

Association between the long-term exposure to air pollution and depression

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Abstract

Background. Air pollution has a negative influence on neurological and psychiatric disorders. However, findings concerning the impact of air pollution on depression remain inconclusive. A deeper insight into these associations is warranted.

Objectives. To evaluate the impact of long-term exposure to air pollution on the incidence of depression among residents of 13 counties in the Lower Silesia region of Poland.

Materials and methods. We used data on cases of depression from the National Health Fund (Narodowy Fundusz Zdrowia – NFZ) from 13 counties of Lower Silesia between January 1, 2010, and December 31, 2015. Patients with a confirmed diagnosis of depression were included. Data on air pollution levels were extracted from the Chief Inspectorate of Environmental Protection (Główny Inspektorat Ochrony Środowiska – GIOŚ), and demographic data were extracted from Statistics Poland (Główny Urząd Statystyczny – GUS).

Results. The percentage of people diagnosed with depression over the 6-year study period depended on the group of counties homogeneous in terms of air pollution exposure ($p < 0.001$). We showed statistically significant correlations between different depression diagnoses and exposure to air pollutants. Elevated concentration of airborne fine particles with a diameter less than $2.5 \mu\text{m}$ ($\text{PM}_{2.5}$) and carbon monoxide (CO), and low benzo(a)pyrene (BaP), sulfur dioxide (SO_2) and cadmium (Cd) levels were independent risk factors for major depressive episodes with psychotic symptoms (F32.3). There was a significant negative correlation between ozone (O_3) levels and depression incidence.

Conclusions. Regions with heavy air pollution had a higher incidence of depression. There is a significant association between the exposure to air pollutants and different depression diagnoses.

Key words: depression, air pollution, particulate matter, ozone, nitrogen oxides

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Background

Depression is a mental disorder that affects 264 million people worldwide, and is a major cause of disability.¹ Beck described depression as a combination of disturbed thinking, low mood and a negative perception of self, the surrounding world and the future.² Depression is associated with excess mortality³ and increased suicide risk.⁴ There are many risk factors for depression,⁵ such as female gender, chronic illness, traumatic life events,⁶ unemployment, lower education, a lack of physical activity, and limited social support.⁷

In recent years, there has been an increasing interest in the environmental risk factors for depression.⁸ Lack of green spaces, poor quality of housing, chronic noise exposure, and air pollution are all strongly associated with risk of depression.⁹ Both chronic stress¹⁰ and gene–environment interactions¹¹ contribute to risk for psychiatric illnesses, such as depression. Neuroinflammation is one of the main pathogenic mechanisms implicated in depression.¹² A prominent environmental risk factor associated with neuroinflammation is air pollution.¹³ The exposure to intense air pollution may disrupt metabolic processes and thus lead to inflammation.¹⁴ For example, experimental studies have shown that high concentrations of air pollutants are associated with systemic inflammation and insulin resistance.^{15,16}

Long-term exposure to certain air pollutants leads to low-grade inflammation.¹⁷ In response, more anti-inflammatory cytokines are released, in turn causing immune tolerance. Chronic inflammation is also linked to the activation of the kynurenine (KYN) metabolic pathway of tryptophan, leading to the synthesis of various oxidant and immunomodulating molecules at the expense of the serotonin production.¹⁸ These metabolites modulate the immune system towards low-grade inflammation, strengthening the vicious cycle of the immune response.¹⁹ The KYN pathway plays a role in the pathogenesis of neurodegenerative and psychiatric diseases.¹⁸ The levels of quinolinic acid (a toxin produced by KYN pathway) are increased in patients with major depression.²⁰ Moreover, experimental data indicate that one compound of air pollution, ozone (O₃), causes increased concentration of kynurenine.²¹ These mechanisms could explain the adverse impact of air pollution on neuroinflammation and risk for mental illnesses.

Air pollution is a mixture of various particles and gases suspended in the air, such as particulate matter (coarse particles with an aerodynamic diameter between 2.5 µm and 10 µm (PM₁₀), fine particles with a diameter less than 2.5 µm (PM_{2.5}), and ultrafine particles with a diameter less than 0.1 µm (PM_{0.1})), e.g., O₃, carbon monoxide (CO), sulfur dioxide (SO₂), nitrogen oxides (NO_x), nitrogen dioxide (NO₂), and polycyclic aromatic hydrocarbons (PAHs). Their main sources are anthropogenic emissions from traffic, industry and coal stoves.²² The Lancet Commission highlighted that air pollution is one of the main environmental causes of disease and premature death.²³ It is estimated that 8.79 million people worldwide died prematurely in 2019.²⁴

Studies consistently indicate that increased mortality associated with exposure to air pollutants is largely due to cardiovascular and respiratory diseases.¹⁴ The health impact of air pollutants has been broadened to include neurological and psychiatric disorders such as anxiety, depression and dementia.²⁵ Research on these associations is extremely important, since mental and neurological conditions are among the main causes of disability, including 30% of all strokes being related to air pollution.²⁶

There are some proposed mechanisms whereby air pollutants can negatively affect the brain. For instance, particulate matter can reach the systemic circulation through the lungs or through olfactory neurons,²⁷ and directly interact with the brain.²⁸ Especially dangerous are ultrafine particles which, due to their small size and the toxic compounds bound to them, can cause pathophysiological alterations in the central nervous system.²⁸ Another mechanism is alveolar inflammation, which leads to the production of cytokines²⁹ that can penetrate the blood–brain barrier.³⁰ The exposure to air pollutants triggers the activation of the hypothalamic–pituitary–adrenal (HPA) axis and the release of stress hormones,³¹ which is commonly associated with cardiovascular disease (CVD), type II diabetes mellitus, dementia, and depression.³² These mechanisms can explain the negative effect of air pollution on the central nervous system and mental health.³³

Findings on the impact of air pollution on depression remain inconclusive. Two meta-analyses confirmed that a long-term exposure to fine particles is associated with increased incidence of depression³⁴ and suicide risk.³⁵ Another study showed that PM_{2.5} is significantly associated with the occurrence of depression for both long, and short-term exposure.³⁶ Long-term exposure to PM_{2.5} and short-term exposure to PM₁₀, NO₂, SO₂, and CO, are risk factors for depression.³⁷ On the other hand, a meta-analysis of 22 studies showed a weaker relationship between air pollution and depression risk. This includes long-term exposure to PM_{2.5}, PM₁₀ and NO₂, as well as short-term exposure to PM_{2.5}, PM₁₀, SO₂, O₃, and NO₂.³⁸ Moreover, current studies are based mostly on self-reports, and they do not specify the association between air pollution and the sub-diagnoses of depression.^{34,37} No studies have examined the relationship between the exposure to air pollution and risk for depression with psychotic symptoms. There is also not enough evidence on long-term exposure to many different air pollutants and its impact on depression, especially at the sub-diagnosis level. Therefore, a deeper insight into these associations is important, and more data are needed to clarify the impact of air pollutants on depression risk.

Objectives

The aim of this study was to evaluate the impact of long-term exposure to air pollution on depression risk among residents of 13 counties in Lower Silesia (Poland).

Materials and methods

Data on depression cases used in the study were derived from the National Health Fund (Narodowy Fundusz Zdrowia – NFZ) from counties (Polish: powiat; Głogów, Jelenia Góra, Kłodzko, Legnica, Lubań, Oława, Oleśnica, Polkowice, Złotoryja, Zgorzelec, Wałbrzych, Świdnica, and Wrocław) pertaining the period between January 1, 2010, and December 31, 2015. The inclusion criteria were based on the International Classification of Diseases, 10th Revision (ICD-10) code diagnosis: F32 (depressive episode), F32.0 (mild depressive episode), F32.1 (moderate depressive episode), F32.2 (severe depressive episode without psychotic symptoms), F32.3 (severe depressive episode with psychotic symptoms), F33 (recurrent depressive disorder), F33.0 (recurrent depressive disorder, current episode mild), F33.1 (recurrent depressive disorder, current episode moderate), F33.2 (recurrent depressive disorder, current episode severe without psychotic symptoms), and F33.3 (recurrent depressive disorder, current episode severe with psychotic symptoms). In total, data on depression diagnoses were available for 318,779 individuals per study year. Data on air pollution levels were extracted from the Chief Inspectorate of Environmental Protection (Główny Inspektorat Ochrony Środowiska – GIOŚ) and covered the period from 2010 to 2015. Considered pollutants included: PM₁₀, PM_{2.5}, SO₂, NO_x, benzo(a)pyrene (BaP)(PM₁₀), O₃, CO, and NO₂. We used demographic data for the period 2010–2015 from Statistics Poland (Główny Urząd Statystyczny – GUS), including marriage and divorce rate, feminization rate, non-working population, working people, people >65 years old, medical help accessibility, beneficiaries of social welfare, unemployment, average salary, and

total pollution emissions. Two statistical methods were used. Cluster analysis was used to distinguish between counties homogeneous in terms of air pollution. The 2nd method utilized all county data to perform univariate and multivariate regression analyses, and an analysis of variance (ANOVA). For multivariate and ANOVA analyses, data on marriage and divorce rate, feminization rate, non-working population, working people, people >65 years old, medical help accessibility, beneficiaries of social welfare, unemployment, average salary, total pollution emissions, and PM₁₀, PM_{2.5}, SO₂, NO_x, BaP(PM₁₀), O₃, CO, and NO₂ concentrations were used. For univariate analyses, we used depression rate and its associations with PM₁₀, PM_{2.5}, SO₂, NO_x, BaP(PM₁₀), O₃, CO, and NO₂ concentrations. The homogeneity of variance in the groups was verified using the Levene's test. In the case of unequal variances in the compared groups, the Welch's correction was applied. Normality of distribution was determined using the Kolmogorov–Smirnov and Shapiro–Wilk tests. For the construction of multivariate linear regression models, non-normal data were transformed using the Box–Cox method.

Results

Air pollution

Table 1 presents data on air pollutant levels. Cluster analysis was used to distinguish homogeneous counties in terms of air pollution. It was possible to reduce a whole set to the average of individual groups. The Euclidean distance was used as a dissimilarity measure. Based

Table 1. Average air pollutant levels (2010–2015) in 13 counties of Lower Silesia (Me (IQR))

County	PM _{2.5} [µm/m ³]	PM ₁₀ [µm/m ³]	NO ₂ [µm/m ³]	CO [µm/m ³]	Pb [µm/m ³]	SO ₂ [µm/m ³]
Głogów	27.5 (1.1)	30.0 (7.5)	11.3 (2.3)	0.36 (0.10)	0.052 (0.021)	5.8 (1.5)
Jelenia Góra	27.2 (1.5)	44.8 (21.0)	15.7 (4.4)	0.45 (0.20)	0.033 (0.017)	10.4 (3.6)
Kłodzko	29.2 (1.4)	32.0 (5.6)	19.1 (4.6)	0.47 (0.02)	0.032 (0.007)	10.0 (2.7)
Legnica	26.7 (4.3)	34.1 (6.7)	22.6 (4.1)	0.47 (0.03)	0.049 (0.008)	7.6 (1.6)
Lubań	17.2 (1.6)	22.4 (4.4)	5.9 (1.8)	0.32 (0.00)	0.009 (0.008)	5.6 (2.1)
Oława	23.9 (1.1)	35.0 (6.7)	17.7 (2.0)	0.41 (0.04)	0.023 (0.004)	7.8 (0.2)
Oleśnica	24.2 (1.6)	31.3 (3.4)	18.8 (0.2)	0.41 (0.02)	0.030 (0.002)	7.1 (1.5)
Polkowice	22.4 (1.6)	29.4 (5.2)	10.4 (7.7)	0.38 (0.01)	0.025 (0.011)	6.5 (2.6)
Złotoryja	25.7 (1.8)	33.7 (3.5)	10.8 (3.7)	0.44 (0.05)	0.032 (0.002)	7.1 (1.2)
Zgorzelec	21.6 (4.8)	23.9 (12.3)	15.8 (9.8)	0.39 (0.05)	0.024 (0.005)	7.5 (1.8)
Wałbrzych	23.9 (2.0)	27.0 (5.1)	15.4 (2.4)	0.39 (0.08)	0.033 (0.015)	8.5 (3.0)
Świdnica	25.7 (2.6)	18.4 (12.2)	16.8 (1.8)	0.41 (0.07)	0.035 (0.004)	11.8 (1.9)
Wrocław	30.6 (1.6)	39.0 (9.5)	55.1 (10.6)	0.61 (0.15)	0.025 (0.009)	6.1 (0.9)
All	25.2 (4.7)	31.1 (8.7)	16.5 (7.6)	0.41 (0.09)	0.030 (0.014)	7.5 (2.9)

Me (IQR) – median and interquartile range; PM_{2.5} – atmospheric aerosols with a diameter of not more than 2.5 µm (the average daily dust standard ≤25 µg/m³ and average annual standard ≤10 µg/m³); PM₁₀ – a mixture of suspended dusts with a diameter ≤10 µm (the average daily dust standard ≤200 µg/m³ and average annual standard ≤20 µg/m³); NO₂ – nitrogen dioxide; CO – carbon monoxide; Pb – lead; SO₂ – sulfur dioxide.

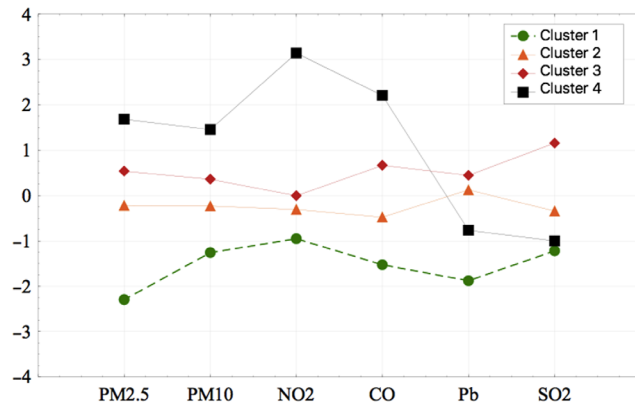


Fig. 1. Average values of pollution in 4 groups of counties (cluster 1 – Lubań county; cluster 2 – Głogów, Oława, Oleśnica, Polkowice, Złotoryja, Zgorzelec, and Wałbrzych counties; cluster 3 – Jelenia Góra, Kłodzko, Legnica, and Świdnica counties; cluster 4 – Wrocław county)

PM_{2.5} – atmospheric aerosols with a diameter of not more than 2.5 µm (the average daily dust standard ≤25 µg/m³ and average annual standard ≤10 µg/m³); PM₁₀ – a mixture of suspended dusts with a diameter ≤10 µm (the average daily dust standard ≤200 µg/m³ and average annual standard ≤20 µg/m³); NO₂ – nitrogen dioxide; CO – carbon monoxide; Pb – lead; SO₂ – sulfur dioxide.

on the hierarchical structure of the set of counties, they were divided into 4 clusters homogeneous in terms of air pollution:

- cluster 1: Lubań county;
- cluster 2: Głogów, Oława, Oleśnica, Polkowice, Złotoryja, Zgorzelec, and Wałbrzych counties;
- cluster 3: Jelenia Góra, Kłodzko, Legnica, and Świdnica counties;
- cluster 4: Wrocław county.

A graph of average values (Fig. 1) for standardized air pollution parameters showed that the highest level of air pollution, except for lead (Pb) and SO₂, was recorded in the Wrocław county (cluster 4). The next most affected counties in terms of the level of air pollution were Jelenia Góra, Kłodzko, Legnica, and Świdnica (cluster 3). The lowest level of pollution was recorded in the Lubań county (cluster 1).

Depression cases

The number of people diagnosed with depression in 2010–2015 was compared between individual counties (Table 2). The structure index (percentage) of people diagnosed with depression in the next 6 years of observation did not change significantly ($p > 0.05$). However, this depended significantly ($p = 0.003$) on the group of counties homogeneous in terms of air pollution (Fig. 2). The average structure index of people diagnosed with depression between 2010 and 2015 across the 13 counties was $2.72 \pm 1.78\%$ (women: $2.04 \pm 1.30\%$; men: $0.67 \pm 0.50\%$).

The linear relationships between depression diagnoses and air pollutant levels measured between 2010 and 2015

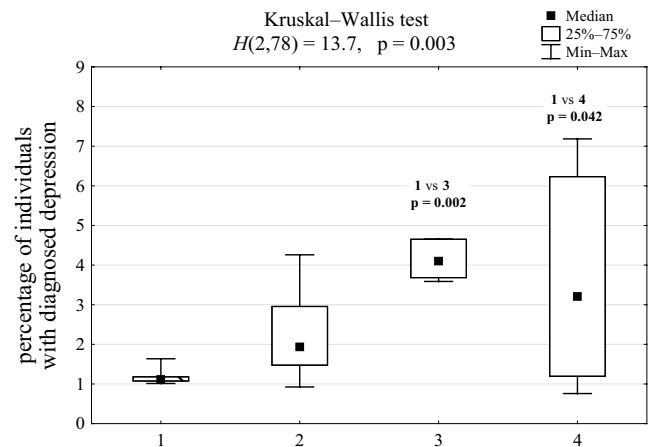


Fig. 2. Percentage of individuals with diagnosed depression in 4 groups of counties homogeneous in terms of air pollution, and results of the analysis of variance (ANOVA)

for all counties are summarized in Table 3. Since there were statistically significant correlations between the independent variables (predictors), the variance inflation factor (VIF) was estimated for each of them (Table 4). The strongest collinearity with PM₁₀ was observed for NO₂ and NO_x (VIF > 10). Variables NO₂ and NO_x were excluded from the predictive model for estimating the depression rate. The concentration of PM₁₀ ($r = 0.385$) and CO ($r = 0.344$) were significantly positively correlated with the frequency of severe depressive episodes with psychotic symptoms (F32.3). The concentration of O₃ was significantly negatively correlated with depression risk ($r = -0.283$). There were statistically significant correlations between different depression diagnoses and the following pollutants: PM_{2.5} and F32 (B = 0.303), PM₁₀ and F32, F32.0, F32.2, and F33; CO and F32, F32.0, F32.1, F32.2, F32.3, and F33; Pb(PM₁₀) and F32, F32.0, and F32.2; BaP(PM₁₀) and F32.0; arsenic (As)(PM₁₀) and F32, F32.0 and F32.2; and cadmium (Cd) (PM₁₀) and F32, F32.0 and F32.2. The O₃ levels were significantly negatively correlated with all depression diagnoses except F33.

Mathematical model of the occurrence of major depressive episodes with psychotic symptoms (F32.3)

The percentage of people diagnosed with a F32.3 in all counties was $0.23 \pm 0.19\%$. Table 5 presents the results of uni- and multivariate regression analyses of predictors associated with the risk for F32.3. The PM_{2.5}, CO, BaP, SO₂, and Cd levels were independently associated with the occurrence of F32.3. The formula for evaluating the structure index of F32.3 can be expressed as:

$$F32.3 = -403.4 + 10.8 \times PM_{2.5} + 379.8 \times CO + 24.1 \times Ni - 5.33 \times BaP - 6.44 \times SO_2 + 25.8 \times Cd$$

$$R = 0.803; F (\text{degrees of freedom (df)}: 7,70) = 18.2; p < 0.001$$

Table 2. Basic statistics (IQR) of the structure (%) of depression diagnosis in 13 counties in 2010–2015

County	Percentage of people diagnosed with depression (ICD-10)					
	F32.0	F32.1	F32.2	F32.3	F33	F34
Głogów	6.1 (1.5)	1.2 (0.6)	4.2 (1.6)	0.2 (0.2)	0.1 (0.1)	10.6 (4.2)
Jelenia Góra	11.8 (5.4)	5.0 (3.4)	8.9 (4.9)	0.4 (0.4)	0.3 (0.3)	10.4 (2.2)
Kłodzko	2.8 (0.7)	0.5 (0.1)	0.6 (0.1)	0.1 (0.1)	0.1 (0.1)	1.4 (0.6)
Legnica	5.9 (1.1)	6.5 (1.8)	15.4 (6.2)	0.4 (0.1)	0.6 (0.3)	6.1 (1.5)
Lubań	2.0 (1.3)	0.7 (0.6)	1.8 (1.6)	0.2 (0.1)	0.1 (0.1)	2.3 (0.3)
Oława	1.2 (0.3)	1.0 (0.2)	1.2 (0.8)	0.1 (0.1)	0.2 (0.2)	3.5 (2.8)
Oleśnica	0.9 (0.7)	0.7 (0.2)	0.7 (0.3)	0.1 (0.0)	0.0 (0.0)	2.6 (0.7)
Polkowice	1.1 (0.4)	3.9 (1.2)	3.9 (2.7)	0.1 (0.1)	0.0 (0.0)	3.3 (2.3)
Złotoryja	1.3 (1.0)	0.9 (0.4)	4.0 (1.3)	0.1 (0.2)	0.1 (0.0)	3.4 (1.1)
Zgorzelec	5.9 (1.8)	1.1 (0.5)	1.5 (0.9)	0.2 (0.1)	0.2 (0.1)	3.6 (0.7)
Wałbrzych	4.4 (0.3)	4.8 (0.5)	5.4 (1.0)	0.5 (0.1)	0.4 (0.0)	4.5 (0.3)
Świdnica	2.3 (1.2)	0.7 (0.6)	1.3 (0.3)	0.1 (0.0)	0.0 (0.0)	3.8 (0.5)
Wrocław	3.3 (1.4)	4.6 (1.7)	4.4 (2.2)	0.4 (0.1)	0.4 (0.2)	4.9 (0.3)
Cluster 1	2.0 (1.3)	0.7 (0.6)	1.8 (1.6)	0.2 (0.1)	0.1 (0.1)	2.3 (0.3)
Cluster 2	1.6 (4.0)	1.1 (2.4)	2.9 (3.3)	0.2 (0.2)	0.1 (0.2)	3.7 (1.9)
Cluster 3	3.3 (1.4)	4.6 (1.7)	4.4 (2.2)	0.4 (0.1)	0.4 (0.2)	4.9 (0.3)
Cluster 4	4.9 (4.1)	2.1 (5.5)	3.6 (11.3)	0.2 (0.3)	0.1 (0.4)	4.8 (5.7)
All	3.1 (3.9)	1.3 (3.5)	3.1 (4.1)	0.2 (0.3)	0.1 (0.3)	4.0 (2.4)

IQR – interquartile range; ICD-10 – International Classification of Diseases, 10th Revision; F32.0 – mild depressive episode; F32.1 – moderate depressive episode; F32.2 – severe depressive episode without psychotic symptoms; F32.3 – severe depressive episode with psychotic symptoms; F33 – recurrent depressive disorders; F34 – persistent mood disorders.

Table 3. Values of Pearson’s correlation coefficients between air pollution and indices of the structure of depressive episodes in all 13 analyzed counties

Air pollutants	F32	F32.0	F32.1	F32.2	F32.3	F33	F34
PM _{2.5}	0.303	0.204	0.198	0.152	0.222	0.197	0.281
PM ₁₀	0.341	0.277	0.198	0.211	0.385	0.328	0.291
CO	0.326	0.226	0.260	0.234	0.344	0.330	0.102
Pb	0.327	0.270	0.213	0.352	0.117	0.157	0.431
SO ₂	−0.040	0.171	−0.093	−0.064	−0.057	0.013	0.032
BaP	0.039	0.269	−0.060	−0.004	0.067	−0.052	0.071
O ₃	−0.412	−0.264	−0.296	−0.288	−0.283	−0.166	−0.375
As	0.433	0.295	0.215	0.513	0.158	0.218	0.491
Cd	0.241	0.237	0.124	0.267	0.073	0.218	0.293
Ni	0.091	0.065	0.017	0.004	0.091	0.163	0.092

Values in bold are statistically significant. BaP – benzo(a)pyrene; PM_{2.5} – atmospheric aerosols with a diameter of not more than 2.5 µm (the average daily dust standard ≤25 µg/m³ and average annual standard ≤10 µg/m³); PM₁₀ – a mixture of suspended dusts with a diameter ≤10 µm (the average daily dust standard ≤200 µg/m³ and average annual standard ≤20 µg/m³); CO – carbon monoxide; Pb – lead; SO₂ – sulfur dioxide; O₃ – ozone; As – arsenic; Cd – cadmium; Ni – nickel.

Table 4. Results of the collinearity analysis (variance inflation factor (VIF) values) of independent variables

Predictors	PM _{2.5}	PM ₁₀	NO ₂	CO	Pb	SO ₂	NO _x	BaP	O ₃	As	Cd	Ni
VIF	8.44	3.21	27.55	4.26	2.99	2.73	20.81	3.07	8.62	3.36	4.57	3.41

Values in bold are statistically significant. BaP – benzo(a)pyrene; NO_x – nitrogen oxides; PM_{2.5} – atmospheric aerosols with a diameter of not more than 2.5 µm (the average daily dust standard ≤25 µg/m³ and average annual standard ≤10 µg/m³); PM₁₀ – a mixture of suspended dusts with a diameter ≤10 µm (the average daily dust standard ≤200 µg/m³ and average annual standard ≤20 µg/m³); NO₂ – nitrogen dioxide; CO – carbon monoxide; Pb – lead; SO₂ – sulfur dioxide; O₃ – ozone; As – arsenic; Cd – cadmium; Ni – nickel.

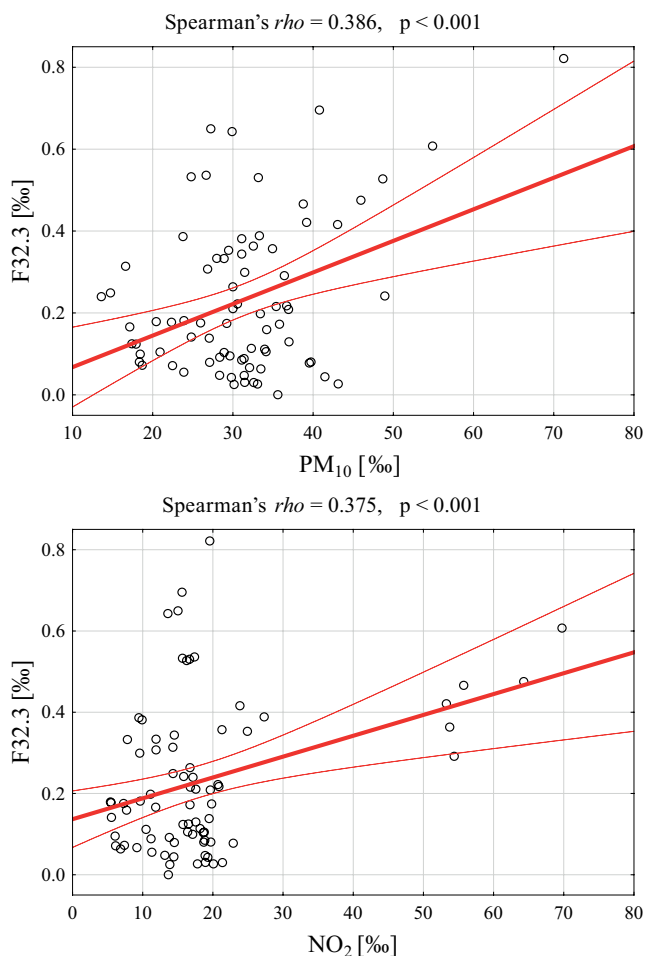


Fig. 3. Scatterplots showing reported cases of depression with psychotic symptoms (F32.3) and coarse particles with an aerodynamic diameter between 2.5 μm and 10 μm (PM_{10}) and nitrogen dioxide (NO_2) concentrations

Table 5. Values of univariate and multivariate regression analyses between air pollution and the occurrence of severe depressive episodes with psychotic symptoms (F32.3)

Risk factors (F32.3 occurrence predictors)	Univariate analysis		Multivariate analysis	
	b	p-value	β	p-value
$\text{PM}_{2.5}$	11.04	<0.001	10.8	<0.001
PM_{10}	-0.42	0.614	0.06	0.918
CO	409.0	<0.001	379.8	<0.001
Pb	154.7	0.775	538.2	0.775
SO_2	-7.36	0.014	-6.44	0.019
BaP	-5.42	0.002	-5.33	0.002
O_3	2.09	0.188	1.95	0.160
As	-0.85	0.702	-0.01	0.682
Cd	-47.2	0.192	-54.4	0.039
Ni	25.7	0.089	24.1	0.040

Multivariate regression statistics: $R^2_{\text{adj.}} = 0.609$, $F(7, 70) = 18.2$, $p < 0.001$, $\text{SE} = 38.3$. SE – standard error; b – linear regression coefficient; β – standardized regression coefficient. Values in bold are statistically significant. BaP – benzo(a)pyrene; $\text{PM}_{2.5}$ – atmospheric aerosols with a diameter of not more than 2.5 μm (the average daily dust standard $\leq 25 \mu\text{g}/\text{m}^3$ and average annual standard $\leq 10 \mu\text{g}/\text{m}^3$); PM_{10} – a mixture of suspended dusts with a diameter $\leq 10 \mu\text{m}$ (the average daily dust standard $\leq 200 \mu\text{g}/\text{m}^3$ and average annual standard $\leq 20 \mu\text{g}/\text{m}^3$); CO – carbon monoxide; Pb – lead; SO_2 – sulfur dioxide; O_3 – ozone; As – arsenic; Cd – cadmium; Ni – nickel.

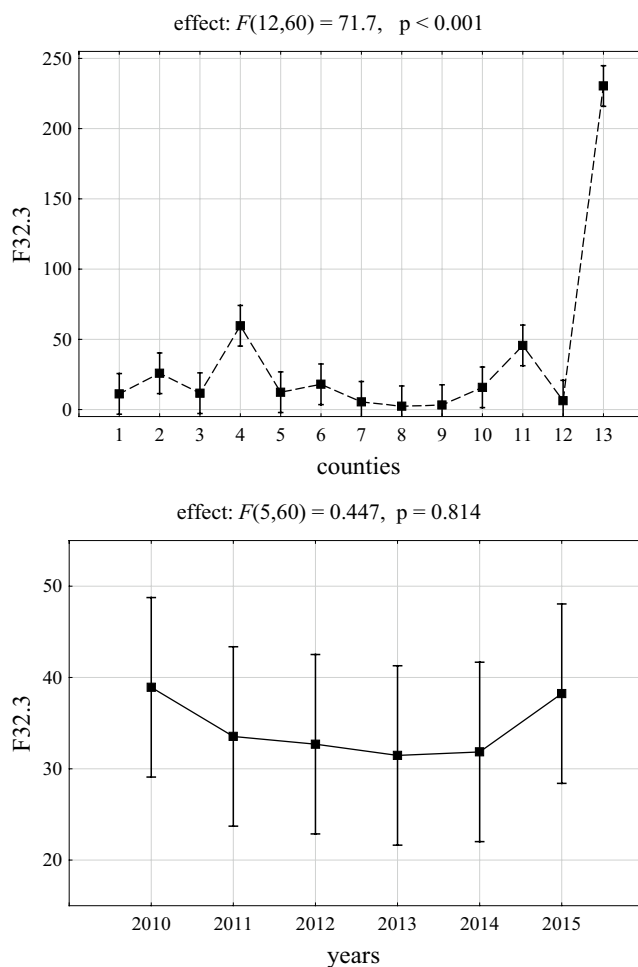


Fig. 4. F-ratio of the analysis of variance (ANOVA) concerning depression with psychotic symptoms (F32.3) ratio

The positive values of the regression coefficients indicated the effects of increased $\text{PM}_{2.5}$, CO, Ni, and Cd on the occurrence of F32.3. All structural parameters of the model were statistically significant ($p < 0.05$), and the model fit was satisfactory ($p < 0.001$). In order to avoid the pseudo-replication problem, and since the measurements of depression rates were taken in each county annually, the correlation analysis in consecutive individual years between air pollution and the occurrence of F32.3 was performed. The PM_{10} correlated significantly with the F32.3 diagnosis in 2010 ($\rho = 0.560$, $p < 0.05$), and both PM_{10} and NO_2 concentrations were linked to this diagnosis across all years ($\rho = 0.386$, $p < 0.001$; $\rho = 0.375$, $p < 0.001$; Table 6; Fig. 3,4).

Analysis including demographic and social data

Over the entire analyzed period, the percentage of diagnosed cases of depression was stable at a level of $2.7 \pm 1.8\%$. The analyzed database lacked information on the depression incidence in the Wałbrzych county in 2010–2012. The missing data were supplemented with average values.

Table 6. Correlation analysis in consecutive individual years between air pollution and the occurrence of severe depressive episodes with psychotic symptoms (F32.3)

Year	PM ₁₀ compared to F32.3	NO ₂ compared to F32.2
2010	rho = 0.560 p < 0.05	rho = 0.407 p > 0.05
2011	rho = -0.044 p > 0.05	rho = -0.077 p > 0.05
2012	rho = 0.440 p > 0.05	rho = 0.198 p > 0.05
2013	rho = 0.104 p > 0.05	rho = 0.473 p > 0.05
2014	rho = 0.544 p > 0.05	rho = 0.401 p > 0.05
2015	rho = 0.429 p > 0.05	rho = 0.099 p > 0.05
All	rho = 0.386 p < 0.001	rho = 0.375 p < 0.001

Values in bold are statistically significant. PM₁₀ – a mixture of suspended dusts with a diameter ≤10 µg (the average daily dust standard ≤200 µg/m³ and average annual standard ≤20 µg/m³); NO₂ – nitrogen dioxide.

Basic demographic data concerning depression cases (2010–2015) across the 13 counties of Lower Silesia are summarized in Table 6 and Table 7. Statistically significant differences were observed between depression incidence in individual counties (Fig. 5) (p < 0.001). The highest incidence of depression was recorded in Jelenia Góra (2) and Legnica (4) counties (6.1%), while the lowest in Kłodzko (0.9%) and Oleśnica (1.1%) counties. Table 8 shows the results of ANOVA concerning depression cases and Table 9 displays the results of post-hoc test (Turkey’s test).

The distribution of depression cases was non-normal (Fig. 6). The analyzed counties were classified into 3 groups: group A – depression rate below 1.5% (Kłodzko, Lubań, Oleśnica, and Świdnica counties); group B – depression rate of 1.5–3.1% (Oława, Polkowice, Złotoryja, and Zgorzelec counties); group C – depression rate over 3.1% (Głogów, Jelenia Góra, Legnica, Wałbrzych, and Wrocław counties) (Fig. 7). In group C, a high percentage of diagnosed depression cases was associated with higher concentrations of PM₁₀ and PM_{2.5}, as well as lower O₃ concentrations. The level of BaP did not differ significantly between

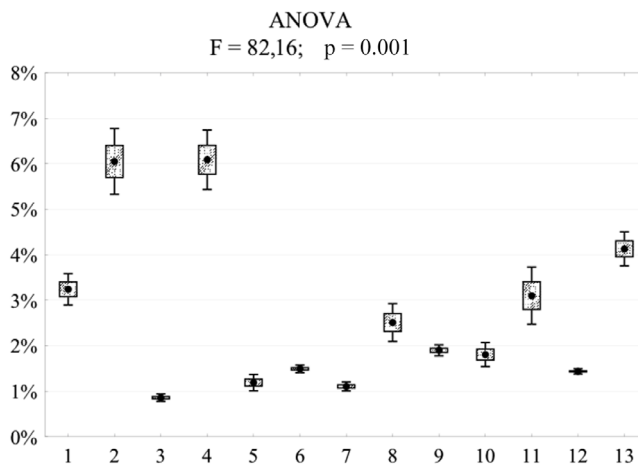


Fig. 5. Percentage of diagnosed depression cases in 2010–2015 in 13 counties of Lower Silesia and the result of the analysis of variance (ANOVA)

Table 7. Statistics of the percentage of diagnosed depression cases in 2010–2015 in 13 counties of Lower Silesia and the results of ANOVA

Years	Mean ±SD	Me (Q1–Q3)	Min–Max	Result of the test
2010	2.5 ±1.5	1.8 (1.5–3.7)	0.8–7.2	F = 0.29 df = 5 p = 0.868
2011	2.4 ±1.5	1.6 (1.4–3.6)	0.8–5.1	
2012	2.7 ±1.8	1.8 (1.4–3.9)	0.8–6.2	
2013	2.8 ±2.0	2.1 (1.5–3.5)	0.9–6.9	
2014	3.0 ±2.1	2.1 (1.5–4.3)	0.8–7.2	
2015	3.0 ±2.0	2.2 (1.3–3.9)	1.0–6.9	
Counties				
Głogów	3.2 ±0.4	3.3 (3.0–3.6)	2.5–3.6	F = 88.6 df = 12 p < 0.001
Jelenia Góra	6.1 ±0.9	6.0 (5.3–6.9)	4.9–7.2	
Kłodzko	0.9 ±0.1	0.8 (0.8–0.9)	0.8–1.0	
Legnica	6.1 ±0.8	6.4 (5.1–6.7)	5.1–6.9	
Lubań	1.2 ±0.2	1.1 (1.1–1.2)	1.0–1.6	
Oława	1.5 ±0.1	1.5 (1.4–1.5)	1.4–1.7	
Oleśnica	1.1 ±0.1	1.1 (1.0–1.2)	0.9–1.3	
Polkowice	2.5 ±0.5	2.8 (1.9–2.9)	1.8–3.0	
Złotoryja	1.9 ±0.2	1.9 (1.8–2.0)	1.6–2.1	
Zgorzelec	1.8 ±0.3	1.8 (1.5–2.1)	1.5–2.2	
Wałbrzych*	3.5 ±0.7	3.9 (3.9–4.0)	2.4–4.3	
Świdnica	1.4 ±0.1	1.4 (1.4–1.5)	1.3–1.5	
Wrocław	4.1 ±0.5	4.1 (3.7–4.7)	3.6–4.7	
All (n = 78)	2.7 ±1.8	1.9 (1.4–3.9)	0.8–7.2	–

* missing data for 2010–2012 have been replaced with averages; ANOVA – analysis of variance; M – arithmetic mean; SD – standard deviation; Me – median (50%); Q1 – lower quartile (25%); Q3 – upper quartile (75%); df – degrees of freedom; Min – the smallest value; Max – the largest value. The differences between the percentages of diagnosed depression cases in 2010–2015 in all counties turned out to be statistically insignificant (Fig. 1; p > 0.05).

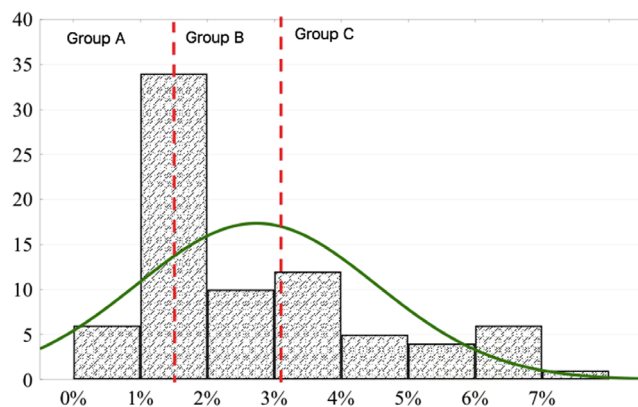


Fig. 6. Histogram of the percentage of depression cases against the normal distribution, the results of normality tests, and the adopted division. Kolmogorov–Smirnov test: d = 0.193, p < 0.01; Lilliefors test: p < 0.01; Shapiro–Wilk test: W = 0.866, p < 0.00001

Table 8. The results of ANOVA concerning depression cases

Effect	SS	df	MS	F	p-value
Constant	52563	1	92564	295	<0.001
Years	701	5	140	0.45	0.814
Countries	270075	12	22506	71.7	<0.001
Error	18821	60	314	–	–

R²adj. = 0.917, F(17, 60) = 50.8, p < 0.001. ANOVA – analysis of variance; SS – sums of squares; df – degrees of freedom; MS – mean squares. Values in bold are statistically significant.

the individual counties. The average values of pollutants in groups of counties differing in the severity of diagnosed depression are summarized in Table 10 and Table 11, as well as Fig. 8.

In counties with the highest percentage of diagnosed depression, there were significantly higher emissions of gaseous pollutants (1000 t/year/km²) (p = 0.003), SO₂ (p = 0.011), NO_x (p = 0.002), CO (p = 0.001), and CO₂ (p = 0.003), as well as concentrations of PM₁₀ (p = 0.039), PM_{2.5} (p = 0.008) and NO_x (p = 0.025). The O₃ levels were significantly inversely correlated with depression (p < 0.001; Table 10,11, Fig. 8).

In order to determine the independent predictors of depression incidence, univariate and multivariate linear regression analyses were performed (Table 12). Univariate regression analysis showed that PM₁₀ and PM_{2.5} concentrations, as well as divorces (per 1000 inhabitants), demographic burden, demographic dependency rate for the elderly, percentage of people >65 years old, feminization rate, outpatient clinics per 1000 population, doctors (total working staff) per 10,000 population, number of beds

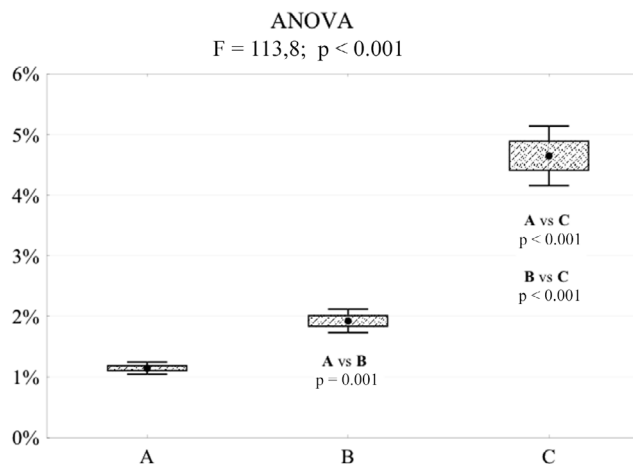


Fig. 7. Percentage of depression diagnosed in 2010–2015 in 3 groups of counties and the result of the analysis of variance (ANOVA) and post hoc tests (Tukey's test)

in hospitals in relation to the population, working people rate, emission of gaseous pollutants, and average monthly gross salary were significantly positively correlated with the incidence of depression. On the other hand, O₃ concentration, the number of marriages and the number of beneficiaries of social welfare were significantly negatively correlated with depression risk. Multivariate regression analysis showed that O₃ concentration, demographic burden, feminization rate, number of doctors, number of hospital beds in relation to the population, number of employed people per 1000 population, and average monthly gross salary were independent predictors of the depression rate. Increased O₃ concentrations were significantly associated with a lower depression risk (p = 0.004).

Table 9. Results of multiple comparisons (post hoc) with Tukey's test: Głogów compared to Jelenia Góra (3.2% compared to 6.1%; p < 0.001) and Głogów compared to Polkowice (3.2% compared to 2.5%; p = 0.261)

Counties	Multiple comparison results (Tukey's test)												
	Głogów M = 3.2	Jelenia Góra M = 6.1	Kłodzko M = 0.9	Legnica M = 6.1	Lubań M = 1.2	Oława M = 1.5	Oleśnica M = 1.1	Polkowice M = 2.5	Złotoryja M = 1.9	Zgorzelec M = 1.8	Wałbrzych M = 3.5	Świdnica M = 1.4	Wrocław M = 4.1
Głogów	–	0.000	0.000	0.000	0.000	0.000	0.000	0.261	0.000	0.000	0.998	0.000	0.068
Jelenia Góra	0.000	–	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Kłodzko	0.000	0.000	–	0.000	0.989	0.478	0.999	0.000	0.014	0.038	0.000	0.623	0.000
Legnica	0.000	1.000	0.000	–	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Lubań	0.000	0.000	0.989	0.000	–	0.995	1.000	0.001	0.305	0.525	0.000	0.999	0.000
Oława	0.000	0.000	0.478	0.000	0.995	–	0.962	0.018	0.947	0.993	0.000	1.000	0.000
Oleśnica	0.000	0.000	0.999	0.000	1.000	0.962	–	0.000	0.161	0.322	0.000	0.989	0.000
Polkowice	0.261	0.000	0.000	0.000	0.001	0.018	0.000	–	0.536	0.314	0.020	0.009	0.000
Złotoryja	0.000	0.000	0.014	0.000	0.305	0.947	0.161	0.536	–	1.000	0.000	0.877	0.000
Zgorzelec	0.000	0.000	0.038	0.000	0.525	0.993	0.322	0.314	1.000	–	0.000	0.974	0.000
Wałbrzych	0.998	0.000	0.000	0.000	0.000	0.000	0.000	0.020	0.000	0.000	–	0.000	0.538
Świdnica	0.000	0.000	0.623	0.000	0.999	1.000	0.989	0.009	0.877	0.974	0.000	–	0.000
Wrocław	0.068	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.538	0.000	–

M – arithmetic mean. Values in bold are statistically significant.

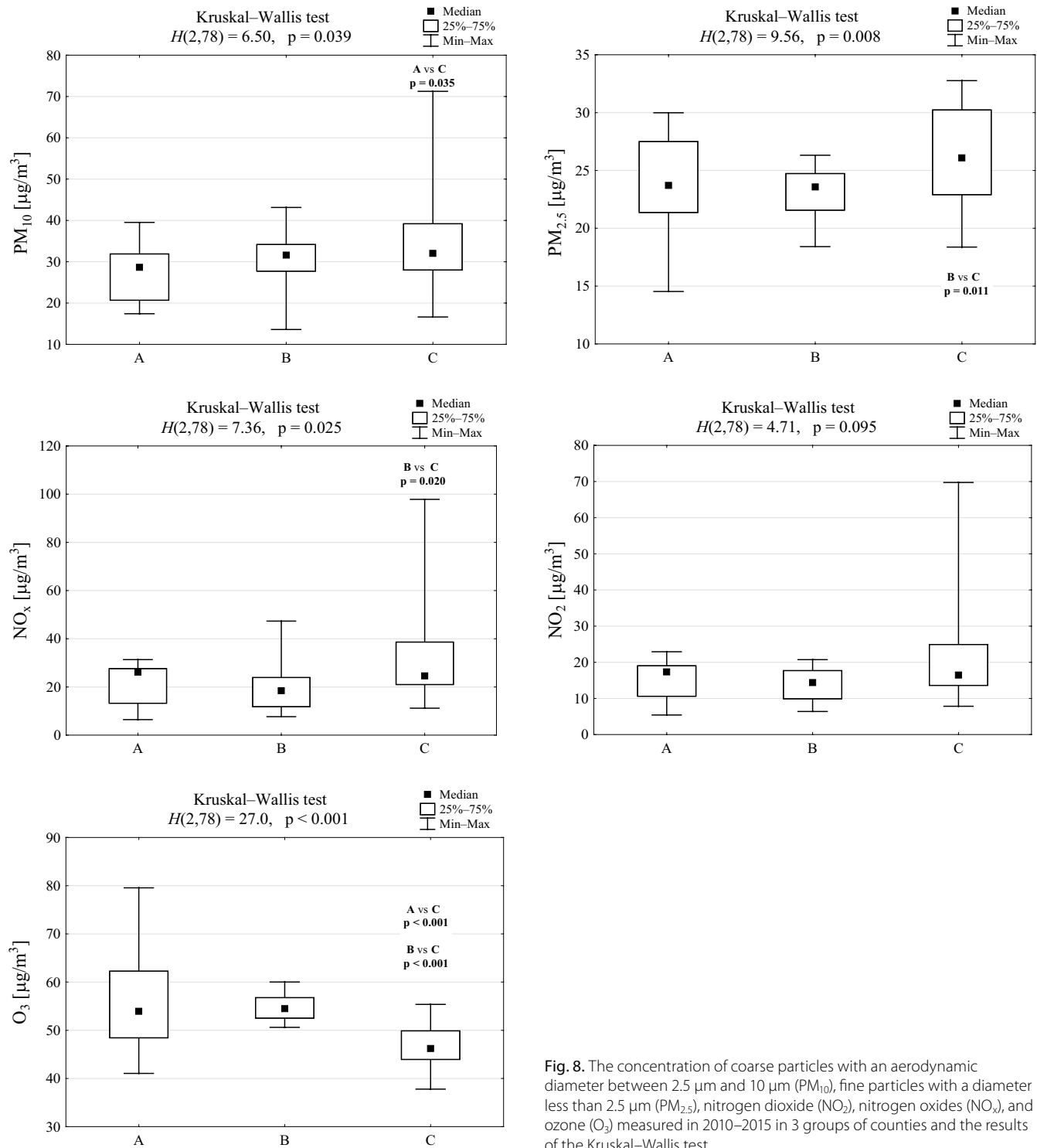


Fig. 8. The concentration of coarse particles with an aerodynamic diameter between 2.5 μm and 10 μm (PM₁₀), fine particles with a diameter less than 2.5 μm (PM_{2.5}), nitrogen dioxide (NO₂), nitrogen oxides (NO_x), and ozone (O₃) measured in 2010–2015 in 3 groups of counties and the results of the Kruskal–Wallis test

Discussion

We showed that depression is associated with long-term exposure to higher concentrations of PM₁₀, PM_{2.5} and NO_x, and high emissions of SO₂, NO_x, CO, and CO₂. Other studies have reported similar results. For example, research using the National Health Insurance Database demonstrated a positive association between PM_{2.5} and depression risk for both 1-year and 4-year exposure.³⁹ Other studies also

found this relationship for periods of 1 year,⁴⁰ 2 years and 5 years.⁴¹ In terms of PM₁₀ long-term exposure, a positive relationship was found over a 1-year time period.⁴² A study by Vert et al. supports these results for both PM fractions.⁴³ However, there was also a negative association for PM₁₀.⁴⁴ Furthermore, only a few studies evaluated the relationship between depression and NO_x. These studies consistently suggest a positive correlation between depression and long-term exposure to NO₂ and NO_x.^{43,45}

Table 10. Comparison of the features characterizing the counties of Lower Silesia in groups differing in the occurrence of depression

Parameter	Group A	Group B	Group C	p-value
Percentage of depression [%]	1.1 (0.4)	1.9 (0.5)	4.3 (2.0)	<0.001^a
PM ₁₀ [µg/m ³]	28.6 (11.2)	31.6 (6.5)	32.0 (11.2)	0.010^b
BaP [µg/m ³]	7.9 (10.7)	4.8 (3.6)	5.6 (3.4)	0.229 ^b
O ₃ [µg/m ³]	54.0 (13.8)	54.5 (4.3)	46.2 (5.9)	<0.001^b
PM _{2.5} [µg/m ³]	23.7 (6.1)	23.6 (3.2)	26.1 (7.3)	0.002^b
D1. Marriages (per 1000 inhabitants)	5.1 (0.7)	5.2 (0.9)	4.7 (1.0)	0.009^b
D2. Divorces (per 1000 inhabitants)	2.0 (0.4)	1.8 (0.3)	2.3 (0.3)	<0.001^b
D3. Demographic burden: non-working age population per 100 working age population	55.3 (3.4)	53.6 (3.4)	57.5 (5.1)	<0.001^b
D4. Demographic dependency rate for the elderly	19.8 (3.2)	17.6 (3.3)	23.2 (6.1)	<0.001^b
D5. Percentage of people aged 65 and over in the total population	14.2 (2.1)	12.7 (2.2)	16.6 (3.8)	<0.001^b
D6. Feminization rate	107 (2)	104 (2)	112 (3)	<0.001^b
D7. Outpatient clinics for 10,000 population	4.0 (1.0)	4.0 (1.0)	5.0 (1.0)	<0.001^b
D8. Medical advice to the population	4.3 (0.9)	4.2 (0.8)	4.0 (0.5)	0.008^b
D9. Total advice (in thousands)	536 (345)	288 (160)	413 (112)	0.004^b
D10. Beneficiaries of social welfare per 10,000 population	744 (192)	784 (276)	584 (250)	<0.001^b
D11. Doctors working according to the basic workplace per 10,000 population	13.4 (4.4)	12.7 (7.4)	24.4 (6.9)	<0.001^b
D12. Doctors (total working staff) per 10,000 population	31.2 (15.5)	26.8 (11.5)	50.4 (16.4)	<0.001^b
D13. Social welfare homes	2.0 (3.5)	1.0 (1.0)	2.0 (2.0)	0.014^b
D14. Inhabitants of social welfare homes (including branches) per 1000 population	3.0 (2.0)	1.0 (2.5)	2.0 (1.0)	<0.001^b
D15. Hospital beds to population (%)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	<0.001^b
D16. Registered unemployment rate	16.1 (9.6)	12.0 (9.0)	10.2 (6.3)	<0.001^b
D17. Working people per 1000 population	167 (45)	250 (198)	284 (74)	<0.001^b
D18. Average monthly gross salaries	3187 (374)	3487 (401)	3580 (639)	<0.001^b
D19. Average monthly gross salaries in relation to the national average (Poland = 100)	82 (6)	91 (6)	88 (12)	<0.001^b

^a – significance level of the Pearson χ^2 test, ^b – significance level of the Kruskal–Wallis test. Values in bold are statistically significant. BaP – benzo(a) pyrene; PM_{2.5} – atmospheric aerosols with a diameter of not more than 2.5 µm (the average daily dust standard ≤ 25 µg/m³ and average annual standard ≤ 10 µg/m³); PM₁₀ – a mixture of suspended dusts with a diameter ≤ 10 µm (the average daily dust standard ≤ 200 µg/m³ and average annual standard ≤ 20 µg/m³); O₃ – ozone.

Table 11. Comparison of the characteristics of the groups of counties in Lower Silesia in terms of pollutant emissions per 1 km² of land in counties with different rates of depression

Parameter	Group A	Group B	Group C	p-value
Percentage of depression	1.1 (0.4)	1.9 (0.5)	4.3 (2.0)	
Z1. Emission of gaseous pollutants (1000 t/year/km ²)	4530 (8864)	14732 (483176)	64755 (58043)	0.003
Z2. SO ₂	0.14 (0.32)	0.27 (7.14)	1.22 (3.46)	0.011
Z3. NO _x	0.06 (0.11)	0.32 (4.61)	0.65 (1.46)	0.002
Z4. CO	0.19 (0.11)	0.42 (0.68)	0.57 (0.56)	0.001
Z5. CO ₂	45.0 (88.1)	146.5 (4820.8)	644.5 (576.1)	0.003

p-value is significance level of the Kruskal–Wallis test. Values in bold are statistically significant. NO_x – nitrogen oxides; SO₂ – sulfur dioxide; CO – carbon monoxide; CO₂ – carbon dioxide.

We have observed a negative association between long-term exposure to O₃ and depression, which contradicts some of the previous results.⁴¹ However, some studies found no relationship between O₃ levels and depressive symptoms.⁴⁶ Volatile organic compounds and NO_x are precursors to O₃ formation,⁴⁷ and photochemical processes which depend on sunlight play a key role.⁴⁸ This can explain our results, since sunlight exposure⁴⁹ and vitamin D₃ production⁵⁰ have a preventive impact on depression. The O₃ exposure

and its health effects are more complicated, and possibly threshold-like.⁵¹ Finally, our study showed the important correlation between NO_x, NO₂ and depression risk, and these pollutants are known to decrease O₃ production.⁵²

We showed that high levels of PM_{2.5}, CO, and low BaP, SO₂ and Cd concentrations are independent risk factors for depressive episodes with psychotic symptoms (F32.3). To the best of our knowledge, there is no available research on this topic. However, some researchers

Table 12. Values of univariate and multivariate regression coefficients between the depression rate and risk factors

Risk factor	Univariate analysis		Multivariate analysis	
	b	p-value	β	p-value
PM ₁₀ [$\mu\text{g}/\text{m}^3$]	0.065	0.002	0.005	0.739
PM _{2.5} [$\mu\text{g}/\text{m}^3$]	0.140	0.007	-0.115	0.080
O ₃ [$\mu\text{g}/\text{m}^3$]	-0.089	<0.001	-0.082	0.004
BaP [$\mu\text{g}/\text{m}^3$]	0.017	0.738	-	-
D1. Marriages (per 1000 inhabitants)	-0.821	0.013	-0.027	0.932
D2. Divorces (per 1000 inhabitants)	3.023	<0.001	0.305	0.580
D3. Demographic burden: non-working age population per 100 working age population	0.208	<0.001	-0.213	0.004
D4. Demographic dependency rate for the elderly	0.234	<0.001	0.123	0.302
D5. Percentage of people aged 65 and over in the total population	0.365	<0.001	0.458	0.718
D6. Feminization rate	0.328	<0.001	0.378	<0.001
D7. Outpatient clinics per 10,000 population	0.384	0.027	-0.054	0.758
D8. Medical advice to the population	0.001	0.127	-	-
D9. Total advice (in thousands)	0.004	0.054	-	-
D10. Beneficiaries of social welfare per 10,000 population	-0.003	0.002	-0.001	0.588
D11. Doctors working according to the basic workplace per 10,000 population	0.091	<0.001	0.158	0.014
D12. Doctors (total working staff) per 10,000 population	0.039	<0.001	-0.043	0.130
D13. Social welfare homes	0.030	0.668	-	-
D14. Inhabitants of social welfare homes (including branches) per 1000 population	-0.294	0.094	-	-
D15. Hospital beds to population (%)	0.001	0.019	-0.001	<0.001
D16. Registered unemployment rate	-0.001	0.434	-	-
D17. Working people per 1000 population	0.010	<0.001	0.007	0.001
D18. Average monthly gross salaries	0.001	0.013	0.003	0.001
D19. Average monthly gross salaries in relation to the national average (Poland = 100)	0.054	0.026	-0.130	0.008
Z1. Emission of gaseous pollutants (1000 t/year/km ²)	0.860	<0.001	0.001	0.324
Z2. SO ₂	-0.001	0.429	-	-
Z3. NO _x	-0.001	0.489	-	-
Z4. CO	0.001	0.120	-	-
Z5. CO ₂	0.001	0.475	-	-

b – linear regression coefficient; β – standardized regression coefficient. Values in bold are statistically significant. BaP – benzo(a)pyrene; PM_{2.5} – atmospheric aerosols with a diameter of not more than 2.5 μm (the average daily dust standard $\leq 25 \mu\text{g}/\text{m}^3$ and average annual standard $\leq 10 \mu\text{g}/\text{m}^3$); PM₁₀ – a mixture of suspended dusts with a diameter $\leq 10 \mu\text{m}$ (the average daily dust standard $\leq 200 \mu\text{g}/\text{m}^3$ and average annual standard $\leq 20 \mu\text{g}/\text{m}^3$); O₃ – ozone; NO_x – nitrogen oxides; SO₂ – sulfur dioxide; CO – carbon monoxide; CO₂ – carbon dioxide.

attempted to find a connection between air pollution and depression severity. Pun et al. showed that PM_{2.5} levels are positively associated with depressive symptom severity.³⁶ On the other hand, Wang et al. found no relationship between depressive symptoms and both long- and short-term exposure to air pollutants.¹³ Similarly, there is very little evidence regarding psychotic symptoms and air pollution. An analysis using machine learning found a connection between schizophrenia emergency room admissions and ambient PM_{2.5},⁵³ which was confirmed by Gao et al.⁵⁴

A multivariate analysis of demographic and pollution data showed that the number of hospital beds, number of welfare recipients, number of employed people, and the average monthly gross salary were all related

to the incidence of depression. These results are inconsistent with other studies, which demonstrated that welfare recipients are more likely to suffer from depression.⁵⁵ However, our results could represent reverse causality. For instance, we showed a positive correlation between depression and the number of hospital beds in the region, which could result from the fact that people with depression are more frequently hospitalized.¹³ Similarly, employment status and depression rates could be related to workplace conditions, burnout, stress, and bullying,⁵⁶ which also translate into monthly salary. Depression accounts for up to 46% of days lost due to illness; therefore, it is more often diagnosed among the working population.^{56,57} However, in our study, data concerning employment were not available.

Limitations

Results of our analyses based on 318,779 cases showed that there is a positive association between air pollutant levels and the risk of depression. However, these results should be interpreted cautiously, because, as an observational study, despite being useful in explaining the exposure to an outcome, they carry out the risk of possible reverse causality or undetected bias.⁵⁸ Other limitations are related to the use of semi-individual data, and potential underestimation of the prevalence of depression due to social stigmatization related to this diagnosis.⁵⁹ Nevertheless, because of the large and standardized sample size, our study provides new insights into the relationship between air pollutant exposure and depression.

The analyzed database lacked information on depression incidence for the Wałbrzych county in 2010–2012. Since regression analysis was used, even if a strong correlation is evident, it does not imply causation. Moreover, some risk factors found in our study could simply reflect the indirect effects of other risk factors. Finally, it is crucial to remember that air pollutant concentrations depend on many variables, such as the direction and speed of the wind, atmospheric stability, solar radiation, or geography.⁶⁰ This can cause spatial and temporal variations of pollutants levels, reaching dramatic changes, even over the course of several hours. Moreover, the stress response in the human population is extremely heterogeneous.⁶¹ Age, gender, existing disease status, and psychosocial stressors play a potential role in the biological response to air pollutants. Given the numerous risk factors of depression, demonstrating the impact of air pollution on depressive disorders is difficult. Therefore, obtaining large-scale data on depression cases, and relating this to demographic and pollution information can help in identifying environmental risk factors, which could be potentially modifiable.

Conclusions

Heavy air pollution is associated with a higher incidence of depression, while O₃ levels were linked to the lower rate of depression. Elevated concentration of airborne PM_{2.5}, as well as CO, and low BaP, SO₂ and Cd levels are independent risk factors for the occurrence of major depressive episodes with psychotic symptoms (F32.3). A high percentage of people with depression could be related to higher concentrations of PM₁₀ and PM_{2.5}, lower O₃ concentrations and higher emissions of gaseous pollutants, such as SO₂, NO_x, CO, and CO₂.


The incidence of depression was associated with high concentrations of PM₁₀ and PM_{2.5}, as well as divorce rate per 1000 inhabitants, demographic burden, demographic dependency rate for the elderly, percentage of people >65 years old, feminization rate, outpatient clinics per


1000 population, doctors (total working staff) per 10,000 population, the number of hospital beds in relation to the population, working people rate, emission of gaseous pollutants, and average monthly gross salary. On the other hand, O₃ concentration, the number of marriages, and the number of welfare beneficiaries were negatively correlated with depression risk. The independent predictors of depression were: O₃ concentration, demographic burden, feminization rate, number of doctors, number of hospital beds in relation to the population, number of employed people per 1000 population, and the average monthly gross salary.


Availability of data and material

Data on air pollution are available on the website of the Chief Inspectorate of Environmental Protection: <http://powietrze.gios.gov.pl/pjp/current>. Demographic data are available on the website of the Statistics Poland: <https://stat.gov.pl/>.

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