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VARIATION IN TIME, AND SPATIAL DISTRIBUTION OF AIR POLLUTANTS AND DUST FALL IN THE VICINITY OF POTABLE WATER RESERVOIR IN DOBCZYCE

ABSTRACT: The dependence of the concentration of fine dust and of sulphur dioxide on the variation of meteorological parameters, terrain configuration, vegetation coverage and land use, was studied in the surroundings of drinking water reservoir in Dobczyce. The studies show, that at night and in winter, the concentrations were three-fold higher than in the afternoon and in summer. The highest concentrations occurred during anticyclonic conditions with the air advection from the east and south east. The average and minimal air temperatures, as well as wind velocity, showed the best, among meteorological parameters, relationships with the concentration of the pollutants measured. Forest causes a decrease in the concentration of pollutants in 10 to 50%.

KEY WORDS: sulphur dioxide, fine dust, meteorological elements, terrain configuration.

1. INTRODUCTION

Concentrations of air pollutants and their variations at the ground level depend on the size of emission, and various factors among which, the diurnal and annual variations of meteorological parameters, as well as variations in the terrain configuration, its coverage and land use, play an essential role (Barratt 1989, Giovanni 1989, Klaic 1988).

In this paper, an attempt was made to determine the effect of these factors on the level of air pollutants deposition in the vicinity of the drinking water reservoir in Dobczyce.

2. METHODS

Two methods were used in the study. Mean diurnal concentrations of fine dust and sulphur dioxide, and those measured in three hours intervals, were determined with the aspiration method using the AKZA–1 apparatus (Polska Norma 1976). Concentration levels were calculated in $\mu g\ m^{-3}$ of air. Dust deposition was measured in $t\ km^{-2}$ by a weighing method using plastic sedimentary chambers with a 1660 cm^2 catching area each. All measurements were done 2 m above ground level.

In order to find variations in the diurnal concentration of fine dust and sulphur dioxide in the period 4–9 May 1987, continuous measurements of the air pollution were done with the aspiration method in three measuring points (Fig. 1). One of them (F) was situated at the reservoir, another (H) over the slope above, and the third one (K) at 90 m height above the reservoir level. Readings of the measurements were done every three hours during day and night. Measuring stations were located in the experimental small watershed of the Ratanica stream flowing into the potable water reservoir.

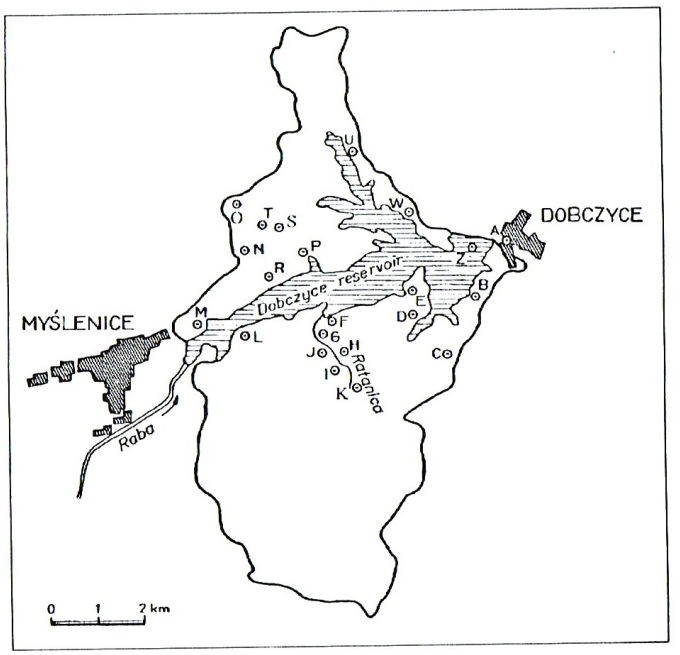

Fig. 1. Location of sampling stations in the vicinity of Dobczyce water reservoir

Similar measurements for determination of the changes in diurnal concentrations of fine dust and sulphur dioxide over the entire period of 1987, were performed at two stations. One (D) was located in the village Gaik-Brzezowa in the river Raba valley, 3 km south-west from Dobczyce; another one (Z) was situted on the dam in Dobczyce (Fig. 1).

In order to determine the amount of dust sedimentation in the neighbourhood of drinking water reservoir, 22 sedimentation containers were installed over an area of ca. 25 km^2 depending on the terrain configuration, vegetation coverage and land use. They were located in the town of Dobczyce; in villages; close to more important roads; over slopes used for farming and those covered with forests; upon deforested areas, and in the closest vicinity of the reservoir (points A to Z; Fig. 1). The sedimentation containers were exposed during the entire year of 1987. Dry weight of the sedimented dust was determined following vaporization each time after the monthly exposure of the sedimentation containers.

3. RESULTS

3.1. DIURNAL AND NIGHT DYNAMICS OF THE AIR POLLUTANTS

Investigations included the end of anticyclonic (high pressure) weather lasting from the end of April till the first days of May; they were carried on during the beginning of a cyclonic weather (low pressure) period formed as a result of a cold air inflow from north-west. The anticyclonic weather continued through the 4th and 5th of May until the evening hours of May 6th. From the evening of May 6th there was a period of cyclonic weather until the end of the month. Generally good weather with a small cloud cover of the cumulus type, and a maximal temperature of 20° C were observed during the anticyclonic period. During the cyclonic weather, cold and rainy, the maximal temperature did not exceed 12° C. The choice of the study period at the break of two weather types, allowed us to estimate the effect of change of the synoptic conditions on the level of air pollution. A change of an anticyclonic into a cyclonic weather, and a resulting inflow of fresh air from north-west had decreased the concentration of fine dust twice, or three times depending on the sampling station.

In the upper part of the valley at the station K, the air during the anticyclonic situation was nearly twice more polluted with fine dust, than at the station F, at the reservoir. The increased dust concentration in the air occurring in the upper parts of the valley suggest, that they were incoming from other, outside areas. The effect of the presence of forest at the station H, can be estimated as generally causing several to more than the 10% decrease of fine dust in the air (Table 1).

A distinct 24 hours rythm in the concentration of fine dust was observed during the anticyclonic weather period. The highest concentrations of fine dust were noted

during night hours with a maximum of 11.2 μg m^{-3} at 2:00 a.m., and a minimum of 4.2 μg m^{-3} in the afternoon, at 17:00. In the cyclonic situation the diurnal rythm was less pronounced. However, it can be assumed, that in the period studied, the concentration of fine dust was twice higher at night than during the afternoon (Table 2).

Table 1. Concentration of fine dust (μg m^{-3}) in the watershed of the Ratanica stream (Fig. 1, stations K, H, F)

Sampling date	Station		
	ridge (K)	forest centre of watershed (H)	stream outflow (F)
5, 6 May 1987 high pressure	10.1	6.4	6.3
7, 8 May 1987 low pressure	2.3	3.8	4.2
Average for the period 5–8 May	6.2	5.1	5.2

Table 2. Average diurnal rythm of dust concentration in the watershed of the Ratanica stream (Fig. 1, average values from stations K, H, F) depending on the baric situation (μg m^{-3})

Baric situation	Hour							
	2	5	8	11	14	17	20	23
High pressure	11.2	10.6	11.0	8.3	4.9	4.2	6.7	4.1
Low pressure	2.6	2.0	2.9	2.2	2.8	3.9	7.1	4.3
Average	6.9	6.3	6.9	5.2	3.8	4.9	6.9	4.2

The influence of analogical factors on the concentration of sulphur dioxide was different. During the anticyclonic weather, the largest concentration of sulphur dioxide occurred at station K, in the upper parts of the Ratanica valley (Table 3). A change from high to low air pressure had caused a general 2–3 fold decrease in the SO_2 concentration in the air. Greatest differences occurred at the station K, situated on an steep slope, where the concentration of sulphur dioxide decreased nearly three times. In the forest at the station H, the air was relatively less polluted. On May 7th, especially in the afternoon, during the inflow of fresh air masses from north-west, the SO_2 concentration was at the limits of detection.

Diurnal cycle of the SO_2 concentration was most pronounced during the high pressure period. Highest concentrations occurred at night, and lowest in the afternoon. The afternoon SO_2 concentrations are 1/3 of those at night (Table 4).

Table 3. Sulphur dioxide concentration in the Ratanica stream watershed (Fig. 1, stations K, H, F; μg m^{-3})

Sampling date	Station		
	ridge (K)	forest centre of watershed (H)	stream outflow
5, 6 May 1987 high pressure	4.1	1.2	3.4
7, 8 May 1987 low pressure	1.5	1.7	2.4
Average for the period 5–8 May	2.8	1.5	2.9

Table 4. Average daily rythm of the SO_2 concentration in the Ratanica watershed (Fig. 1, avera values from stations K, H, F) depending on the baric situation (μg m^{-3})

Baric situation	Hour							
	2	5	8	11	14	17	20	23
High pressure	2.2	3.7	3.8	1.8	2.6	4.0	2.5	2.3
Low pressure	0.5	1.5	1.2	0.5	0.9	0.9	5.4	4.0
Average	1.5	2.6	2.5	1.1	1.8	2.4	3.9	3.2

3.2. ANNUAL DYNAMICS OF AIR POLLUTION

Meteorological conditions in the vicinity of the reservoir in Dobczyce a characterized on the basis of meteorology data obtained by the measuring station the Climatology Department in the village Gaik Brzezowa. Monthly meteorologic data of the IMGW Institute were also used. Meteorological data from 1987 we compared with annual averages for the 20 years period between 1951 and 19 (Chomicz 1977). It was also found, that January 1987 belonged to the colde months in this century, while March was one of the coldest in the last 20 years. T average monthly wind velocities in the study period were usually slightly lower th normal. It is thus probable, that the pollution measurements may have values high than they are in reality, especially during January and March.

3.2.1. Concentration of fine dust

An estimate of the mean monthly concentrations shows to the distinct annu rythm. Highest concentrations of fine dust were observed during the winter month and the lowest during summer (Table 5). Highest mean monthly values were record in January, and they were 68.4 μg m^{-3} at the station D in the village Gaik Brzezow

Table 5. Average monthly concentrations of fine dust in 1987 (μg m^{-3})

Sampling station	Jan.	Febr.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Gaik-Brzezowa (D)	68.4	45.7	47.8	20.4	9.4	9.8	6.9	5.0	11.6	15.2	29.0	32.0
Dam (Z)	64.7	56.8	45.9	20.4	13.3	9.9	9.2	4.0	15.8	54.4	42.3	39.0

and 64.7 μg m^{-3} at the station Z located over the dam. The lowest mean concentrations of dust were noted in August, at the stations D (5.0 μg m^{-3}) and Z (4.0 μg m^{-3}). The measured concentrations of fine dust were also related to the synoptic situations. It was found, that during anticyclonic weather, the concentrations of fine dust were about 30% higher than during cyclonic conditions.

3.2.2. Concentration of SO_2

Mean concentration of SO_2 showed a characteristic annual rythm. The highest mean monthly averages were observed in winter, and the lowest in summer (Table 6). January was the month with the highest average concentrations of SO_2 78.7 μg m^{-3} at the station D in Gaik -Brzezowa, and with 62.5 μg m^{-3} at the station Z over the dam. In July, SO_2 concentrations were at the lowest level (3.4 μg m^{-3} at station D; 4.6 μg m^{-3} at the station Z). During the anticyclonic weather situations, SO_2 concentrations at both measuring stations were about 40% higher than during cyclonic weather.

Table 6. Average monthly concentrations of SO_2 in 1987 (μg m^{-3})

Sampling station	Jan.	Febr.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Gaik-Brzezowa (D)	78.7	34.7	33.8	9.1	5.5	4.2	3.4	11.1	8.1	9.2	11.5	32.1
Dam (Z)	62.5	45.0	22.8	12.6	7.3	6.6	4.6	13.7	18.5	11.2	14.3	28.7

3.2.3. Influence of synoptic conditions on the concentrations of fine dust and sulphur dioxide

21 types of the air circulation distinguished (Niedźwiedź 1988) have been related to the average diurnal concentrations of air pollution. The highest concentrations of dust and of SO_2, both, at the station D in Gaik-Brzezowa (46 μg m^{-3} for dust; 48 μg m^{-3} for SO_2), and at the station Z located over the dam (58 μg m^{-3} dust; 41 μg m^{-3} SO_2), occurred during an anticyclonic situation E_a+ SE_a with an air advection from the east and south east. High concentrations of these pollutants were also found for a central anticyclo situation C_a and K_a without advection, at the centre of high pressure above soutl Poland, as well as during an anticyclonic wedge and ridges of high pressure (sta in Gaik-Brzezowa: 40 μg m^{-3} dust concentration; 32 μg m^{-3} SO_2, dam station: 55 m^{-3} dust concentration; 32 μg m^{-3} SO_2).

High concentrations of pollutants are significantly related to high press synoptic conditions. Descending currents help in the concentration of polluta which are carried with the air from the upper to near ground layers. Sta equilibrium which is characteristic of anticyclonic situations, provides conditions the high concentration of pollutants.

It is to be expected, that the highest concentrations of fine dust and SO_2 at station D in Gaik-Brzezowa, will occur during days with minus air temperatu mostly below –5° C, at the time of no wind, or mild winds.

3.2.4. Statistical correlations between concentration of pollutants and meteorological factors

Calculations were done in order to determine a relationship between pollutants measured and the values of meteorological parameters. The best equat was chosen by the method of stepwise regression (Draper and Smith 1973). T average diurnal concentrations of fine dust and of SO_2 have been chosen as dependent variables for both measuring stations, in Gaik-Brzezowa and over the da On the basis of the earlier investigations of this type carried on by the autl (Mieczyński 1989), the mean diurnal values of meteorological parameters w reduced to seven independent variables. They were: average diurnal air temperatu minimal temperature, minimal temperature at the ground level, wind veloci cloudiness, visibility and relative air humidity. The following is an example of multiple regression equation for the situation E_a + SE_a, station in Gaik-Brzezowa:

For dust concentration $Y = 30.0148 - 2.8775\ T_{min}$; R^2 = 62%; F = 42.84
For SO_2 concentration $Y = -191.2169 - 4.4630\ T + 2.7489f$; R^2 = 67%; F = 20.94

where: Y is the average diurnal concentration of the pollutants measured (μ m^{-3}); T is the average diurnal air temperature; T_{min} minimal air temperature (° f is the relative humidity (%).

For data at the Gaik-Brzezowa station, a number of equations were obtain with a high determination coefficient R^2 above 50%. Much lower values were fou for the station on the dam in Dobczyce. In the course of the year one should expe high concentrations of air pollutants in winter, especially during anticyclon conditions, with the air advection from the east and south east. The same can l expected during central anticyclonic situation without advection, and with a hig pressure centre located above southern Poland.

Significant statistical correlations between meteorological parameters and air pollution enable their prognosis. Our calculations show, that the best correlations are between air pollutants values and such factors, as the average daily air temperature, the minimal temperature, and wind velocity.

3.3. DUST FALL IN THE SURROUNDINGS OF THE DRINKING WATER RESERVOIR IN DOBCZYCE

The highest dust fall of 56 t km^{-2} yr^{-1} occurred in dense populated areas (Dobczyce and Myślenice, Osieczany, Brzaczowice) . The characteristic phenomenon in these areas, is the higher dust concentration in the air (5.0 t km^{-2} $month^{-1}$) during the winter months between November and April, than during summer (4.3 t km^{-2} $month^{-1}$). This shows a large contribution of combustion products to the general balance of dust pollution in the city, and an area of compact housing. A high dust fall of 47 t km^{-2} yr^{-1} was recorded in the areas in smaller villages and close to the more important roads (Fig. 2). The pollutants emitted by vehicles having combustion motors, and also by secondary dust pollution from road surfaces, specially from road sides play an important role in dust pollution balance.

Over the deforested slopes taking the largest areas of the terrain studied, the recorded dust fall was 44 t km^{-2} yr^{-1}. Deforested slopes used as farm fields and meadows are characterized by a small coarsness of surfaces, which does not affect a high dispersion of pollutants. A smaller dust fall in the winter, and higher during the months when the soil is not entirely covered with vegetation, gives an evidence that in the general balance of dust pollution, a certain role is being played by the soil surface, as the secondary source of dust.

Ridges and slopes covered with forests were characterized by some of the lower dust pollution (37 t km^{-2} yr^{-1}). This is caused by the specific termodynamic conditions of the forest, as well as by the cumulation of dust pollutants at the edge of the forest, and the filtration effect of the trees. The lowest dust deposition of the order of 30 t km^{-2} yr^{-1} was noted in the belt surrounding the reservoir, a result of the absence of local pollution sources in the vicinity.

4. CONCLUSIONS

(1) Maximal concentrations of the pollutants measured occurred at night, while the lowest values, one third of those at night, were noted in the afternoon. (2) Compared with the open sites, the forest caused a >10% decrease in the concentration of dust, and nearly 50% decrease in the value of SO_2. (3) Twice lower concentration of the pollutants measured occurred during a change of anticyclonic into cyclonic conditions, at the inflow of fresh air from north-west. (4) The average winter concentrations of fine dust were significantly higher than in summer, and the relevant

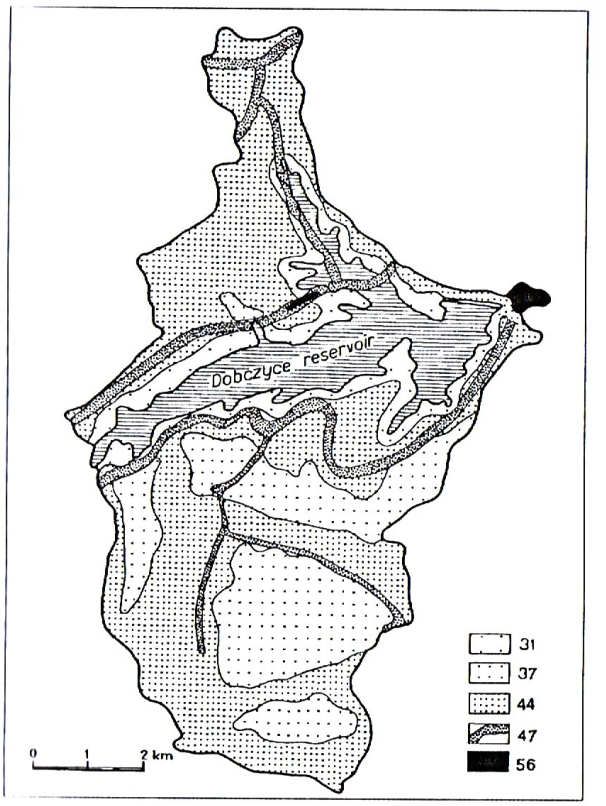

Fig. 2. Variation in the spatial distribution of dust fall in the surroundings of the water reservoir in Dobczyce (t km^{-2} yr^{-1})

winter concentrations of SO_2 compared to the summer values were in proportion of 3:1. (6) Concentrations of the air pollutants varied depending on the synoptic conditions. The highest concentrations of dust and sulphur dioxide occurred for the situations E_a+ SE_a, thus during an anticyclonic weather with the air advection from the east and south-east. (7) Among the meteorological parameters, the minimal temperature, average diurnal air temperature, and wind velocity show the closest relationship with the concentrations of pollutants. (8) The calculated equations

(9) Statistically significant correlation was found between the dust fall and the configuration of the studied sites, vegetation type and its coverage and the type of land use. (10) The highest dust fall was found in an area of dense populated areas (towns) and the lowest close to the reservoir.

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6. SUMMARY

Investigations of the dynamics of atmospheric air pollution with dust and sulphur dioxide, were carried out in 1987 in the surroundings of drinking water reservoir in Dobczyce. The average 3-hours and diurnal concentrations of fine dust and sulphur dioxide were determined with the aspiration method using the AKZA–1 apparatus. Sedimenting dust was measured using plastic containers with the surface catching area of 1660 cm^2 (Fig. 1).

A distinct diurnal rythm in the concentration of the pollutants measured was found, particularly during anticyclonic weather conditions, when the concentration of fine dust in the afternoon hours reached values of the order of 4–5 $\mu g\ m^{-3}$, compared to the night values of 11 $\mu g\ m^{-3}$. The concentration of sulphur dioxide was recorded as 2 $\mu g\ m^{-3}$ in the afternoon, and almost 4 $\mu g\ m^{-3}$ during the night and in the morning (Tables 2, 4). A change of synoptic conditions from anticyclonic into cyclonic was accompanied, in a period of two consecutive days, by a 2–3 fold decrease in the concentrations of fine dust and sulphur dioxide. The forests contributed to a 10–20% decrease in the concentration of dust, and 50% decrease in the amounts of SO_2 (Tables 1, 2). The highest values of the pollutants occurred in winter time, especially in January, with the fine dust value of >60 $\mu g\ m^{-3}$, and sulphur dioxide 70 $\mu g\ m^{-3}$. The lowest concentrations were recorded in summer, mainly in August, with the values being 5 $\mu g\ m^{-3}$ for dust, and 4 $\mu g\ m^{-3}$ for SO_2. (Tables 5, 6). The largest concentrations of fine dust and SO_2 occur during an anticyclonic weather with the air advection from the east and south east.

The finding of significant statistical correlations between the values of meteorological elements and the pollution, allows us to prognosticate these parameters. The results of stepwise multiple regression show, that concentrations of pollutants are mostly dependent on the average air temperature, the minimal temperature, and wind velocity.

The measurements of sedimenting dust in the surroundings of drinking water reservoir in Dobczyce showed, that the highest dust fall (56 t km^{-2} yr^{-1}) occurred in the town, and in large villages. Dust pollution of 47 t km^{-2} yr^{-1} was recorded for the areas with smaller villages; the value was 44 t km^{-2} yr^{-1} for deforested slopes; and 37 t km^{-2} yr^{-1} for ridges and slopes covered with forests. The lowest dust fall of the order of 30 t km^{-2} yr^{-1} was observed in the nearshore belt of the water reservoir (Fig. 2).

7. POLISH SUMMARY

W roku 1987 w otoczeniu zbiornika wody pitnej w Dobczycach przeprowadzono badania dynamiki zanieczyszczenia powietrza atmosferycznego przez pył i dwutlenek siarki. Średnie stężenia trzygodzinne i dobowe pyłu drobnego i dwutlenku siarki określono za pomocą metody aspiracyjnej [illegible]

Zaznacza się wyraźny rytm dobowy stężenia mierzonych zanieczyszczeń, zwłaszcza w sytuacj [illegible]cyklonalnej, kiedy to stężenie pyłu drobnego w godzinach południowych osiągało wartości rzędu [illegible] $\mu g\ m^{-3}$, podczas gdy w godzinach nocnych około 11 $\mu g\ m^{-3}$. Stężenie dwutlenku siarki wynosiło [illegible]powiednio 2 $\mu g\ m^{-3}$ w południe i prawie 4 $\mu g\ m^{-3}$ w godzinach nocnych i porannych (tab. 2, 4). [illegible] dniach przy zmianie sytuacji synoptycznej z antycyklonalnej na cyklonalną stężenie pyłu [illegible] i dwutlenku siarki zmniejszyło się 2–3-krotnie. Las powodował zmniejszenie stężenia pyłu [illegible] procent, a dwutlenku siarki prawie dwukrotnie (tab. 1, 3).

Najwyższe wartości mierzonych zanieczyszczeń występowały w okresie zimowym, zwłaszcza [illegible], kiedy to stężenie pyłu drobnego wynosiło powyżej 60 $\mu g\ m^{-3}$, najmniejsze zaś w lecie [illegible] w sierpniu – rzędu 5 $\mu g\ m^{-3}$. Odpowiednie wartości dla stężeń dwutlenku siark [illegible] 70 $\mu g\ m^{-3}$ i 4 $\mu g\ m^{-3}$ (tab. 5, 6). Największe stężenie pyłu drobnego i dwutlenku siark [illegible] przy pogodzie antycyklonalnej przy adwekcji powietrza ze wschodu i południoweg [illegible]

[illegible] statystycznych związków pomiędzy wartościami elementów meteorologicznych [illegible] zanieczyszczeń pozwala na ich prognozę. Z przeprowadzonych obliczeń metodą regres [illegible] wielokrotnej wynika, że stężenia zanieczyszczeń zależą najbardziej od średniej temperatur [illegible], temperatury minimalnej i prędkości wiatru.

[illegible] pyłu sedymentującego w otoczeniu zbiornika wody pitnej w Dobczycach wykazały, ż [illegible] opad pyłu 56 t km^{-2} r^{-1} występował w mieście i terenach o zwartej zabudowie wiejskie [illegible] o luźnej zabudowie wiejskiej odznaczały się zapyleniem 47 t km^{-2} r^{-1}, stoki wylesione 44 [illegible] r^{-1}, wierzchowiny i stoki zalesione 37 t km^{-2} r^{-1}. Najniższy opad pyłu rzędu 30 t km^{-2} r^{-1} [illegible] w przybrzeżnym pasie zbiornika wodnego (rys. 2).

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