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Analysis of Selected Health Problems in Children and Youth with Environmental Issues in the Context of Air Pollution Emissions in Poland

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ABSTRACT

The study aims to analyze selected environmental aspects and trends in morbidity for specific diseases among children and youth due to emissions of selected air pollutants in various regions of Poland from 2015–2022. The frequency of certain diseases among children and youth depended on the type of county (urban or predominantly agricultural pressure) and the county's location. The results indicate that data from the KOBIZE (National Center for Emission Balancing and Management) database is insufficient for studying youth morbidity. Statistical analyses show a correlation with the frequency of cancer and bronchial asthma in counties with livestock at the province level. Analyses concerning soil nitrogen load from NH_3 and NOx emissions show significant differences between counties.

Keywords: air pollution, animal production, asthma, chronic diseases, nitrogen.

INTRODUCTION

A report by the European Commission on the impact of air pollution on human health states that it causes 47.000 deaths annually in Poland, including 36.500 due to PM2.5 particulate matter [Uwak et al., 2021]. In terms of average annual PM10 particulate matter concentration, Poland ranks third among the most polluted capitals in Europe (after Bulgaria and Cyprus) [Landrigan et al., 2019]. In 2016, environmental pollution caused 940.000 deaths among children worldwide, two-thirds of whom were under the age of 5. Most of these, about 543.000, were due to respiratory infections [WHO, 2021]. Nine out of ten people worldwide breathe polluted air, causing around 7 million deaths annually. Over 90% of children breathe polluted air, with more than 300 million living in areas where pollution exceeds standards by six times. Nearly 18 million of them die from smog, including one in ten under the age of 5 [Czubaj-Kowal et al., 2022]. The risk of illness due to air pollution is much higher in children than in adults and can lead to a deterioration in quality of life in adulthood. Factors contributing to children's susceptibility to illness include an underdeveloped respiratory system and a higher breathing rate per minute. During respiration and air exchange, younger children intake higher doses of pollutants. Additionally, an underdeveloped immune system makes children more susceptible to the negative health effects of pollutants. It has been found that children of women exposed to air pollution during pregnancy have a lower birth weight - on average, 9 grams less for every 10 $\mu g \cdot m^3$ increase in PM10 concentration [Ahn et al., 2024].

The risk associated with breathing polluted air indoors can be as high as being outside [Anenberg et al., 2022]. The response to breathing polluted air is assessed in terms of short-term and long-term exposure. Short-term exposure, lasting from a few hours to a few days, causes an acute reaction in the body, with effects including: adverse impact on lung function, especially in groups sensitive to air pollution; exacerbation of existing disease symptoms, mainly cardiovascular and respiratory; and premature deaths, particularly related to respiratory and cardiovascular diseases. The occurrence of health pathologies is associated with increased medical visits and hospitalizations due to respiratory and circulatory diseases, increased drug consumption, and more days of school and work absenteeism [WHO, 2023]. Long-term exposure to air pollution, lasting from several months to years, is closely related to the incidence of diseases such as asthma, chronic obstructive pulmonary disease, lung cancer, cardiovascular diseases, and increased mortality from circulatory and respiratory diseases. Additionally, long-term exposure to certain chemicals usually leads to chronic changes in the physiological functions of other organs. Women exposed to long-term air pollution during pregnancy experience fetal development disorders: intrauterine changes, low birth weight at term, and inadequate fetal weight gain [Orellano et al., 2020; Southerland et al., 2022; Holloway et al., 2021].

Air pollution can originate from various sources, including natural processes like volcanism, wind erosion, decomposition of organic matter, and methane generation, as well as human activities such as industry and agriculture. In recent decades, industrialized agriculture has developed worldwide, negatively impacting the environment and the health of local communities. One aspect is industrial animal farms. In many countries, these take on a monstrous scale. In the USA, they are known as concentrated animal feeding operations (CAFOs) [Wang, 2022]. According to FAOSTAT statistics, between 1961 and 2021, the increase in all groups of farm animals was 382%, except for horses (-10%). Cattle increased by 60%, and pigs grew by 191%. The number of chickens rose by 584%, and geese by 1181%. According to GUS data [GUS, 2020], the number of farm animals in Poland increased from 2010 to 2019: cattle by 11%, chickens by 36%, ducks by 113%, and turkeys by 116%. Animal production is a source of various pollutants that can affect the health of local communities. Sources on farms include animals, their excrement, feed, equipment operation, and technological processes. The impact of an animal facility depends on the scale of production, animal species, feeding methods, excrement removal frequency, manure storage location, cleaning methods, ventilation systems, meteorological parameters, and the physical and chemical properties of the manure [Clangal et al., 2018]. Animal excrement is also a source of greenhouse gases like methane and nitrous oxide. In addition, odor substances (including ammonia, hydrogen sulfide, nitric oxide, aldehydes, amines, aromatic hydrocarbons, organic acids, and sulfur compounds) are emitted, causing unpleasant odors as well as dust, microbiological pollutants, or bioaerosols. Manure contains about 400 volatile compounds with unpleasant odors. Their concentration can cause numerous respiratory diseases and skin problems [Haider et al., 2024]. Odors can negatively affect human health, depending on the amount and nature of the emitted odor, the distance of inhabited areas from the emission source, atmospheric conditions, terrain topography, and human sensitivity and tolerance. Studies have shown that long-term exposure to odors negatively impacts well-being and behavior. It can cause various ailments such as insomnia, stress, apathy, irritability, depression, migraines, cough, nasal congestion, chest tightness, and other respiratory ailments, as well as inflammatory and allergic reactions [Conti et al., 2020].

One of the more troublesome substances that can spread over long distances is ammonia. It can pose a threat to habitat richness and biodiversity by introducing additional nitrogen into ecosystems. The negative impact of this substance can occur directly, as a toxic substance, or indirectly, by causing excessive nitrogen load on ecosystems. Ammonia can also contribute to soil acidification due to nitrifying bacteria activity. Both direct and indirect impacts can lead to significant disturbances in ecosystem functioning, increasing plant stress and eliminating some plant species from habitats. The combination of ammonia with bacterial bioaerosol is particularly harmful to health. Concentrations of ammonia at 5 ppm can lead to health deterioration. At concentrations around 30 ppm, upper respiratory tract irritation begins. Concentrations above 50 ppm can cause tracheal burns and bronchial damage. The issue of norms for maximum concentrations has been raised for many years. Some researchers argue that allowable concentration norms are too high. Increased ammonia concentrations in the air promote the formation of sulfate and nitrate aerosols, posing additional health risks [Wyer et al., 2022].

Numerous studies indicate that limiting the number and accumulation of large industrial farms near human settlements is justified to protect health. For example, studies in Germany found that alarm pathogens LA-MRSA – methicillin-resistant Staphylococcus aureus strains – were found 1 km from farms. This poses a real epidemic threat, especially since studies in Denmark in 2016 showed that 88% of pigs were carriers of this pathogen. MRSA pathogens have high survival rates in unfavorable environments. It has been shown that LA-MRSA strains can survive in organic dust for up to 2 months. Dust emitted from animal farms can therefore carry this pathogen [Feld et al., 2018].

In recent decades, we have seen worrying symptoms of what industrial animal production can threaten when carried out irrationally, contrary to animal biology and natural needs. On average, animal diseases that can be transmitted to humans appear every few years. Studies on the impact of specific substances on human health often focus on only one selected air pollutant component. However, several pollutants can be present in the air simultaneously, which act synergistically. The International Agency for Research on Cancer has classified a mixture of pollutants (i.e., synergistic interaction) as a major carcinogenic factor [Wyer et al., 2022; Feld et al., 2018]. The general objective of this study was to analyze the trends in morbidity of selected diseases in youth, resulting from emissions of selected air pollutants in various regions of Poland. The specific objectives included: (a) analyzing the levels of pollutants in selected counties; (b) analyzing the incidence of selected diseases among children and youth in individual counties; (c) analyzing the differences between cities with county rights and counties dominated by animal production, which is a source of specific pollutants; (d) analyzing the possibility of using emission data to record the potential impact of emission levels on the frequency of certain diseases; (e) analyzing the nitrogen load on land from emissions.

MATERIALS AND METHODS

Study area

For the study, 10 counties were selected where the development of intensive industrial animal production is observed or those that dominate in terms of the intensity of animal production within the region (Figure 1). These counties are: Bialski, Kartuski, Tomaszowski, Cieszyński, Ostrowski,

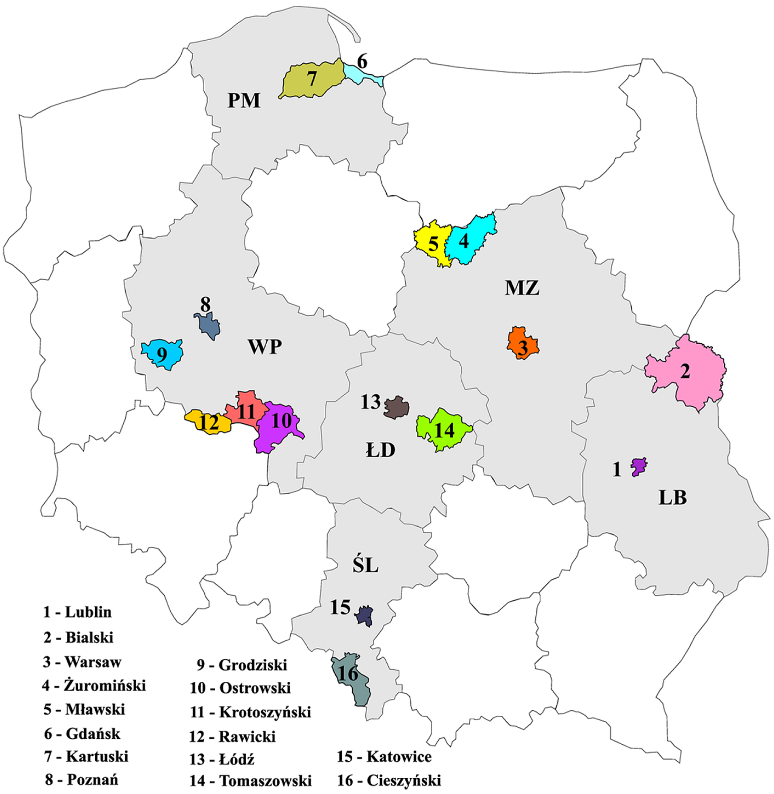

Figure 1. Location of the analyzed counties and provinces

Krotoszyński, Rawicki, Grodziski, Mławski, and Żuromiński. According to the Nomenclature of Territorial Units for Statistics (NUTS) classification in the European Union, these counties are classified as NUTS4 units (Regulation (EC) No 1059/2003). For contrast, cities with slightly different sources of pollution were selected. These were large cities with county rights: Katowice, Gdańsk, Poznań, Łódź, Warsaw, and Lublin. All regions were located in six provinces (NUTS2): Lublin (LB), Pomeranian (PM), Łódź (ŁD), Silesian (ŚL), Greater Poland (WP), and Masovian (MZ) (Figure 1).

Data sources

Data on pollutants emitted from facilities with a particular environmental nuisance were obtained from the National Centre for Emissions Management (KOBiZE). The Centre operates within the structures of the Institute of Environmental Protection – National Research Institute. One of the primary tasks of KOBiZE is to administer the EU Emissions Trading System in Poland. It also maintains a national database where data on greenhouse gas emissions and other substances, as well as parameters related to them, are collected. KOBiZE is responsible for performing annual national inventories of greenhouse gas and other substance emissions, including reports under the UNFCCC convention in accordance with the requirements of the Kyoto Protocol. KOBiZE is supervised by the Minister of Climate, and its tasks are financed by the National Fund for Environmental Protection and Water Management.

Information on the incidence of selected diseases was obtained from the National Institute of Public Health – National Hygiene Institute in Warsaw (based on the MZ-11 report). This data pertains to the health status of children and adolescents aged 0 to 18 years under the care of a primary care physician (family doctor), who have been diagnosed with a specific disease (as of December 31 of the every year) according to the ICD10 disease code (morbidity rate 10/000).

Data on the number of animals in 2020 was obtained from the Agricultural Census conducted in 2020. The results of the agricultural census are the only source that allows for an accurate characterization of Polish agriculture. The data is used by local and central authorities for making strategic decisions. Current information on the 2020 Agricultural Census can be found at https://spisrolny.gov.pl. Since the data from the Agricultural Census is developed at the NUTS2 level, additional data for two groups of livestock, pigs, and poultry, was obtained from the Central Statistical Office.

Analyzed pollutants

Information on the emission levels of 14 substances was obtained from the database of the National Centre for Emissions Management (KOBiZE). Ultimately, substances for which complete data were obtained were selected:

- ammonia (NH_3),
- benzo(a)pyrene,
- carbon dioxide (CO_2),
- PM10 suspended dust,
- PM2.5 suspended dust,
- carbon monoxide (CO),
- nitrogen oxides (NO_x/NO_2),
- sulfur oxides (SO_x/SO_2),

The data covered the years 2015–2022.

Analyzed diseases

The studies focused on diseases that may accompany areas where the pressure from animal production is greater. These diseases can be indicators of environmental pollution or the exceeding of certain environmental standards. Some of the selected pollutants occur in greater quantities in urban or industrial areas. The following diseases were chosen for the studies:

- cancer (C00-C97, D00-D48),
- bronchial asthma (J45),
- hypertensive disease (I10-I15),
- food allergies, inflammation of the stomach, small intestine and colon (K 52.2),
- allergic contact dermatitis (L27.2),

The data covered the years 2015–2022.

Statistical analyses

Statistical analyses were conducted using the PQStat statistical package version 1.8.4.152 and the Statistica package version 13.1. The relationships between the occurrence of diseases and pollutant emissions as well as the intensity of pig and poultry farming were analyzed by estimating Pearson's linear correlation coefficients and Spearman's non-parametric correlation coefficients. A test probability level of $p < 0.05$ was considered significant, and a test probability level of $p < 0.01$ was considered highly significant.

RESULTS AND DISCUSSION

Characteristics of analyzed counties

Counties were selected as territorial units with the characteristics of subregions for the study. The selected counties can be divided into two groups: counties with a lower degree of urbanization (Bialski, Kartuski, Tomaszowski Cieszyński, Ostrowski, Krotoszyński, Rawicki), with agriculture being the main economic sector, and cities with county rights with an urbanized character and a predominance of other economic sectors (Katowice, Gdańsk, Poznań, Łódź, Warsaw, Lublin). These two groups of counties were chosen to differentiate the source, type, and scale of certain emissions. One of the selection criteria for non-urbanized counties was animal production. In recent years, animal farming with a high degree of concentration and intensity has been intensively developing in Poland. Based on available data, counties characterized by intensive animal production and the expansion of animal farms were selected. The selection of counties also took into account their spatial and geographical dispersion. The characteristics of the selected counties, considering the two most dynamically developing branches of animal production, are presented in Table 1.

Some analyses, primarily concerning the impact of animal production on human morbidity, were conducted in a broader context. Since a significant portion of pollutants can migrate over long distances due to so-called transboundary pollution spread [Kim et al., 2022], the potential impact on morbidity does not necessarily have to result from conditions in the territorially isolated area being studied or local sources of pollution. While they are important, regional conditions can also influence the frequency of illnesses. The spread of pollutants is also affected by terrain roughness and topography. Table 2 presents the basic elements of the characteristics of the individual analyzed provinces, considering the share of the two most important land use components, namely agricultural land and forests.

Analysis of pollutant emissions in counties

The highest concentrations of SO_x/SO_2 were observed in Tomaszowski, Rawicki, Mławski, Żurominski counties, as well as in Katowice and Gdańsk (Figure 2). In turn, the highest nitrogen oxide emissions per capita were observed in Tomaszowski, Mławski, and Żurominski counties.

Table 1. Basic parameters of the surveyed counties in 2020

County (NUTS4)	Code of province (NUTS2)	Share of agricultural land	Share of forests	Number of residents	County area	Pigs	Poultry
		[%]		–	km^2	head·km^2	
Bialski	LB	65.7	27.9	110454	2759	22.8	1174.7
Kartuski	PM	55.7	31.1	138363	1 126	42.2	2924.8
Tomaszowski	ŁD	59.6	31.5	116614	1025	77.0	1742.8
Cieszyński	ŚL	58.4	37.7	178005	730	6.7	1178.4
Ostrowski	WP	62.6	28.2	161581	1161	11.0	42.9
Krotoszyński	WP	72.6	18.6	77182	714	201.9	3159.5
Rawicki	WP	76.6	14.9	60231	553	234.5	20054.6
Grodziski	WP	71.8	23.7	51940	367	178.0	2472.2
Mławski	MZ	52.6	21.1	72448	1182	58.0	7913.2
Żurominski	MZ	74.7	21.7	38337	807	662.2	13498.8
Katowice	ŚL	11.9	40.1	290553	165	3.8	882.7
Gdańsk	PM	34.6	17.2	473917	263	0.4	18.3
Poznań	WP	31.8	15.1	532048	262	422.5	675.3
Łódź	ŁD	40.6	8.9	678341	293	15.4	119.0
Warszawa	MZ	24.6	14.9	1794166	517	7.3	80.2
Lublin	LB	35.4	11.1	335114	148	0.5	711.2

Table 2. Basic parameters of the surveyed counties in 2020

Province (NUTS2)	Code of province	Number of counties	Share of the province in the country's area	Share of agricultural land	Share of forests
		Number	[%]		
Lubelskie	LB	20	8.1	70.6	23.4
Mazowieckie	MZ	42	11.4	67.7	23.4
Łódzkie	ŁD	21	5.8	70.3	21.6
Pomorskie	PM	16	5.9	51.1	36.4
Wielkopolskie	WP	31	9.6	64.6	26.2
Śląskie	ŚL	36	3.9	50.4	32.2

Nitrogen dioxide is considered very toxic. A few minutes of exposure to concentrations of 7.5–9.4 mg/m^3 causes a significant increase in respiratory resistance, which persists for several dozen minutes after inhalation ceases. Bronchial reactivity increases in most asthma patients in response to concentrations of 0.19–0.38 mg/m^3. Short-term exposure to high concentrations of 94–7500 mg/m^3 causes pulmonary edema and death. Chronic occupational exposure promotes the development of chronic bronchitis and emphysema. Moreover, increased susceptibility to respiratory infections is suggested [Russell et al., 2020].

The highest carbon oxide emissions occurred in Rawicki, Mławski, and Żuromiński counties (Figure 2). Emissions of particulates (PM10 and PM2.5) showed similar trends, indicating they are emitted by similar sources. The highest recorded emissions were in Rawicki, Grodziski, Mławski, and Żuromiński counties. Suspended particulate matter is particularly harmful from the perspective of protecting human health and life. Studies have revealed a suggestive link with mortality related to cerebrovascular diseases [Beelen et al., 2014]. A link between short-term exposure and overall mortality has also been discovered. In the APHEA-2 project, 43 million people from 29 European cities (including several Polish cities) were studied. The project's results indicate that each increase of 10 µg/m^3 in the average daily PM10 concentration increases the daily risk of death by 0.52%, and deaths from cardiovascular and respiratory causes by 0.76% and 0.71%, respectively. It has also been shown that an increase in PM2.5 concentration by 10 µg/m^3 increases overall mortality by 1–3%, but this result varies significantly depending on the region of the world. These studies also observed a slight increase in cardiovascular mortality of about 0.8%. They indicate a greater effect of PM2.5 on daily mortality in cities with higher air temperatures. In Asian countries, where air pollution is significantly higher than in some European countries and the USA, this impact on cardiovascular mortality is weaker [Yin et al., 2020; Tiotiu et al., 2020].

The impact of particulate pollution is stronger in the elderly and in cities with higher nitrogen dioxide concentrations. We now have strong evidence that exposure to air pollutants such as particulate matter is associated with an increased likelihood of exacerbating asthma symptoms [Lu et al., 2023]. Particulate pollution is correlated with biological pollutants and facilitates their spread. Microorganisms present in the air form dust-bacterial complexes, whose composition significantly facilitates their growth and survival. They occur in the air as biological aerosols (aeroplankton) and can play an important role in the transmission of allergic and infectious diseases and even contribute to epidemics. Bioaerosols can affect the health of humans and animals. Biological aerosols spread similarly to non-biological aerosols and can travel long distances with air currents [Kim et al., 2022].

Ammonia emissions were high in counties where high emissions of other studied pollutants were observed, namely Rawicki, Grodziski, Mławski, and Żuromiński counties (Figure 2). In turn, the level of carbon dioxide emissions based on data from the KOBIZE database indicates higher emissions in cities with county rights. The highest emission of this compound was observed in Gdańsk. Among the remaining agricultural counties, relatively high emissions were observed in Tomaszowski County (Figure 3). Benzo(a)pyrene emissions were highest in Bialski, Ostrowski, Krotoszyński, and Rawicki counties (Figure 4).

Based on the obtained results, it can be concluded that the emissions of most of the

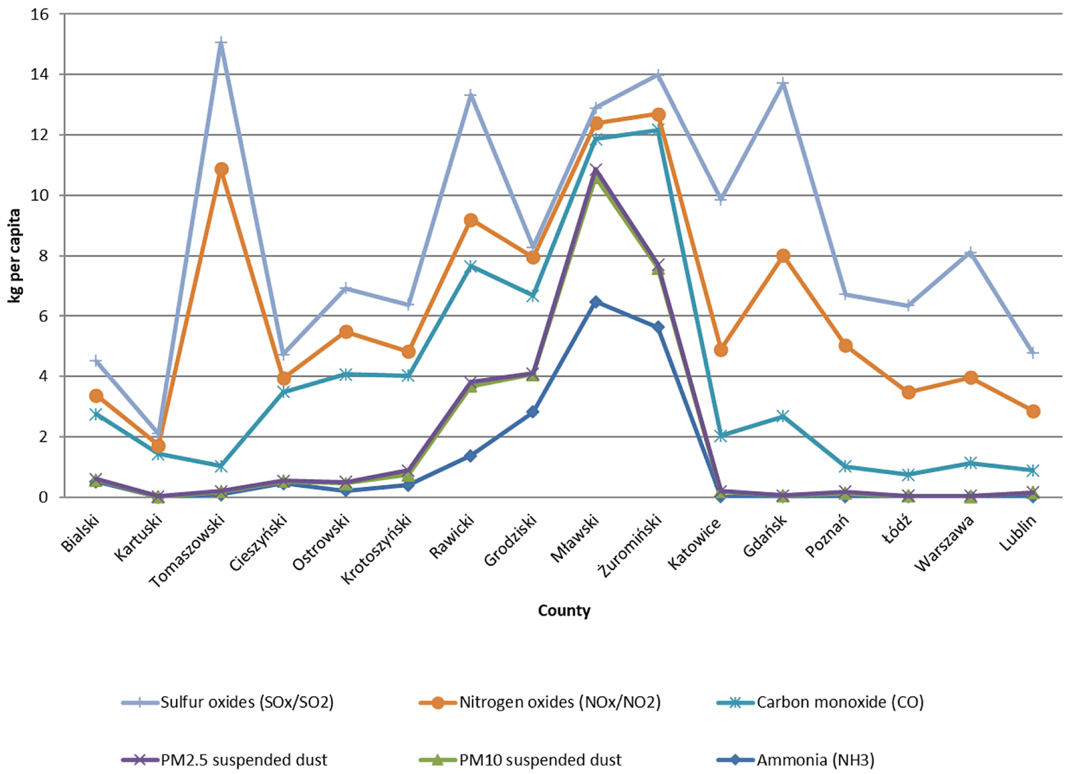

Figure 2. Average emission of the analyzed pollutants in individual counties in the period 2015–2022

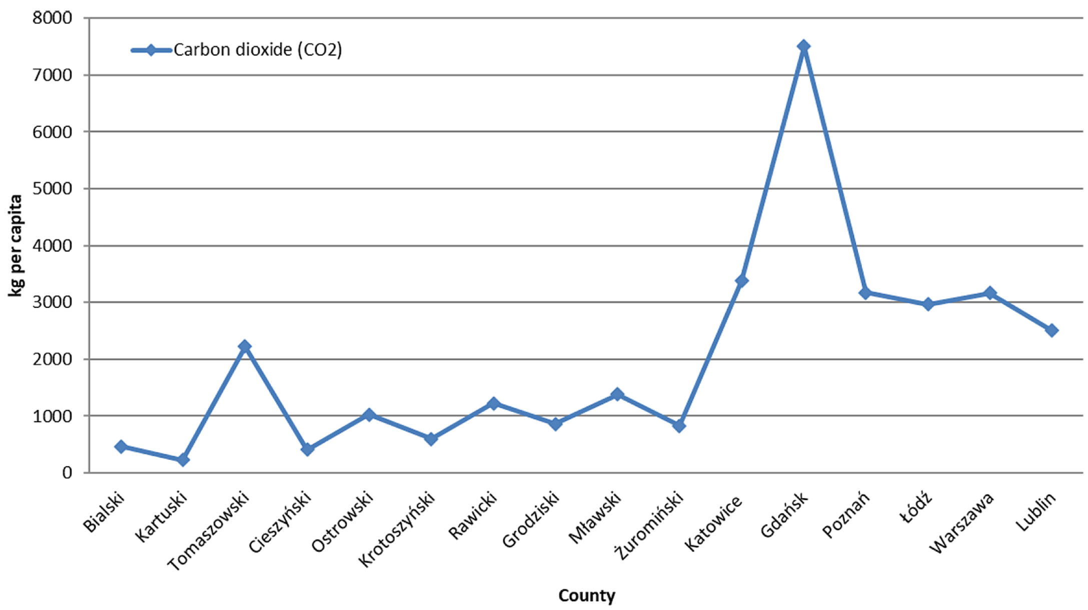

Figure 3. Average carbon dioxide emissions in individual counties in the period 2015–2022

analyzed substances, except for carbon dioxide and benzo(a)pyrene, were characteristic of counties with a large share of industrial farms, mainly those with laying hens, broiler chickens, and turkeys. These counties included Rawicki, Grodziski, Mławski, and Żuromiński.

Analysis of disease development in counties

The frequency of certain diseases varied depending on the type of county (urban or predominantly agricultural pressure) and the county's location. For cancerous diseases, their frequency

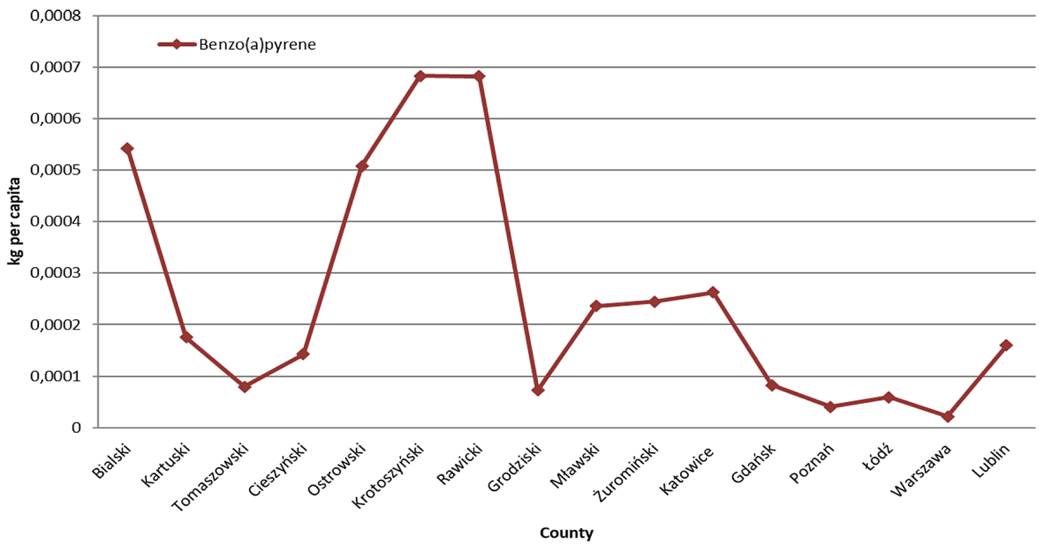

Figure 4. Average benzo(a)pyrene emissions in individual counties in the period 2015–2022

was higher in cities with county rights (Figures 5 and 6). Among the counties with a predominance of agricultural functions, Rawicki County clearly dominated over others in terms of cancer incidence during the period of 2015–2022. In urban counties, the highest incidence was observed in Warsaw and Poznań. This study focused on overall cancer incidence without distinguishing between types. One of the most common malignant tumors worldwide is lung cancer. In 2020, approximately 10 million people died globally from this cause, with nearly 110.000 deaths in Poland [Turner et al., 2020]. The highest incidence is recorded between the ages of 55 and 70. One of the reasons is particulate matter with an aerodynamic diameter below 10 µm. It is noted that even low concentrations of PM2.5 and other air pollutants can induce adverse health effects [Huang et al., 2021].

In contrast, the European Study of Cohorts for Air Pollution Effects (ESCAPE) in 2018, involving 282194 people from 12 cohorts in six European countries, showed a positive association between PM2.5 concentrations and the occurrence of malignant brain tumors in children aged 0–15 years, as well as in adults. Central nervous system tumors are the second most common group of tumors in children in developed countries. A study conducted in Texas, USA, between 2001 and 2009, involving over 1900 children diagnosed with brain tumors, showed an increased risk of astrocytomas in children exposed to moderate concentrations of particulate matter compared to those exposed to low concentrations of these substances. There was also a positive association between exposure to these harmful substances and the occurrence of medulloblastomas [Andersen et al., 2018].

Cases of bronchial asthma were characterized by similar intensity in both counties with agricultural predominance and urban counties (Figures 5 and 6). During the analyzed period of 2015–2022, the highest number of registered cases of this disease occurred in Rawicki County and Poznań. Research conducted in Katowice and its outskirts, analyzing the health effects of children's exposure to air pollution, demonstrated a correlation between concentrations of particulate matter and SO_2 in the air and the incidence of respiratory diseases and allergies. This correlation was confirmed in approximately 20% of children on days when air pollution levels were exceeded multiple times. The same study evaluated the impact of particulate and gaseous air pollutants (SO_2, particulate matter, NO_x, and CO) on the clinical course of asthma and allergies in children. The study involved 1549 children previously diagnosed with these conditions. The authors demonstrated a strong positive influence of SO_2 concentration and particulate matter on the frequency of asthma symptoms in 13% of the children studied [Żywiołowska-Smuga et al., 2023].

The frequency of hypertension did not differ by county type; it was independent of county character. The highest incidence was recorded in Grodziski County, Rawicki County, and the city of Warsaw (Figures 5 and 6). During periods of elevated air pollution levels, symptoms of cardiovascular diseases can significantly intensify, even in individuals receiving appropriate medication. A significant increase in the risk of heart attack, stroke, death due to heart failure, sudden cardiac death, overall mortality, and hospitalization frequency in patients with cardiovascular diseases is recognized. Along with other risk factors, this also accelerates premature aging of blood vessels and promotes atherosclerosis. Environmental pollution has been identified as a risk factor for developing arterial hypertension in children. Research indicates that inhaled nanoparticles from the air penetrate from the lung alveoli into the bloodstream and then into blood vessels [Bont et al., 2023].

For food allergies, a higher incidence was observed in cities (Figures 5 and 6). This may be related to urban residents' dependence on highly processed, lower-quality food and external supplies. In rural areas, some residents grow their own vegetables and fruits, often without using artificial fertilizers and chemical plant protection products. The highest number of cases of food allergies was observed in

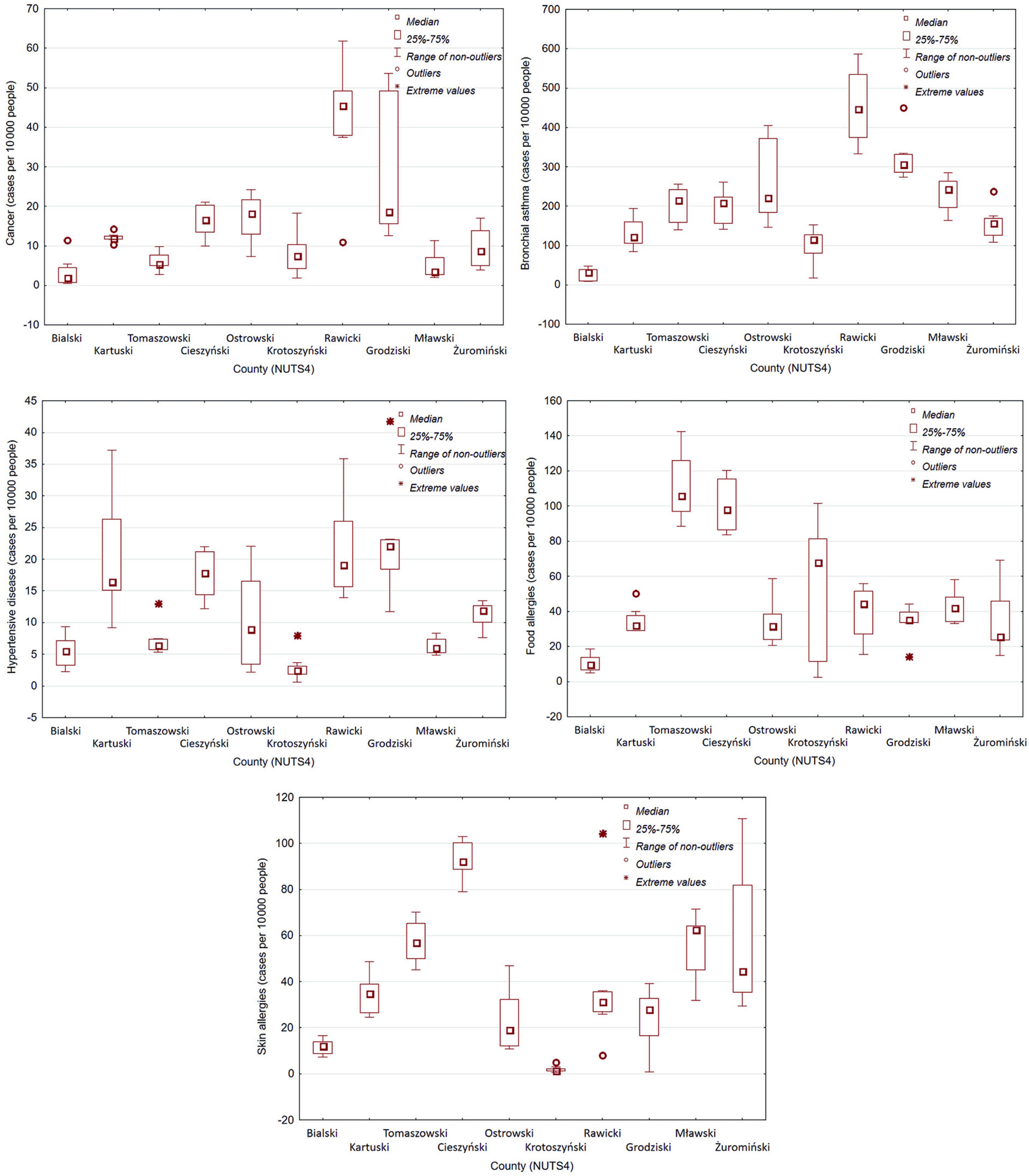

Figure 5. Frequency of occurrence of selected disease entities in the analyzed counties in the period 2015–2022

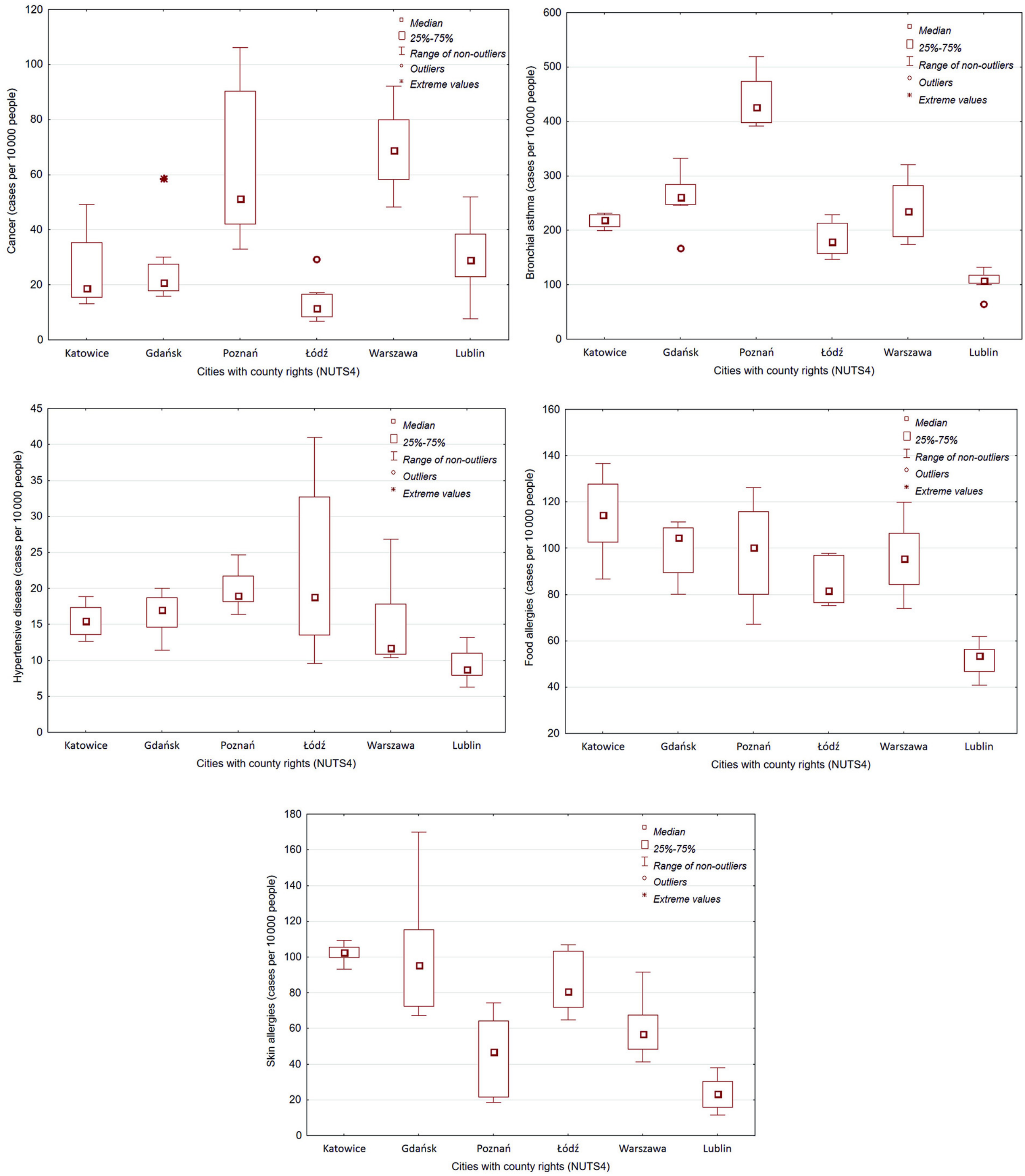

Figure 6. Frequency of occurrence of selected disease entities in the analyzed cities with county rights in the period 2015–2022

Tomaszowski County, Cieszyński County, and the city of Katowice. Food allergy affects approximately 13% of children aged 6–7 years and 11% of children aged 13–14 years in Poland [Samoliński et al., 2019]. Environmental factors such as environmental pollution, including air pollution, viral infections, and changes in dietary habits, contribute to the development of allergies [Lu et al., 2020].

Skin allergies were equally common in counties with predominantly agricultural functions as well as in urban counties. In this regard, Cieszyński County dominated, along with the cities of Katowice and Gdańsk. The prevalence of allergic diseases is increasing worldwide, especially in industrialized countries. In Poland, about 20% of the pediatric population suffers from allergic diseases. Approximately 30–40% of the world's population has at least one allergic disease, with symptoms of allergy diagnosed in 40% of children aged 6–7 years and in about 17% of those aged 13–14 years in Poland. The prevalence of this disease varies by region within the country. According to national data from the Polish Society of Allergology, atopic dermatitis affects 4.7% of children aged 3–16 years. Other studies of Polish children have shown that atopic dermatitis occurs in approximately 9% of children in the 6–7 and 13–14 age groups, and allergic rhinitis affects 24% of children aged 6–7 years and 30% of those aged 13–14 years [Samoliński et al., 2019].

The obtained results also confirm the findings of other authors. Weinmayr [Weinmayr et al., 2010], in rural areas of Bavaria, found that among the study population of children aged 8 to 17, their overall health condition, including not only chronic diseases (asthma, hypertension) but also cancer incidence, varied significantly. The author noted that as many as 74% of the children studied living in agricultural areas without industrial plants had exacerbated asthma compared to the rest of the population residing in urban areas where air quality standards were exceeded. Similar results were observed in other studies showing a high incidence rate among children and adolescents for asthma, hypertension, and cancer in rural areas [Shakerkhatibi et al., 2021].

Nitrogen load per county area

The European Environment Agency states that ammonia emitted in large quantities from animal farms is among the most dangerous substances deteriorating the quality of natural ecosystems [EEA, 2016]. The presence of point and diffuse sources of pollution from agriculture can cause transformations in natural and semi-natural habitats found within agricultural production areas, as well as in associated ecosystems, thereby reducing their attractiveness to certain organisms and even eliminating links in the food chain. One of the main issues in the non-urbanized districts analyzed in this study is ammonia. The estimated atmospheric lifetime of this compound ranges from half an hour to 5 days. During this time, it can be deposited on soil, water, or plants, or transform into the aerosol form NH_4^+, which has a residence time ranging from 5 to 10 days. In subsequent stages, it undergoes wet or dry deposition. Most organisms have adapted to exist in environments with low nitrogen levels. The amount of this compound should not exceed critical values for natural ecosystems. Nitrogen input to different habitats should not exceed 5–35 $kg·ha^{-1}$ annually. Exceeding these critical values can lead to gradual habitat degradation. Lichens are the most vulnerable to nitrogen input, but aquatic habitats and those dependent on water (2–10 $kg·ha^{-1}·year^{-1}$) are also highly susceptible. Nitrogen, originating from agriculture, is present in the environment as ammonia and nitrogen oxides, primarily from animal production. In surface waters, nitrogen excess can lead to eutrophication and excessive biomass growth. Additionally, algae in water bodies readily absorb easily assimilable reduced nitrogen, thereby intensifying their growth significantly. Ammonia in water is highly toxic to aquatic fauna even at levels of 0.2–2 mg/L^{-1}. Intensive animal production, alongside domestic and agricultural waste discharges, can entirely disqualify surface waters in terms of their natural value. Excess nitrogen entering through ammonia and surface runoff can contribute to habitat acidification, leading subsequently to a dystrophic or hypertrophic state [Asman, 2008]. Research conducted by numerous scientific environments on reduced nitrogen forms has proven that under favorable atmospheric conditions, it can travel long distances in the air from emission sources. High nitrogen loads can displace C4 plants capable of binding additional carbon dioxide. Over the long term, high nitrogen loads have a very adverse effect on forest ecosystems. Critical nitrogen loads for forest ecosystems range from 10 to 30 $kg\ N·ha^{-1}$. Potential threats posed by excess nitrogen to forest complexes include: reduced phosphorus assimilation and decreased potassium and magnesium content in plants due to increased nitrogen content; needle drop resulting from impaired potassium, magnesium, and phosphorus assimilation; decreased phenolic compound content, increasing tree susceptibility to pathogens; and decreased diversity of fungi in mycorrhiza with forest vegetation. Forest soils also exhibit high sensitivity to the harmful effects of ammonia. Ammonium nitrogen entering the soil is oxidized to NO_2^- and subsequently to NO_3^-, disturbing the nutritional balance in the soil. However, it should be noted that changes in forest ecosystems can take decades and may be imperceptible over a few years. Some animal species are also highly sensitive to pollution from agricultural sources. Swedish studies have shown that increased nitrogen compound concentrations adversely affect the reproduction of amphibians [Loman and Lardner, 2006].

The nitrogen load from ammonia and nitrogen oxides per 1 hectare of the studied districts was sometimes high and exceeded the tolerance range for all ecosystems (Table 3). Average values in the districts ranged from 0.27 to 38.23 kg·ha^{-1}. For comparison, in intensive individual conventional farms, emissions per farm area range around 26 kg N-NH$_3$·ha^{-1}. Higher nitrogen loads occurred in cities with county rights. Maximum values recorded during the period 2015–2022 reached 47.5 kg·ha^{-1} and were registered in Warsaw. However, this nitrogen load is due to different causes compared to less urbanized districts. The main source of nitrogen in urban areas was nitrogen oxides, which are more commonly produced in industrial processes or emitted from transport, with the N-NH$_3$ to N-NO$_x$ ratio sometimes being 1:522.3. In less urbanized districts, the maximum recorded load during the study period was 17.73 kg·ha^{-1} in Kartuski County.

Characteristics of animal production in provinces

Air pollution by certain substances can affect areas located far from emission sources. This is due to the poor mixing of these substances with atmospheric air, their movement in concentrated streams, and their easy transport by wind. Due to the phenomenon of transboundary pollution spreading, it was decided to analyze disease data at the district level (NUTS4) in relation to livestock production in regions (NUTS2). This is because certain pollution levels may flow from neighboring areas, causing pollution accumulation and increased frequency of diseases. Research by various authors indicates significant nuisance from livestock farms in relation to residential buildings. In some states in the USA, due to the real nuisance, livestock farms must be located no less than 3 km from large city residential areas [Fernanders et al., 2021].

There was significant variation in livestock production in the analyzed provinces, both in terms of individual species of animals per capita in the province and in the trends observed from 2015 to 2022 (Table 4). The highest number of cattle per capita was recorded in the Greater Poland Province. This region also registered the highest upward trend in the number of animals. All provinces observed an increase in the number of cattle.

Pigs also developed most intensively in Greater Poland (WP). In Mazovia Province (MZ), however, the highest increase of about 34% was recorded over 7 years. Meanwhile, there was a decrease in pig farming interest in Lubelskie (LB), Greater Poland, and Silesian Provinces (ŚL).

Table 3. Emission of ammonia and nitrogen oxides expressed in pure nitrogen per surface of the surveyed districts in 2015–2022

County	Value kg N·ha^{-1} (N-NH$_3$+N-NO$_x$)				Ratio N-NH$_3$: N-NO$_x$
	Mean	Min.	Max.	Standard deviation	
Bialski	0.27	0.14	0.42	0.09	1:0.6
Kartuski	13.89	10.68	17.73	2.08	0:1.0
Tomaszowski	4.43	2.67	5.98	1.43	1:65.5
Cieszyński	1.38	1.22	1.59	0.13	1:0.5
Ostrowski	1.02	0.46	1.35	0.25	1:3.4
Krotoszyński	0.70	0.49	1.35	0.26	1:1.2
Rawicki	1.88	1.43	2.20	0.27	1:0.5
Grodziski	4.00	2.79	5.48	0.81	1:0.2
Mławski	3.44	2.16	4.91	0.83	1:0.04
Żuromiński	2.34	1.25	3.79	0.67	1:0.04
Katowice	19.89	13.47	23.37	3.21	1:522.3
Gdańsk	36.87	30.11	45.49	5.14	1:240.3
Poznań	32.31	22.67	40.46	6.15	1:90.1
Łódź	24.93	18.08	40.37	7.93	1:216.7
Warszawa	38.23	24.34	47.35	6.28	1:88.5
Lublin	17.89	15.96	21.92	1.86	1:43.2

Chickens were most commonly kept in the Greater Poland and Mazovia Provinces. The largest increase, however, was noted in the Silesian Province, reaching over 105% in 7 years. In two provinces, Pomeranian (PM) and Silesian, there was a decrease in chicken farming per capita by 12.3%.

Turkey farming has been increasingly popular among breeders in recent years in Poland. Increases in the number of turkeys were noted in almost all analyzed provinces. In Łódź Province (ŁD), it reached nearly 220%. Only in Silesian Province was there a decrease in the number of this species. The highest number of turkeys per capita was registered in Greater Poland, Mazovia, and Lublin Provinces (LB).

Analysis of the suitability of a national emissions database for assessing disease susceptibility

The conducted analyses showed that the distributions of results deviated from the theoretical normal distribution. Therefore, correlations were calculated in two ways – estimating Pearson's linear correlation coefficients and Spearman's non-parametric correlation coefficients. Ammonia pollution was highly ($p < 0.05$) negatively correlated with the occurrence of cancer, hypertension, food allergies, and skin allergies (Tables 5 and 6). The negative correlation clearly indicates that the available KOBIZE database on pollutant emissions is insufficient for analyzing the occurrence of specific diseases in

Table 4. Animal production of the most important livestock species in individual voivodeships in 2015–2022

Province (NUTS2)	Mean	Min.	Max.	Standard deviation	Trends 2015–2022 (2015 = 100%)
Cattle [head per capita]					
LB	0.16	0.15	0.18	0.01	21.28
PM	0.09	0.08	0.10	0.00	19.40
ŁD	0.19	0.18	0.20	0.01	5.06
ŚL	0.03	0.03	0.03	0.00	19.64
WP	0.30	0.26	0.34	0,02	29.14
MZ	0.21	0.20	0.22	0.01	7.20
Pigs [head per capita]					
LB	0.21	0.18	0.24	0.02	-3.02
PM	0.32	0.29	0.36	0.02	3.98
ŁD	0.44	0.36	0.49	0.04	13.23
ŚL	0.05	0.04	0.06	0.01	-9.23
WP	1.13	0.98	1.22	0.07	-12.30
MZ	0.21	0.17	0.24	0.02	33.93
Chicken poultry [head per capita]					
LB	3.09	1.99	4.46	0.80	105.87
PM	2.39	2.02	2.75	0.25	-12.63
ŁD	5.17	4.41	6.05	0.59	36.97
ŚL	1.63	1.40	1.86	0.15	-7.61
WP	9.88	8.15	11.49	1.07	28.64
MZ	6.73	4.68	8.34	1.13	58.05
Turkeys [head per capita]					
LB	0.39	0.16	0.57	0.14	12.5
PM	0.03	0.01	0.05	0.01	36.8
ŁD	0.07	0.03	0.10	0.03	219.7
ŚL	0.03	0.02	0.03	0.01	-32.4
WP	0.76	0.46	1.17	0.27	138.9
MZ	0.35	0.17	0.63	0.14	94.4

Table 5. Pearson's linear correlation coefficients between disease rates and pollutant emissions

Type of contamination	Value	Cancer	Bronchial asthma	Hypertensive disease	Food allergies	Skin allergies
Ammonia (NH_3) [kg per capita]	r	**-0.2586**	**-0.2466**	**-0.2908**	**-0.2698**	**-0.3441**
	p	0.0032	0.005	0.0009	0.0021	0.0001
Benzo(a)pyrene [kg per capita]	r	0.0854	**0.3475**	**0.2226**	**-0.4054**	**-0.2375**
	p	0.3376	0.0001	0.0116	<0.0001	0.0069
Carbon dioxide (CO_2) [kg per capita]	r	**0.2961**	**0.2004**	0.1206	**0.3968**	**0.4199**
	p	0.0007	0.0233	0.175	<0.0001	<0.0001
PM10 suspended dust [kg per capita]	r	-0.1538	-0.0582	-0.1711	**-0.2532**	**-0.4025**
	p	0.0831	0.5142	0,0535	0.0039	<0.0001
PM2.5 suspended dust [kg per capita]	r	-0.0211	0.0767	-0.1647	**-0.2563**	**-0.4049**
	p	0.8132	0.3896	0.0632	0.0035	<0.0001
Carbon monoxide (CO) [kg per capita]	r	0.0657	**0.3261**	**0.2605**	**-0.371**	-0.1054
	p	0.4613	0.0002	0.003	<0.0001	0.2365
Nitrogen oxides (NO_x/NO_2) [kg per capita]	r	0.0064	**0.183**	-0.0605	0.0015	**0.1808**
	p	0.9425	0.0387	0.4974	0.9864	0.0411
Sulfur oxides (SO_x/SO_2) [kg per capita]	r	0.1171	**0.2341**	**0.1828**	0.0409	**0.2703**
	p	0.1879	0.0078	0.0389	0.6466	0.002

Note: r – correlation coefficient, p – test probability value.

Table 6. Spearman's rank correlation coefficients between disease rates and pollutant emissions

Type of contamination	Value	Cancer	Bronchial asthma	Hypertensive disease	Food allergies	Skin allergies
Ammonia (NH_3) [kg per capita]	r	**-0.3281**	-0.1481	**-0.3411**	**-0.5059**	**-0.5924**
	p	0.0002	0.0952	0.0001	<0.0001	<0.0001
Benzo(a)pyrene [kg per capita]	r	-0.0863	**0.2224**	0.1439	**-0.5119**	**-0.3314**
	p	0.3328	0.0116	0.1052	<0.0001	0.0001
Carbon dioxide (CO2) [kg per capita]	r	**0.4169**	**0.2341**	0.1513	**0.2957**	**0.2802**
	p	<0.0001	0.0078	0.0882	0.0007	0.0014
PM10 suspended dust [kg per capita]	r	-0.1014	**0.2208**	-0.1463	**-0.241**	**-0.3488**
	p	0.2546	0.0122	0.0993	0.0061	0.0001
PM2.5 suspended dust [kg per capita]	r	-0.0316	**-0.1994**	**-0.2985**	-0.1725	**-0.2996**
	p	0.7237	0.024	0.0006	0.0516	0.0006
Carbon monoxide (CO) [kg per capita]	r	-0.0168	0.1013	0.1349	**-0.4488**	-0.1505
	p	0.8507	0.2551	0.129	<0.0001	0.0899
Nitrogen oxides (NO_x/NO_2) [kg per capita]	r	**0.3345**	**0.3325**	**0.1944**	**0.2262**	**0.2721**
	p	0.0001	0.0001	0.0279	0.0103	0.0019
Sulfur oxides (SO_x/SO_2) [kg per capita]	r	**0.3037**	**0.2892**	**0.3032**	-0.0017	**0.1935**
	p	0.0005	0.0009	0.0005	0.985	0.0287

Note: r – correlation coefficient, p – test probability value; the marked correlation coefficients are significant with $p < .05000$.

children and youth. The obtained results indicate that emissions of nitrogen and sulfur oxides are indeed associated with increased morbidity, although at a low level. Many authors have clearly demonstrated the impact of the analyzed pollutants on the occurrence of specific diseases, including in children and youth [You et al., 2021].

Among the associations between the occurrence of diseases and the intensity of livestock farming, only one rank correlation proved to be significant ($p < 0.01$), namely the correlation between the occurrence of cancer and poultry density (Table 7). However, this is a negative correlation, which confirms the limited

Table 7. Pearson's linear correlation coefficients and Spearman's rank correlations between the frequency of diseases and the number of farm animals

Type of disease	Value	Pearson's linear correlations		Spearman's linear correlations	
		Pigs	Poultry	Pigs	Poultry
		[head·km²]			
Cancer	r	-0.0368	-0.3779	-0.2588	-0.5618
	p	0.8925	0.149	0.3331	0.0235
Bronchial asthma	r	-0.3191	-0.4823	-0.3029	-0.2441
	p	0.2283	0.0585	0.2541	0.3622
Hypertensive disease	r	0.005	-0.319	-0.3294	-0.3235
	p	0.9853	0.2286	0.2128	0.2216
Food allergies	r	-0.2467	-0.4326	-0.2941	-0.2324
	p	0.3571	0.0942	0.2688	0.3865
Skin allergies	r	-0.2102	-0.313	-0.3618	-0.3206
	p	0.4346	0.2378	0.1686	0.2260

Note: r – correlation coefficient, p – test probability value; the marked correlation coefficients are significant with $p < .05000$.

Table 8. Pearson's r correlation coefficients for selected diseases and the level of animal production in provinces

Variables	Cattle	Pigs	Chicken poultry	Lying hens	Turkeys	Ducks	Poultry
	[head per ha]						
Cancer	0.264791	0.188641	0.228679	0.275320	0.282782	0.148402	0.268852
Bronchial asthma	0.486090	0.545822	0.470592	0.599232	0.341988	0,386301	0.473068

Note: the marked correlation coefficients are significant with $p < .05000$.

usefulness of the KOBIZE database for analyzing the occurrence of diseases in children and youth in relation to recorded pollution.

The conducted correlations for two diseases – cancer and bronchial asthma – with the numbers of individual species of animals at the province level indicate positive correlations (Table 8). Two diseases were selected for analysis, whose frequency may be associated with emissions of pollutants from livestock production. Also selected were animal species that are intensively developed in the regions. Some of the coefficients are low but statistically significant. Therefore, it can be presumed that livestock production may directly contribute to the development of cancer and asthma in children and adolescents up to 18 years old in the studied regions. This also confirms the preliminary assumption that the development of certain diseases is influenced by regional emissions as well as local ones.

CONCLUSIONS

Based on the obtained results, the following conclusions can be drawn:

1. In terms of the amount of pollutants emitted per capita in selected counties, Rawicki County, Mławski County, and Żuromiński County stood out significantly, where high levels of all analyzed air pollutants were recorded. Grodziski County also characterized by higher emissions. In Tomaszowski County, one of the higher emissions of sulfur oxides and nitrogen oxides was recorded.
2. The frequency of occurrence of specific diseases among children and adolescents depended on the type of county (urban or predominantly agricultural) and the county's location. In the case of cancer, its frequency was higher in counties with city rights. Among counties predominantly agricultural, Rawicki County clearly dominated, where the highest incidence

of cancer was recorded in the period 2015-2022. Regarding urban counties, the highest incidence was in Warsaw and Poznań.

3. Incidence of bronchial asthma showed similar intensity in both predominantly agricultural counties and urban counties. In the analyzed period 2015–2022, the highest number of registered cases of this disease occurred in Rawicki County and Poznań. The frequency of hypertension did not differ by county type and was independent of county character. The highest incidence was noted in Grodziski County, Rawicki County, and the city of Warsaw. For food allergies, higher incidence was observed in cities. Skin allergies occurred equally frequently in predominantly agricultural counties and urban counties. The highest number of skin allergies was registered in Cieszyński County and Katowice.
4. Data obtained from the KOBIZE database are not sufficient for studying the incidence of youth diseases such as cancer, bronchial asthma, hypertension, food allergies, and skin allergies. Potential reasons include the specific characteristics of the analyzed population group (0–18 years old), insufficient data in the database, which includes only facilities of a certain scale of production. The database does not include small, numerous, and dispersed enterprises that are sources of air pollution emissions, or underestimation of emissions in reports by reporting entities.
5. Analyses of nitrogen load on soils from NH_3 and NO_x emissions indicate significant differences across counties. The highest average nitrogen load, exceeding critical values for all natural ecosystems, was recorded in Warsaw and Gdańsk, reaching up to 38.23 kg $N \cdot ha^{-1}$. In less urbanized (non-urban) counties, the average load was significantly lower, not exceeding 13.89 kg $N \cdot ha^{-1}$ (Kartuski County). However, the proportions of NH_3 nitrogen to NO_x nitrogen were markedly different. In urban counties, the ratio of $N\text{-}NH_3 : N\text{-}NO_x$ was as high as 1:522.3. In less urbanized counties, the amount of NO_x nitrogen was often lower than NH_3 nitrogen, with ratios as low as 1:0.04.
6. Statistical analyses showed statistically significant relationships between selected species of animals in provinces and the incidence of cancer and bronchial asthma in counties. Sometimes these relationships were not large, but they indicate connections between livestock production, and consequently the emission of specific air pollutants, with the occurrence of certain diseases. This is related to the migration of pollutants between regions.

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