increase of UV-radiation ($\lambda \leqslant 350$ nm)	No necessary influence
Type of inversion	Subsidence inversion	Ground or subsidence inversion
Occurrence	Summer-early fall (July - October)	Winter (November - January)
Pollutants (as indicators)	Ozone (nitric oxides, hydrocarbons)	Sulphur dioxide and transformed products, soot
Produced mainly by	Oil and benzine	Coal and oil products
Burning formation	Within a short period of time in the air by photo-induced reactions	Combustion chambers of polluters
Nature of pollution	Predominantly gaseous	Bound to particles and gaseous
Time of maximum concentration	Summer midday sun position (summer smog)	In the morning and in the evening in winter (winter smog)
Chemical reactions	Oxidizing	Reducing
Effects on man, plants and materials	Irritation of conjunctiva, ozone-spots; leaf-pigment damages, damage to plants; decomposition of rubber	Irritation of respiratory ducts and organs; damage to conifers; decomposition of sandstone

ever I will now deal in more detail with the winter SO_2 smog which has several influences on human health.

Winter smog episodes, which lead to high SO_2 concentrations in industrial regions of Central Europe, were registered in February 1959 [28], in December 1962 [22], in January 1979 [17], and in January 1982 [20]. In January 1979, it was the first time that a smog alarm had been exceeded (as shown in Fig. 6). The reason for this was the

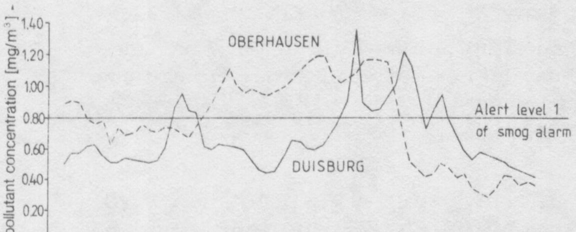

Fig. 6. Daily course of SO_2 concentration in Oberhausen and Duisburg during the time span January 16, 1979, 12 a.m. to January 17, 1979, 6 p.m. (after [20]).

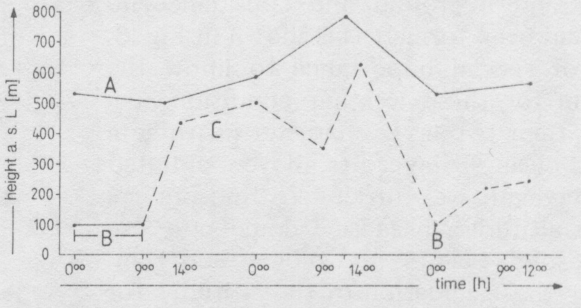

Fig. 7. Daily course of upper and lower levels of inversions between January 15, 1979, 0 a.m. and January 17, 1979, 12 a.m. (A = upper level of inversion, B = ground inversion, C = sub-level of inversion) (after [20]).

dominance of a low-exchange weather condition with low winds for several days in which ground as well as high altitude inversions considerably limited the mixing layer (Fig. 7).

The smog of December 1962, however, has been the most marked of all with SO_2 concentrations five times as high as in January 1979. The extremely low air exchange in December, 1962 was caused — as for nearly all episodes with high SO_2 concentrations — by an anticyclone with a central pressure of

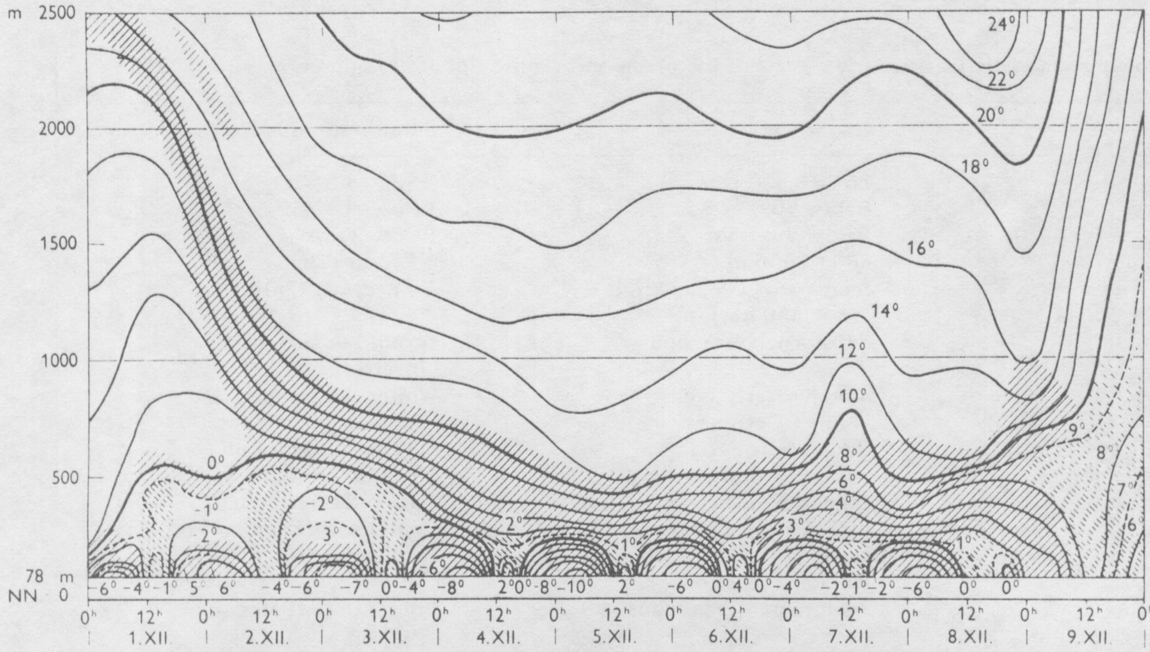

Fig. 8. Air temperatures over Cologne during the time span December 1 - December 9, 1962 (lines are potential temperature) (after Keil in [22]).

inversion layer,

strong lapse rate. Ground level 78 m.

1030 mbar. The wind force was below 1 Beaufort and a ground and subsidence inversion had been formed as is shown in Fig. 8.

It is of special importance to know the borderline for these weather conditions because of their two-layer character in which a separated clean air layer lies above a polluted cold air layer. It was difficult to find out the inversion altitudes, because I could only use the radiosonde values of Cologne and Hannover for the calculation of the altitudes for the examination area Ruhrgebiet/Sauerland. That is why I additionally referred to the graphic method of Schulz [28] for the limitation of inversion altitudes for a similar weather condition. The long-term mean values (1951 - 1970, respectively 1931 - 1960, broken line) and values during the smog period have been evaluated with this method for stations with different altitudes within the Sauerland and arranged in a diagram according to the altitudes. The course of both temperature curves (Fig. 9) shows that the lower stations had considerably lower temperatures during the smog period as could be expected by the long-term values. The point of intersection can be seen as the altitudes of the inversion. The results are two temperature–altitude distributions which intersect altitudes of 450 m and 700 m. Above the intersections we have a maximum positive deviation of 1 K. Below them we have a negative temperature deviation of up to 3.7 K. According to this method it is quite

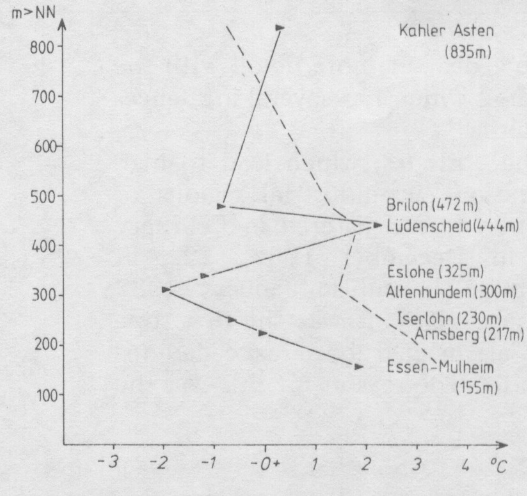

Fig. 9. Temperature-altitude ratio for the Sauerland-region (10-day mean of air temperature during time span Dec. 1 to Dec. 12; — — — = 1951 - 1970; ——— = 1962) (after [22]).

clear that the inversions had been at altitudes of about 450 m and 700 m. The monthly data from Kahler Asten station show that the inversions had been at altitudes of between 600 m and 700 m. The different inversion altitudes between Western and Eastern Sauerland are underlined by the comparison of the values for Lüdenscheid station (Western Sauerland, 440 m altitude) and Brilon (Eastern Sauerland, 470 m altitude). Although the altitudes of both stations show a difference in elevation of only 30 m, we find an inversion altitude for Lüdenscheid of nearly 440 m altitude, for Brilon, however, it is 130 m above the station. This is confirmed by the monthly data.

Before it is possible to classify potential recreation areas in the Sauerland, we exemplify the characteristics of inversions for the Greater Ruhrgebiet and the Bergisch-Sauerländische Gebirge with the help of inversion statistics.

4. CHARACTERISTICS OF INVERSIONS IN THE RUHRGEBIET AND THE BERGISCH-SAUERLÄNDISCHES GEBIRGE

The dates which could be used for an arrangement of inversions derive from evaluations of radiosonde ascents of Wetteramt Essen (Dt. Wetterdienst). The period is 1966 to 1976 [22]. I evaluated isothermics as well as inversions in the atmosphere between the ground and an altitude of 1000 m above sea level which meant an evaluation of 1509 single inversion results (137 inversions per year). The distribution of inversions shows a marked seasonal course with a maximum in the cold season. Nearly 78% of all inversions occurred during the heating period from October to March while the remaining 22% are registered in the period from April to September. In the winter months, excluding March, we find more than 10% of all registered inversions while we have less than 5% in the summer months, excluding August and September.

What is the distribution of inversions and the height of their lowest level in the course of the year? Figure 10 shows the monthly distribution percentage of the altitude of the lower level inversions. A comparison of the maximum values for January and February shows an accumulation below 500 m while most inversions occurring in March are clearly above 500 m as is the predominating maximum in the summer months. In October, however, the trend decreases again to inversions at lower levels and reaches the maximum number in November and December. A relatively high number of up to 4% of lower inversions ($\leqslant$300 m) in July can be explained by the amount of radiation in good weather conditions and immensely long spells of warm radiation during clear nights.

Figure 10 also shows that inversions in the winter months November to February have lower levels and thus reduce the mixing layer considerably in comparison to the summer layers. The winter inversions not only show a higher frequency, but also are stronger with higher temperature differences*. In the winter months the inversions have higher temperature gradients ($\gamma = -0.91$ K/100 m) than in the summer months ($\gamma = -0.60$ K/100 m).

The distribution of temperature gradients for certain months is shown in Table 5. About 70% of all temperature gradients occur in the range $0 \text{ K} \geqslant \gamma \geqslant -1 \text{ K}$. About 20% of all inversions have a temperature gradient of $-1 \text{ K} > \gamma \geqslant -2 \text{ K}$, 5% of all inversions reach a temperature increase of $-2 \text{ K} > \gamma \geqslant -3 \text{ K}$. The additional 5%, however, are distributed in the category $-3 \text{ K} > \gamma > -9.2 \text{ K}$. This survey shows that we have relatively weak inversions in most cases, while extreme situations are quite rare and occur mainly in the winter months. About 30% of the 70% 'weak' inversions ($\gamma \geqslant -1$ K) occur in the summer-half, 50% in the winter-half. In the higher category ($\gamma \geqslant -2$ K) we find 3% of 20% in summer and 17% in winter. The 5% of inversions with values of $\gamma \leqslant -3$ K are distributed to only 0.7% in the summer months and 4.3% in the winter months. The rare stronger inversions occur exclusively in the cold season. In 118 cases during the 11-yr observation period we registered two inversions between ground level and 1000 m of altitude at the same time. These occurrences, which are shown in Fig. 11, were registered almost exclusively in the

*We did not only show the absolute values of temperature differences between certain inversion layers, but the temperature gradient within the inversion (γ in K) related to an inversion density of 100 m.

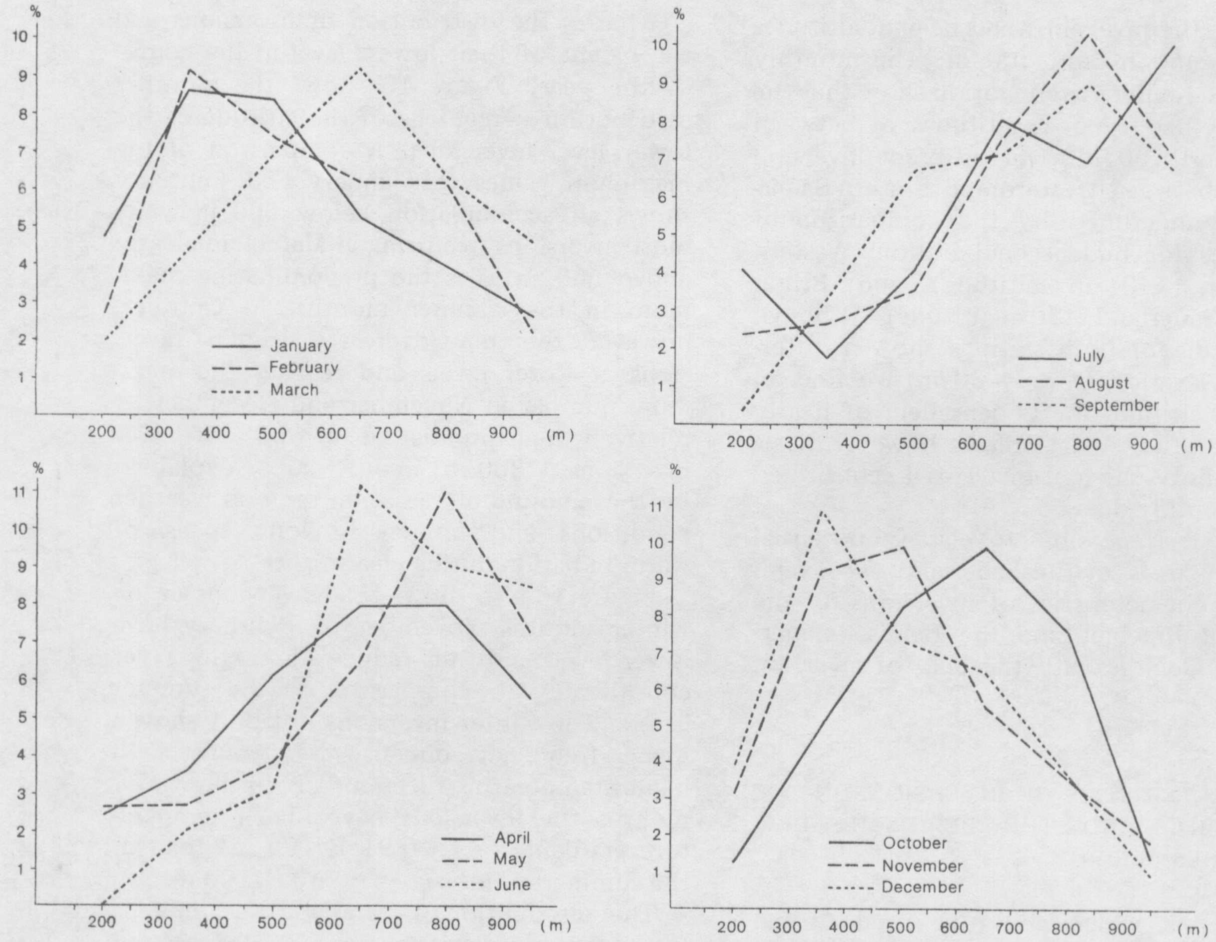

Fig. 10. Seasonal proportion of altitudes for sub-levels of inversions (settled) (after [22]).

TABLE 5

Monthly frequency distribution (%) of different lapse rates in inversion layers (γ in K/100 m) (after [22])

Month \ γ	−0.2	−0.4	−0.6	−0.8	−1.0	−1.2	−1.4	−1.6	−1.8	−2.0	−2.2	−2.4	−2.6	−2.8	−3.0
January	2.2	1.6	2.0	1.5	1.6	1.1	1.0	0.9	0.4	0.5	0.3	0.3	0.3	0.2	0.2
February	1.9	1.7	1.9	1.2	0.9	0.8	0.9	0.9	0.1	0.5	0.2	0.1		0.3	0.1
March	2.0	1.5	0.6	1.7	0.6	0.7	0.6	0.4	0.1	0.3			0.1	0.1	
April	1.1	0.6	0.5	0.5	0.1		0.3	0.1	0.1	0.1		0.1			0.1
May	1.1	0.2	0.6	0.5	0.3	0.2	0.1			0.1	0.1				
June	0.9	0.7	0.3	0.5	0.1	0.2	0.1	0.1	0.1						0.1
July	1.2	0.5	0.4	0.5	0.3	0.3	0.2	0.1		0.1	0.1	0.1			0.1
August	1.8	0.7	0.5	0.9	0.3	0.1	0.1	0.1	0.1	0.1					
September	1.8	1.1	0.6	0.9	0.8	0.1	0.1	0.2	0.1						
October	2.4	1.6	1.1	1.3	1.3	0.6	0.7	0.3	0.4	0.3	0.3	0.1	0.1	0.1	0.1
November	3.0	1.5	1.6	1.5	0.9	0.6	0.5	0.5	0.3	0.4	0.2	0.1	0.1	0.1	
December	2.8	1.8	2.1	1.7	1.6	1.0	0.5	0.5	0.7	0.4	0.2	0.3		0.2	0.2
Summer half-year	7.9	3.8	2.9	3.8	1.9	1.0	0.9	0.6	0.9	0.4	0.2	0.2	0.0	0.0	0.3
Winter half-year	14.3	9.7	9.3	8.9	6.9	4.8	4.2	3.5	2.0	2.4	1.2	0.9	0.6	1.0	0.6
Total	22.2	13.5	12.2	12.7	8.8	5.8	5.1	4.1	2.4	2.8	1.4	1.1	0.6	1.0	0.9

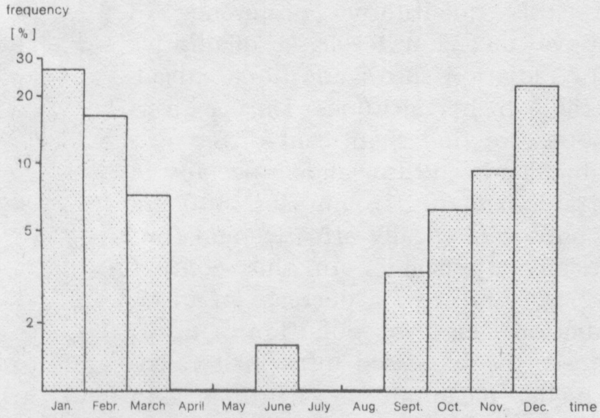

Fig. 11. Annual trend of the 2nd inversion in the atmosphere below 1000 m of altitude (after [22]).

winter-half. Additionally, they occurred mainly at higher altitudes (Fig. 12): 21% were registered at altitudes of 600 - 650 m, as was the case during the smog episode of 1962 in the Ruhrgebiet-Sauerland; 13% at altitudes of 800 - 850 m and 11% at 900 - 950 m. The remaining 55% lie between 650 m and 800 m while only a few had been registered below 600 m.

Coming to the duration of inversions, we found that the majority (30%) lasted for a maximum of one day. The frequency decreases with the duration of inversions, so that a 6-day inversion has only been registered 7 times in the 11-yr period. Inversions lasting more than 10 days occurred less than 5 times in these 11 years. Even longer periods of 12 - 20 days occurred, but only twice during the observation period.

Coming to the time in between the inversions (repetition period) we can conclude the following: while one-day inversions occurred quite frequently — after about 10 days — the frequency decreases rapidly with the duration of the inversions; six-day inversions can mostly be registered after about 18 months while the mean frequency of 10- to 11-day periods of inversions are 3.5 to 5.5 years. This analysis explains that the circum-

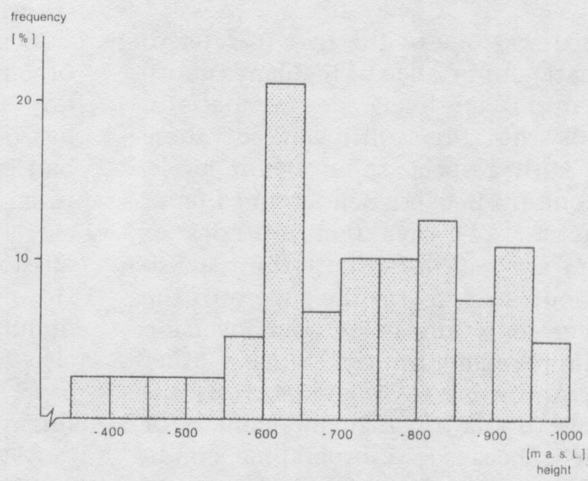

Fig. 12. Frequency distribution of the altitudes of the 2nd inversion (after [22]).

−3.2	−3.4	−3.6	−3.8	−4.0	−4.2	−4.4	−4.6	−4.8	−5.0	−5.2	−5.4	−5.6	−5.8	≥−6.0	≤−9.2
0.1	0.2	0.2			0.1		0.1	0.1							0.2
		0.1				0.1	0.1	0.1		0.1					0.2
	0.1		0 1			0.1				0.1	0.1				
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							0.1								
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				0.1											
0.1							0.1	0.1				0.1			
		0.1						0.1							0.1
0.3	0.1	0.1		0.1	0.3	0.1	0.1				0.1				0.4
0.2	0.2	0.0	0.1	0.1	0.0	0.0	0.1	0.0		0.0	0.1	0.0		0.0	
0.5	0.4	0.5	0.1	0.1	0.4	0.3	0.4	0.4		0.2	0.2	0.1		0.9	
0.7	0.6	0.5	0.2	0.2	0.4	0.3	0.5	0.4		0.2	0.3	0.1			0.9

stances for marked inversion conditions (excluding the analysis of the necessary low winds) are quite rare.

Beside the rareness (as has been observed) of long and strong inversions, as the one in December 1962, they are an important negative factor to air hygienic factors. Thus, to go to clean air areas above the inversions is a constructive measure to counteract the possibility of bioclimatic prevention.

5. BIOCLIMATIC ADVANTAGES OF CLEAN AIR AREAS DURING SMOG EPISODES

Undt [30] was one of the first to refer to the bioclimatic importance of highlands above inversions in his air hygienic examinations. Work about the direct influence of these inversions, with respect to inversion levels, has been done by Becker, Bender and Pfeifer [7]. Bacmeister [4] says that altitudes of 200 - 400 m are seen as an important transition phase but are lying in the sphere of the ground layer and thus below the inversion limits during permanent anticyclonal weather conditions. According to Amelung [1, 2] it is only possible to talk of a highland climate for places which, because of orographic conditions, are lying above the high fog layers of winter inversion periods.

The attractiveness of these regions can be analyzed with the help of the bioclimatic order schemes with the factors of thermic, radiation-dependant and air-chemical complexes [5]. Taking these aspects as the basis, I will deal with the chief factors of preference for the clean air areas depending on inversion altitudes.

A clear sky and an extremely good view are an indication that we find radiation conditions above the inversion which are essentially more favourable than in the valleys. The higher intensity of radiation depends on the one hand on the purity of the air and on the other hand on a lower humidity. Besides a stronger direct radiation there is another preference for regions above the mist and haze layer because of the additional reflection of radiation. According to Schulz [28] the global radiation (in the highlands) during inversion periods is 150 - 300% higher than in misty and hazy lowlands.

Besides this quantitative preference of places above inversion levels, a qualitative analysis of radiation shows additional advantages of these higher altitudes. During inversion episodes we find significant differences between highlands and lowlands especially in the spectral range of 315 nm and 400 nm which is photobiologically effective and thus bioclimatically applicable. In this context Landsberg [24] talks of a decrease of ultraviolet radiation caused by pollution of up to 30%. Indeed, the increased ultraviolet radiation of higher clean air areas influences a number of important biochemical reactions which influence the human organism in different ways [5].

Besides the favourable radiation conditions of places above inversions it is important to note better chemical conditions in the air. As has been emphasized, the inversion layer is a barrier to the vertical air exchange and leads to an accumulation of pollutants in the lower air layers. This leads to relatively high immission concentrations near conurbations. However, such an increased accumulation of pollutants is not limited to big cities, but is also found in the valleys of highlands (which have hardly any winds). Impressive examples for a considerable change of dust and pollutant concentrations during inversion periods are shown in the examinations of Becker *et al.* [7] (see also ref. [2]) in a highland town, according to which the number of particles can decrease from 20 000 /ml to 6000 /ml above the inversion.

The daily course of air temperature — besides wind speed and humidity — is also important for the human well-being. The temperature differences at the time of the strongest inversion condition on December, 4 and 5, 1962, were compared at stations of Kahler Asten (840 m of altitude) above the inversion and Eslohe (325 m of alt.) below. While at the Kahler Asten station, temperatures of 3.5 °C (I), 5.5 °C (II) and 4.6 °C (III) were registered at the three climatological times, the temperatures for Eslohe were −10.2 °C (I), 3.2 °C (II) and −8.4 °C (III). The lower amplitude of only 2 K is a contrast to the 13.4 K for Eslohe and had a gentle influence on human well-being compared to the irritative condition for Eslohe. Additionally, a comparatively high humidity at lowland stations of 47 - 75% (15 - 29% rela-

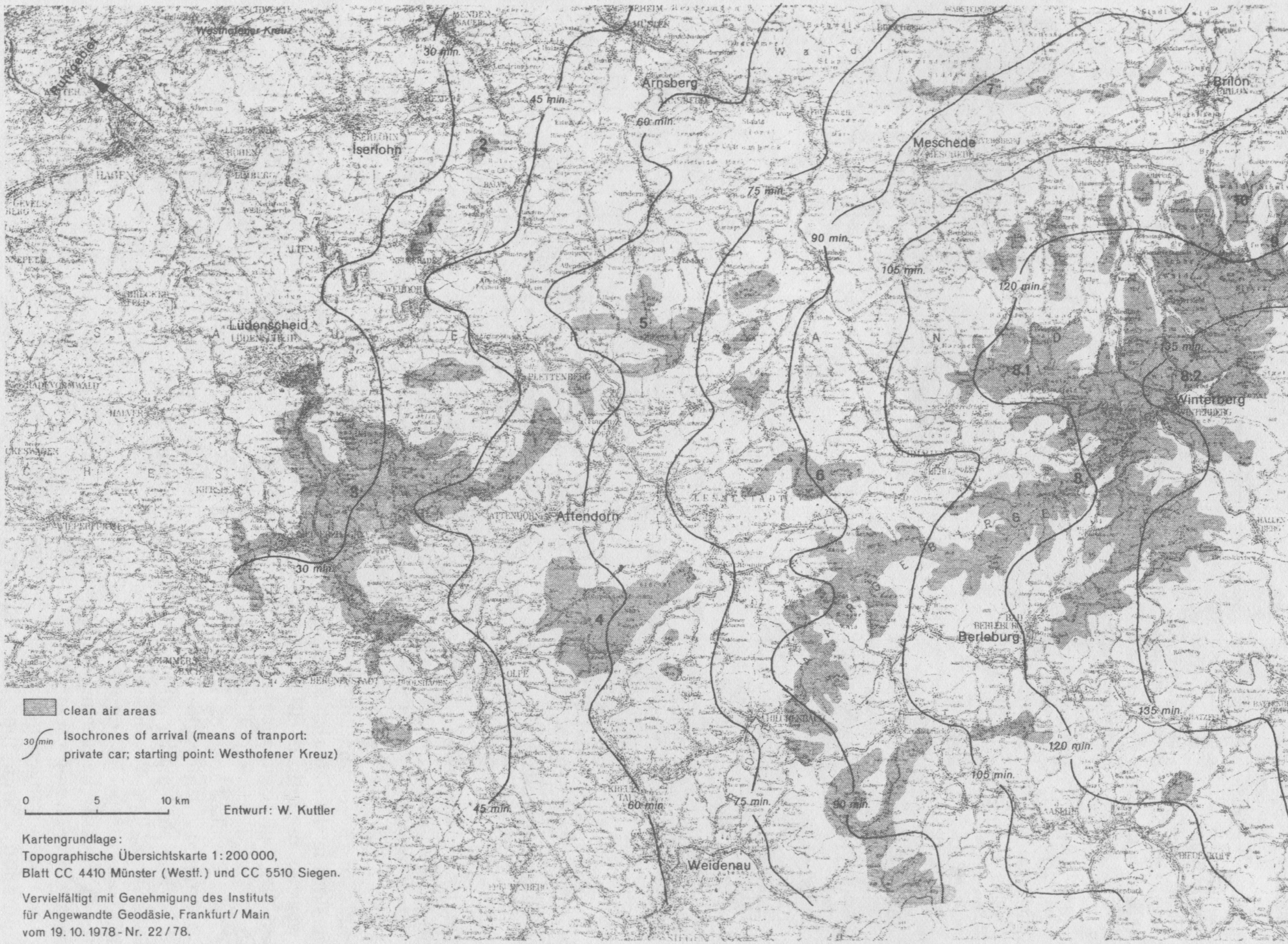

Fig. 13. Clean air areas in the Sauerland region during smog weather conditions in the Ruhrgebiet (after [22]).

TABLE 6

Clean air areas during smog weather conditions (after [22])

No. on the map in Fig. 13	Name of areas	Location	Highest Mountains (m.a.s.l.)		Federal highways
1	Kohlberg	im Lennegebirge	Kohlberg	(514)	B 236, B 229
2	Balver Wald	im Lennegebirge		(546)	B 7, B 515
3	Ebbegebirge	im Naturpark Ebbegebirge	Nordhelle	(663)	BAB Sauerland-linie, A 45
4	Bilsteiner Land	im Naturpark Ebbegebirge	Wollfahrt Hohe Bracht	(626) (584)	BAB Sauerland-linie, B 54, B 517
5	Wilde Wiese/ Homert	im Naturpark Homert	Homert Schomberg	(656) (648)	B54, B 517
6	Saalhauser Berge	ostnordöstlich v. Altenhundem	Himberg Auergang	(685) (584)	BAB Sauerland-linie, B 54, B 517
7	Warsteiner Stadtwald	im Naturpark Arnsberger Wald	Nuttlar-Höhe Stimmstamm	(542) (540)	BAB Kassel, B 475 bzw. B 7, B 55
8	Rothaargebirge	im Naturpark Rothaargebirge	Kahler Asten Nordhelle	(841) (775)	B 7, B 480
8.1	Hunau	im Naturpark Rothaargebirge	Hunau	(818)	B 7, B 480
8.2	Winterberger Hochfläche	im Naturpark Rothaargebirge	Hohe Seite	(753)	B 7, B 480
9	Upland	im Naturpark Rothaargebirge/ Diemelsee	Ettelsberg	(838)	B 7, B 480
10	Briloner Stadtwald	z.T. im Naturpark Diemelsee	Traiskopf	(781)	B 7, B 251

tive humidity for Kahle Asten station) leads to a raw and cold weather feeling which increases the incidences of colds.

6. THE SITUATION OF PERIPHERAL CLEAN AIR NEAR INDUSTRIAL REGIONS DURING SMOG EPISODES

With the results of the estimation of the altitudes of inversions in the Sauerland during low-exchange weather conditions, it is possible to indicate those regions on a map which are permanently above the ground layer of misty cold air. The greater area of the 12 clean air areas is situated in the region of the "Hochsauerland" while the smaller area is in the Western Sauerland. The regions in the Western Sauerland are of special importance for people for they can easily be reached from Ruhrgebiet. For a better survey these potential recreation areas are arranged in Table 6. Additional information about the shortest distances by using federal highways (Bundesstrassen or Autobahnen) has been added.

The high recreation value of these peripheral clean air areas, which is predominately caused by their situation during unhealthy weather conditions, is increased by two different factors: firstly, because the areas are partly integrated (to a different extent) in the various national parks or nature reserves of Northrhine-Westphalia, secondly, by predominating evergreen coniferous forest which, apart from its constant winter O_2 production, makes it possible to recover in a 'green' forest. For better guiding data, we have arranged the duration of travel in an isochrone map (lines of same duration) (see Fig. 13). The 'Westhofener Autobahnkreuz' was chosen as the basis of calculation for the isochrones. This is the essential point to reach most of the recreation areas either by the 'Sauerlandlinie' or by the highways leading to the eastern and western 'Sauerland'. The calculation is based on the average speeds of passenger-car traffic

[19] and differentiated into 15-min periods. For country roads I calculated an average speed of 50 km/h and for 'Bundesautobahnen' I took an average of 90 km/h. This map shows that the potential recreation areas in the 'Ebbegebirge' can be reached within a relatively short time, and, that the clean air areas in the 'Rothaargebirge' are still within the 2-h isochrone and can as well be visited during smog episodes in the Ruhrgebiet.

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