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# CHEMICAL STATE AND ECOLOGICAL ASSESSMENT OF ATMOSPHERIC AIR QUALITY

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***Abstract***

*Research was conducted on the state of atmospheric air in the region of the village of Voyvodino, Maritsa municipality, and Plovdiv district, Bulgaria, influenced by industrial sources of impact. The indicators of main pollutants of the atmospheric air above populated areas were measured (PM10, SO2, CO, NO2, NO, O3, Benzene, Toluene, m-p-xylene, o-xylene). The research was carried out according to established standards. The chemical and ecological state is presented. The air quality index is analyzed. An ecological assessment of the state of atmospheric air was carried out. The risk to human health, the impact of pollution on living organisms, on protected species, habitats and territories was assessed. Measures to improve the ecological state of the air have been identified.*

***Key words**: air pollution, air quality index, chemical state, ecological assessment, industrial impact.*

## INTRODUCTION

Clean air is a fundamental human right. Air pollution is identified as the biggest environmental threat to health and a leading cause of non-communicable diseases such as heart attack and stroke. According to World Health Organization (WHO), "there are no safe levels of air pollution". The organization identifies air pollution as one of the risk factors for early mortality worldwide (WHO, 2021; EEA, 2024). Article 6 of Directive 2016/2284/EU requires each EU Member State to submit a national air pollution control program (Directive (EU) 2016/2284 of The European Parliament and of the Council, 2016). Air pollution emissions have decreased significantly in recent decades. Nevertheless, problems with pollutant emissions from individual industries persist (Directive (EU) 2024/2881 of the European Parliament and of the Council, 2024; Nunez et al., 2024).

There are different systems for ambient air quality in individual countries and regions. Each system uses its own hazard index, pollution concentration, and time of measurement. This makes it difficult for the average consumer to navigate between the systems of different countries.

The United States Environmental Protection Agency (US-EPA) defines the Air Quality Index (AQI) – a number used to inform the public about the level of air pollution and to predict the expected level of pollution. The AQI is based on measurements of particulate matter emissions (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide, and carbon monoxide. The AQI values indicate 6 levels of air pollution, each of which is color-coded and provides information on possible health effects (Table 1). The AQI provides the public with important information about the state of air pollution over the past five decades (Sheikh, 2019; Horn & Dasgupta, 2024).

The European Environment Agency is developing and implementing the European Air Quality Index (EAQI) for the countries of the European Union. The (EAQI) is based on the measurement of the following main pollutants in ambient air: PM10, PM2.5, ozone, nitrogen dioxide and sulphur dioxide. The scale for each pollutant is different, and for PM10 it is presented in Table 2. The individual zones are based on the relative health risk, as defined by the World Health Organization, associated with short-term exposure to the pollutants. The Air Quality Index is not a tool for checking compliance with air quality standards but allows users to orient themselves on the quality of ambient air in populated areas or in places of travel and work.

These indices raise public awareness of the importance of clean air and help build broader support for air quality and emissions regulations. As regulatory constraints change, both indices change, keeping them relevant and alive (Sheikh, 2019; EAQI, 2024).

Table 1. Air Quality Index (AQI) values and corresponding condition color scale

| Values | Condition color scale |
|---|---|
| 0-50 | good |
| 51-100 | moderate |
| 101-150 | unhealthy for sensitive individuals |
| 151-200 | unhealthy |
| 201-300 | very unhealthy |
| 300+ | dangerous |

Table 2. European Air Quality Index (EAQI) values for PM10 and the corresponding condition color scale

| EAQI, PM10, µg/m$^3$ | Condition color scale |
|---|---|
| 0-20 | good |
| 20-40 | fair |
| 40-50 | moderate |
| 50-100 | poor |
| 100-150 | very poor |
| 150-1200 | extremely poor |

There is growing interest in the contribution of fine particulate matter to air quality, climate and human health. The negative effects of these particles depend mainly on their chemical composition and physicochemical properties (Lei et al., 2024).

In aerosol science, heavy metal pollution is also a current problem, especially when it comes to road dust in densely populated cities. The main sources of heavy metals in road dust are industrial activities (32.05%), transport (34.90%), and a combination of transport, industrial, and construction activities (33.05%) (Ma et al., 2025).

The increase in public health incidents resulting from air quality, as well as environmental degradation, is prompting authorities and experts to improve and seek new ways to monitor air quality and "adequately" deploy air quality sensors (Chaudhuri & Roy, 2024).

Air pollution continues to have a negative impact on the health of Europeans. A significant part of Europe's population lives in cities where EU air quality standards to protect human health are often exceeded. These health impacts shorten lives, increase economic and medical costs and reduce work productivity. The pollutants with the most serious impact on human health are particulate matter, nitrogen dioxide and ground-level ozone. According to the latest EEA estimates, at least 239,000 deaths in the EU in 2022 were due to exposure to PM2.5 pollution above the WHO recommended limit 5 µg/m$^3$. 70,000 deaths were due to exposure to ozone pollution, and 48,000 deaths were due to exposure to nitrogen dioxide pollution. These deaths could have been avoided if WHO guidelines had been followed (EEA, 2024a).

For Bulgaria, deaths due to long-term exposure to fine particles decreased by 53% between 2005 and 2022. Yield losses due to ozone exposure at the national level in 2022 were estimated at 1.98% yield loss for wheat and 4.22% yield loss for potatoes. This represents an economic loss of approximately €26 million for wheat and €1.6 million for potatoes (EEA, 2024a).

Air pollution has a negative impact on both terrestrial and aquatic ecosystems, degrading the environment and reducing biodiversity. Different pollutants damage ecosystems in different ways. Ozone (secondary air pollutant) damages crops, forests and plants by reducing growth rates, lowering yields and affecting biodiversity. Reduced yields of wheat and potatoes demonstrate the negative impact of ozone layer, with losses expected to amount to €1.3 billion for wheat and €680 million for potatoes across Europe by 2022.

Nitrogen deposition on land and in water bodies is mainly caused by ammonia from agricultural activities and nitrogen oxides from combustion processes. In water bodies, increased nitrogen content contributes to eutrophication, characterized by algal blooms and less available oxygen due to excess nutrients. In sensitive terrestrial ecosystems, such as grasslands, exceeding critical loads for nitrogen deposition can lead to the loss of sensitive species. At the same time, species requiring high levels of nitrogen may develop excessively, which can alter the structure and function of the ecosystem.

Sulfur dioxide can also have a significant negative impact on ecosystems. Its deposition can lead to changes in the chemical composition of soil, lakes, rivers and seas. This can cause acidification, which disrupts ecosystems and leads to a loss of biodiversity. A major source of $SO_2$ is coal-based energy.

Heavy metals are toxic pollutants that travel long distances in the atmosphere and are deposited in ecosystems. They accumulate in soils and subsequently bioaccumulate and biomagnify in the food chain (i.e., concentrations of substances in animal tissues increase progressively through the food web). The main sources of heavy metals include the processing and mining industries, energy, and road transport.

Europe's waters continue to be affected by chemicals, mainly from atmospheric pollution from coal-fired power generation and diffuse pollution from agriculture. The main pollutants in surface waters are related to pollution from diffuse sources, such as atmospheric deposition (52%) (Impacts of air pollution on ecosystems in Europe, 2024)

The latest data confirms once again that Europeans remain exposed to concentrations of air pollutants well above the World Health Organization (WHO) recommended levels. Nearly three quarters of European ecosystems are exposed to harmful levels of air pollution (EEA, 2024).

The main indicators characterizing the quality of atmospheric air in the ground layer are suspended particles, fine dust particles, sulfur dioxide, nitrogen dioxide and/or nitrogen oxides, carbon monoxide, ozone, lead (aerosol), benzene, polycyclic aromatic hydrocarbons, heavy metals - cadmium, nickel and mercury, arsenic (RIAA, 2023; 2024).

The present research concerns the region of Plovdiv, Bulgaria. The territory of the city is urbanized, with high density of construction, intensive automobile traffic and industrial activity. The main factors of air pollution are combustion processes, transport, the condition of the road and adjacent infrastructure and finally the industrial sector. During the summer period, construction and repair-construction activities acquire significant importance for atmospheric air pollution.

Specific climatic conditions have a significant impact on the quality of atmospheric air. The Plovdiv Field is alluvial lowland formed by the Maritsa River and its tributaries. There is a so-called trough-shaped morphostructure, at the "bottom" of which the city is located. Plovdiv is located on six syenite hills. These natural features significantly contribute to the adverse meteorological conditions associated with temperature inversions, fogs along the Maritsa River, long periods of drought and a large number of days a year with calm weather, reflecting on the dispersion of locally emitted pollutants. (RIAA, 2023; 2024).

## MATERIALS AND METHODS

The measurements were carried out hourly with a Mobile Automatic Station in 2023 in spring (13 days), summer (14 days) and autumn (16 days) (Figure 1). The following main indicators of atmospheric air quality were recorded – Particulate matter, Sulphur dioxide, Carbon monoxide, Nitrogen dioxide, Nitrogen monoxide, Ozone, Benzene, Toluene, m-p-xylene, o-xylene. The main characteristics of these indicators are presented in Table 3. The total number of samples taken is as follows – 3116 for spring, 3240 for summer and 2784 for autumn. The production activities carried out in the study area are in the field of metalworking, chemical and food industry.

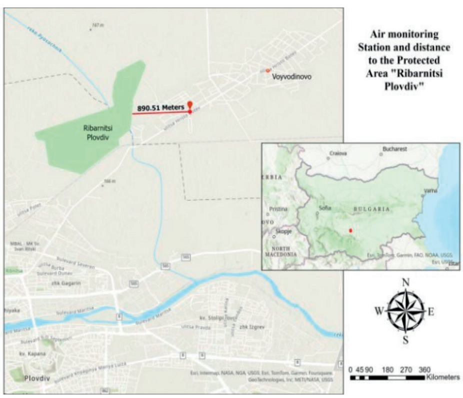


Figure 1. Location of the air monitoring station and the protected area "Ribarnitsi", Plovdiv

The dust emissions formed are of short-term local nature, with a low discharge height and high gravitational deposition velocity (RIAA, 2023; 2024).

Table 3. Main characteristics of the measured indicators

| Indicator | Unit of measure | Analysis method | Uncertainty | Standard, μg/m³ |
|---|---|---|---|---|
| Particulate matter | μg/m³ | BDS EN 16450:2017 | U=14.7% | ADN – 50<br>AAN – 40 |
| Sulphur dioxide | μg/m³ | BDS EN 14212:2012 | U=3.70% | AHN – 325<br>AND – 125 |
| Carbon monoxide | μg/m³ | BDS EN 14626:2012 | U=3.75% | HHPS – 10 |
| Nitrogen dioxide and Nitrogen oxides | μg/m³ | BDS EN 14211:2012 | U=3.74% | AHN – 200<br>AAN – 40 |
| Ozone | μg/m³ | BDS EN 14625:2012 | U=3.60% | HHPS – 120 |
| Benzene | μg/m³ | BDS EN 14662-3:2015 | U=4.5% | AAN – 5 |

Legend: ADN – Average daily norm for the protection of human health; AAN – Average annual norm for the protection of human health; AHN – Average hourly norm for protecting human health; HHPS – Human health protection standard (maximum eight-hour average value within 24 hours); Regulation No. 12 (2010).

The norm for the PM10 indicator is average daily, that is, the registered hourly values during the day are averaged, which does not imply exceedances of the average daily values, due to the fact that the likely intensive transport traffic is in the period 08.00 – 17.00. Based on the results obtained in 2023, an assessment of the pollution levels in the studied area was carried out in accordance with the requirements of the currently current Regulation No. 12 of 2010 (Regulation No. 12, 2010).

## RESULTS AND DISCUSSIONS

The measurements in 2023 were carried out with a Mobile Automatic Station in spring, summer and autumn, as indicated in the previous chapter. The choice of the location of the station is in accordance with the requirements of Regulation No. 12 of 2010 (Regulation No. 12, 2010). The monitoring station is a non-urban background station, located more than 5 km from the city of Plovdiv (Figure 1). Point sources of emissions from industrial sites are located more than 5 km from the station area. In the area studied there are both industrial enterprises and residential buildings.

Emission sources can be combustion processes; road transport; other mobile sources and machinery; natural processes - adverse weather conditions that contribute to the accumulation and hinder the dispersion of pollutants.

The results obtained as a range of values are presented in Table 4.

Table 4. Interval of measured daily average concentrations for the reported indicators by season

| Indicator | Value range, μg/m³ | | |
|---|---|---|---|
| | spring | summer | autumn |
| Particulate matter | 9 ÷ 48 | 15 ÷ 33 | 23 ÷ 73 |
| Sulphur dioxide | 8 ÷ 14 | 1 ÷ 10 | 7 ÷ 16 |
| Carbon monoxide | 0.1 ÷ 0.4 | 0.2 ÷ 0.4 | 0.2 ÷ 0.4 |
| Nitrogen dioxide | 7 ÷ 23 | 9 ÷ 15 | 10 ÷ 34 |
| Nitrogen monoxide | 1 ÷ 8 | 1 ÷ 2 | 1 ÷ 12 |
| Ozone | 30 ÷ 67 | 37 ÷ 66 | 17 ÷ 53 |
| Benzene | 0.20 ÷ 0.60 | 0.12 ÷ 0.25 | 0.27 ÷ 0.40 |
| Toluene | 0.17 ÷ 1.35 | 0.24 ÷ 0.70 | 0.39 ÷ 0.58 |
| m-p-xylene | 0.14 ÷ 0.67 | 0.27 ÷ 0.61 | 0.34 ÷ 2.10 |
| o-xylene | 0.06 ÷ 0.23 | 0.01 ÷ 0.17 | 0.09 ÷ 0.49 |

The only exceedances of the average daily concentrations were for PM10 during the autumn period – 56, 61, 70 and 73μg/m³ at a norm of 50μg/m³. All other measured average daily indicators have values in accordance with the regulatory requirements.

The hourly exceedances of the norm for the average daily concentration (50 μg/m³) are only for the PM10 values for the measurement intervals during the 3 seasons (Table 5). Of the total 1032 hourly PM10 values obtained for the measurements made during the spring, summer and autumn seasons, 10.17% (105 values) indicate poor air quality; 1.07% (11 values) indicate very poor air quality, and 0.48% (5 values) indicate extremely poor air quality (Table 5). The main PM10 assessment indicators for ambient air quality are summarized in Table 5.

The lower and upper assessment thresholds for the average daily and annual values are two exceedances of the upper threshold for spring, one for summer and 10 for autumn. The average annual norm of the upper threshold is exceeded based on the results obtained for the three seasons 31.30 μg/m³.

This exceedance is below the average daily norm for the protection of human health (50 μg/m³) and below the average annual norm for the protection of human health (40 μg/m³) from the legislation in Bulgaria (Regulation No. 12, 2010).

With increasing temperatures, PM10 values decrease, which is why lower maximum short-term (60 minutes) single values and average daily values are recorded during summer days.

Table 5. Summarized exceedances of PM10 according to the main assessment standards for ambient air quality

| Criteria | Overshoots, µg/m³ | | |
|---|---|---|---|
| | spring | summer | autumn |
| Maximum hourly values measured, µg/m³ | 198, 461 | 57, 85, 52, 88 | 60, 53, 94, 114, 70, 84, 71, 150, 55, 63, 69, 139, 178, 159 |
| Number of hourly exceedances of the average daily norm (over **50** µg/m³) | 10 | 5 | 107 |
| Average daily norm for the protection of human health - **50** µg/m³ (exceeded no more than 35 times per calendar year) | - | - | 56, 61, 70, 73 |
| Lower and upper assessment thresholds - norm **25 – 35** µg/m³ **average daily value** (exceeded no more than 35 times per calendar year) | 43, 48 | 36 | 43, 47, 56, 47, 61, 40, 42, 49, 70, 73 |
| Lower and upper assessment thresholds - norm **20-28** µg/m³ **average annual value** | **31.30 µg/m³ – upper assessment threshold exceeded for the period spring, summer and autumn** | | |
| Average annual norm for the protection of human health - **40** µg/m³ | – | | |

Legend: EAQI – poor, very poor, extremely poor; Regulation No. 12 (2010).

In calm weather (wind speed < 1.5 m/s) and fog, pollutants are retained and accumulated. The number of days and nights with calm weather during the periods of measurements taken is respectively: 7 in spring, 14 in summer and 15 in autumn. As humidity increases, the levels of pollutants in the air decrease. According to the PM10 indicator, maximum short-term values were not recorded only at 100% relative humidity. Such are only 5 days of the reporting periods. The hourly and daily average exceedances recorded during the autumn period from the measurements of the quality of the ambient air in the range of 20.00-07.00 hours of the day could be the result of the operation of wood and coal-fired heating appliances, although the night temperatures in October and the reporting period are not low, but also as a result of the certain meteorological conditions that hinder the dispersion of pollutants (calm, others). Overall, for the year - the unfavorable climatic conditions in the region - more than 50% days a year with calm weather and over 75% days a year with inversion processes, lead to the retention of the formed relatively high background concentrations of PM10.

The impact of the obtained values of the monitored air quality parameters on the health of the population was assessed on the basis of the Environmental Protection Act, the Clean Air Act, the Health Act, and Regulation No. 12 from 2010 on standards of harmful substances in the ambient air of populated areas. (AAPL, 1996; Law on environmental protection, 2002; Law of Health, 2005; Regulation No. 12, 2010).

The exceeded average daily values indicate acceptable ambient air quality, moderately dangerous for very sensitive people with respiratory diseases. The hourly standards exceed the average daily standard by 1.02 – 9.22 times. Of the total 1032 hourly values for PM10 obtained, 8.72% of the values (90 values) indicate a moderate state of ambient air quality, with a risk for very sensitive people with respiratory diseases; 0.39% (4 values) indicate an unhealthy state of ambient air quality for sensitive groups of the population; 0.1% or 1 value is dangerous for the entire population. Even though the relative share of the results for the most part indicates a good state of AQI (below 50 µg/m3; 90.60%, 937 values), the obtained exceedances are not to be ignored, especially those associated with risks to human health.

PM is not a single substance, but a mixture of pollutants with different chemical properties and varying physical properties such as size and surface area, which has a major impact on the distribution and deposition in the respiratory tract. A significant relationship has been found between high PM concentrations and mortality, hospital admissions for respiratory diseases, and person-days of bronchodilator use.

The resulting exceedances have a negative impact on the health of the population. The increase in PM levels is also expected to affect cultural, household, agricultural and other economic activities. All this requires immediate measures to be taken to eliminate the sources of pollution and provide permanent control by the control bodies, aimed at achieving good ecological status for PM10 and the overall quality of air.

The protected area BG0002016 "Fisheries Plovdiv" is located near the assessed site (Figure 1; Natura 2000).

The objectives of declaring the protected area are related to the protection and maintenance of the habitats of the bird species specified in the Biodiversity Act to achieve their favorable conservation status, as well as the restoration of the habitats of those bird species for which it is necessary to improve their conservation status (Biodiversity Law, 2002).

Of the total 43 protected species, 39 bird species are concentrated in the protected area (c), 15 species are wintering (w, non-migratory species) and 3 species are breeding in the protected area (r). Two of the species are not sufficiently studied in the protected area but are represented (p; *Ardea cinerea* and *Tachybaptus ruficollis*). Overall, the quality of data on birds in the protected area is good (G), with minor exceptions (2 cases with insufficient study (DD) and one with moderate (M)). Of the 43 protected bird species, the International Red Data Book includes: 33 species with the category Least Concern (LC); 4 species with the category Vulnerable (VU); 5 species with the category Near Threatened (NT). 18 species are included in Appendix 2 of the Bern Convention; 16 species – in Appendix 3 and respectively 2, 23 and 1 species are included in Appendix 1, 2 and 3 of the Bonn Convention. In CITES – Appendices 1 and 2, 1 and 5 species are included respectively, and in the Birds Directive – 16 species in Annex 1 and 3 and in Annex 3. The Red Book of the Republic of Bulgaria includes 28 species with the following protection categories: vulnerable (VU) – 12 species; endangered (EN) – 8 species; critically endangered (CR) – 7 species; near threatened (NT) – 1 species. The Biodiversity Act protects: 16 species included in Annex 2; 26 species included in Annex 3 and 1 species included in Annex 4 (Biodiversity Law, 2002; Biserkov et al., 2015; Golemanski et al., 2015; Red List of Peev et al., 2015; RLTS, 2025;).

Increasing PM10 levels are expected to worsen the living conditions of these species and their ability to inhabit the protected area.

Air pollutants of various anthropogenic origins have an adverse effect on plant and animal life. These effects occur not only at high concentrations, but also at values close to or even below the maximum permissible concentrations. Phytotoxicity depends on many factors such as the type of plants, duration of exposure to pollutants, nature of pollutants, and others. As a result, a number of consequences are observed, such as disruption of normal metabolism, disruptions in the process of photosynthesis, and even death of plants and animals (Chuturkova, 2015).

## CONCLUSIONS

The resulting exceedances have a negative impact on the health of the population. The increase in PM levels is expected to also affect the cultural, household, agricultural and other economic activities carried out. All this requires immediate measures to be taken to eliminate the sources of pollution and provide permanent control by the control bodies, aimed at achieving a good ecological status for PM10 and air quality in general.

The increase in PM10 levels is expected to worsen the living conditions of people, plants and animals (including those living in the vicinity of the protected area).

Particulate matter is a serious problem. To reduce the impact of this pollutant on atmospheric air, the following are necessary: modernization and quality maintenance of the road surface; control of construction activities; quality washing of road arteries; landscaping of open areas.

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