

AIR POLLUTION STUDY FOR BULGARIAN PART OF BULGARIA–ROMANIA TRANS-BORDER AREA

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ABSTRACT: The paper presents statistical analysis of air pollutants in the Bulgarian part of trans-border BG–RO area. Air contamination characteristics and norms are also presented and commented in the present survey. Ecological monitoring system in the BG–RO trans-border area is described. Particulate matter (PM), nitrogen dioxide (NO₂) and ground-level ozone (O₃), are now generally recognised as the three pollutants that most significantly affect human health. Because of this, further in the paper concentration levels of these three pollutants are statistically studied, based on official monitoring data. Results are graphically presented and commented. Ambient air quality in the BG–RO trans-border area is better today than it was two decades ago, but despite improvements, pollutant levels still show significant adverse effects on human health and the environment. To improve air quality in the future, it will be necessary to increase the use of "green" and more efficient technologies in terms of thermal insulation of buildings, as well as the use of alternative sources of fuel in the household and transport, use of best available technology in the industry, green roofs in urban areas and more. Also it is necessary more precise mathematical modeling of the data series, which take into account more factors to be developed and used for better understanding and forecasting the air contamination processes.

KEY WORDS: Air contamination, Concentration levels of air pollutants PM, NO₂, O₃, Statistic analysis, Trans-border BG–RO area.

1 INTRODUCTION

The Bulgarian-Romanian (BG–RO) border has a length over 631 km, of which around 470 km are formed by the river Danube. The border begins in the west at the tripoint formed with the Serbian border, near the town of Bregovo in Bulgaria, and follows the river as far as the cities of Silistra (Bulgaria) and Călărași (Romania). Beyond this

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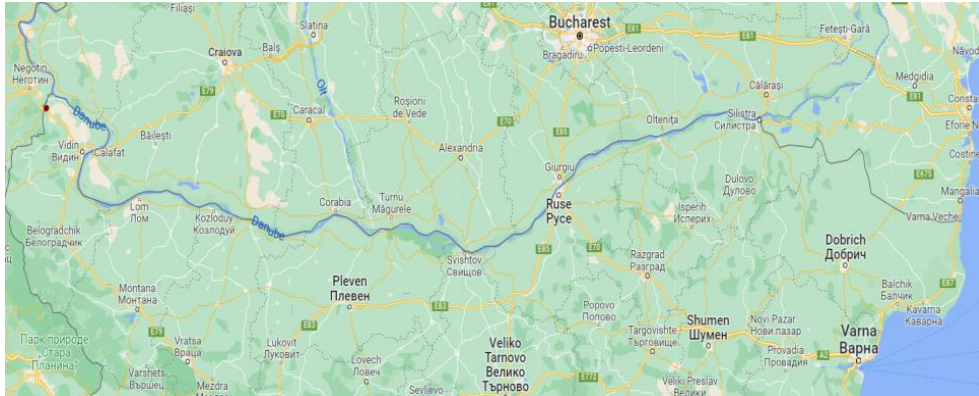


Fig. 1: Map of BG–RO trans-border area [1–3].

point, to the east the border becomes terrestrial until it reaches the Black Sea between the towns of Shabla (Bulgaria) and Mangalia (Romania) (See Figs. 1, 2).

Bulgarian part of the BG–RO transborder area is a part of the Danube hilly plain and it is located between the Danube River in the north and the Pre-Balkans in the south, extending to the Timok River in the west and the Black Sea in the east. It



Fig. 2: Map of Bulgaria-Romania trans-border area: in green – Romanian districts (Mehedinti, Dolj, Olt, Teleorman, Giurgiu, Calarasi, Constanta); in orange – Bulgarian districts (Vidin, Montana, Vratsa, Pleven, Veliko Tarnovo, Ruse, Razgrad, Silistra, Dobric) [1–3].

extends over the territory of 9 Bulgarian regions – Vidin, Montana, Vratsa, Pleven, Veliko Tarnovo, Ruse, Silistra and Dobrich. Through Dobruja in the northeast of Bulgaria it connects with the Eastern European Plain in Romania. The Romanian plain which is north to the river Danube is often called Wallachian lowland. Romanian districts of this area are Mehedinti, Dolj, Olt, Teleorman, Giurgiu, Calarasi, Constanta (see Figs. 1, 2) [1–3].

The weather of the BG–RO transborder area is usually temperate, continental, arid [3]. The climate here can be described as moderate-continental. Thus the climate of the area around Danube river (north and south) is determined by its considerable openness to the northeast and the relatively uniform relief. The average annual temperature varies from 10°C to 12.2°C in different parts of the plain. The lowest winter average monthly temperatures are in the month of January. Due to the unimpeded invasion of cold air masses in winter, cold weather is established in the plain for a long time, often accompanied by persistent temperature inversions. This is the reason that even at a low altitude of the area about 100 - 200 m, the January temperatures are negative. In the eastern part, due to the climatic influence of the Black Sea and less pronounced temperature inversions, the winter is significantly milder. The average January temperature for the plain is around -3°C. During the rest of the seasons, oceanic air masses from the west and northwest prevail. The highest summer temperatures occur in July, reaching 23–24°C in the western part of the plain. The highest annual temperature amplitude (25°C) is measured in the Danube Plain.

Annual amount of precipitation in the area is 400–600 mm. Summer is dry, and in winter the snow cover is unstable. In the area precipitation amounts are greatest in the western and southern parts of the plain 600–650 mm. Gradually in the north and east the amount of precipitation decreases to 550–500 mm. They are the smallest along the banks of the Danube River, due to the rain shadow caused by the Carpathians in Romania and Stara Planina in Bulgaria, as well as in Dobruja (45–50 mm), due to the strengthening of the steppe features of the climate. The precipitation regime is characterized by the highest precipitation amounts in summer and an average monthly May-June maximum and February minimum. The duration of the snow cover is 40–50 days a year. West, north-west and north winds prevail in BG–RO transborder area. The main water artery of the area is of course the Danube River, which crosses it from west to east. Other big rivers, all its tributaries are: Jiu, Olt, Vedy, Argesh, Ialomitsa, Siret, etc. left, in Romania and Lom, Ogosta, Iskar, Vit, Osam, Yantra, Rusensky Lom and others right, in Bulgaria. All of them have a snow-rain recharge, with a pronounced spring high water and summer low water [3]. Frequent and prolonged fogs are characteristic of the BG–RO trans-border area along the Danube River.

2 AIR CONTAMINATION CHARACTERISTICS AND NORMS

Air pollution is a general term for a condition in which chemical and biological substances are introduced into the air that are not part of its natural composition, or the amount of a constituent contained in its natural composition is excessively high [4]. The words “contamination” and “pollution” reflects the fact that these substances to one degree or another are harmful to human, animal and plant life. Air pollution is a local, pan-European and hemispheric issue. Air pollutants released in one country may be transported in the atmosphere, contributing to or resulting in poor air quality elsewhere.

Air contamination is caused mainly by two types of sources: man-made pollution which is caused by industrialization, transportation, heating and others, and pollution caused by natural phenomena, such as volcanic eruptions, natural fires, and others. The anthropogenic influence on the biosphere is increasing more and more nowadays. As of early 2019, the World Health Organization has identified air pollution as the greatest environmental threat to public health [4].

The substances that are the most common air pollutants are: particulate matter (PM_{2.5}, PM₁₀), carbon and nitrogen dioxides (CO₂, NO₂) carbon and nitrogen monoxides (CO, NO), hydrocarbons; aldehydes; radioactive substances, heavy metals, sulfur dioxide (SO₂), ozone (O₃) etc. Carbon dioxide CO₂ is a colorless and odorless gas. Carbon dioxide is more soluble in water than carbon monoxide. Carbon monoxide is a colorless, odorless, toxic gas. It is obtained during the incomplete combustion of coal, natural gas and wood materials. Cars also produce Carbon monoxide. Sulfur dioxide is a colorless gas that is a product of volcanic eruptions and various industrial processes. Sulfur dioxide is usually released when coal and oil are burned. Further oxygenation and reactions with water lead to H₂SO₄ (sulfuric acid) and acid rain. Nitrogen oxides, especially nitrogen dioxide, are a poisonous gas with a pungent, suffocating odor and a brownish-red color. It dissolves well in water. Particulate matter (PM), nitrogen dioxide (NO₂) and ground-level ozone (O₃), are now generally recognised as the three pollutants that most significantly affect human health.

According to the Bulgarian and European legislation, there are standards for maximum permissible concentrations of pollutants in ambient air. Bulgaria and Romania, as parts of the European Union, complies with its legislation.

In Bulgaria, in **1997, Ordinance No. 14** [5] on limit values for limit concentrations of harmful substances in the ambient air of settlements was issued. This Ordinance deals with 166 harmful substances and sets limit concentrations of harmful substances. In addition to the maximum single (30 min. or 1 h), daily average and annual average limit concentration of harmful substances, sum concentrations

are also determined in the presence of harmful substances. Also in **1999, Ordinance No. 7** [6] on ambient air quality assessment and management was issued. The Ordinance describes the conditions, procedure and manner of assessment and management of ambient Air Quality (AQ), defines the areas for assessment of the Air Quality Requirements (AQR), the requirements for carrying out measurements for determining the AQR, as well as the competent authorities and the requirements for the air quality management [6].

The **Clean Air Act** [8] defines the indicators and standards for ambient air quality, emission control, rights and obligations of the relevant bodies for control, management and maintenance of ambient air quality. This law also regulates the limitation of harmful emissions from various sources. When designing, constructing and operating sites with emission sources, they must comply with the requirements of the same law.

The **Environmental Protection Act** is a framework in relation to other laws related to the environment. It regulates the main frameworks for the protection of the components of the environment – air, water, soil, landscapes, biodiversity, as well as the procedures for Environmental Assessment and Environmental Impact Assessment (EIA), permit regimes, management and financing [9].

In 2010 Bulgarian Minister of Health and the Minister of Environment and Water issue **Ordinance No. 12** on standards for sulfur dioxide, nitrogen dioxide, fine particulate matter, carbon monoxide and ozone in ambient air [7].

In Romania are accepted the same norms and requirements for AQ and AQR (see Table 1) [10, 11].

Table 1: Norms of permissible concentrations of air pollutants in Bulgaria and Romania [10, 11]

Norm	Averaging period	Value	Tolerance
Sulphur dioxide SO₂			
Hourly average rate for the protection of human health	1 hour	350 $\mu\text{g}/\text{m}^3$ (not to be exceeded more than 24 times in a calendar year)	150 $\mu\text{g}/\text{m}^3$ (43 %)
Average 24/7 norm for the protection of human health	24 hours	125 $\mu\text{g}/\text{m}^3$ (not to be exceeded more than 3 times within one calendar year)	N/a
Norm for the protection of natural ecosystems (not applied in the immediate vicinity of sources)	one calendar year and winter (1 October to 31 March)	20 $\mu\text{g}/\text{m}^3$	N/a

Table 1: continued

Norm	Averaging period	Value	Tolerance
Nitrogen dioxide (NO₂) and oxides of nitrogen NO_x			
Hourly average rate for the protection of human health	1 hour	200 µg/m ³ NO ₂ (not to be exceeded more than 18 times within one KG)	50% on 19.07.1999, decreased linearly on 1.01.2001 and every 12 months thereafter until reaching 0% at 1.01.2010.
Annual average rate for the protection of human health	one calendar year	40 µg/m ³ NO ₂	50% on 19.07.1999, decreased linearly on 1.01.2001 and every 12 months thereafter until reaching 0% at 1.01.2010.
Norm for the protection of vegetation (not applied in the immediate vicinity of the sources)	one calendar year	30 µg/m ³ (NO+NO ₂)	N/a
Fine particulate matter (PM10)			
Average 24/7 norm for the protection of human health	24 hours	50 µg/m ³ PM10 (not to be exceeded more than 35 times within one calendar year)	50 %
Annual average rate for the protection of human health	one calendar year	40 µg/m ³ PM10	20 %
Fine particulate matter (PM2,5)			
Stage 1			
Annual average rate for the protection of human health	one calendar year	25 µg/m ³ PM2,5	20 % on 11.06.2008, decreasing linearly on 1.01.2009 and every 12 months thereafter to reach 0 % as at 1.01.2015.
Stage 2			
Annual average rate for the protection of human health	one calendar year	20 µg/m ³ PM2,5	
Carbon monoxide CO			
Conservation of human health	Norm maximum eight-hour average over the day	10 mg/m ³	(60 %)

3 ECOLOGICAL MONITORING IN BG–RO TRANS-BORDER AREA

Ecological monitoring is an important scientific practice of taking systematic, repeated measurements of environmental conditions, using the same methods in the same places over time so long-term comparisons can be made. Long-term data is extremely valuable in understanding changes in ecosystem health brought on by climate change, contamination of environment, invasive species, urbanization, and extreme natural and weather events such as volcanic eruption, flooding and drought. It can also help explain other interactions between species and their environment.

According to EU legislation ecological monitoring is the system of regular long observations in space and time, informing about environmental conditions with the purpose to estimate the past, the present and the future forecast of environmental parameters which are important for the human being. Ecological monitoring is the information system that deal with the observation, estimation and forecast of changes in environment, created with the purpose of allocating anthropogenous component of these changes on the background of natural processes.

Also the European Environment Agency (EEA) [12] is the European Union's air pollution data center; it supports the implementation of EU legislation linked to air emissions and air quality. The EEA also contributes to the evaluation of EU air pollution policies and to the development of long-term strategies to improve air quality in Europe. EEA's work focuses on: making a range of air pollution data publicly available; documenting and assessing air pollution trends and related policies and measures in Europe, and investigating the trade-offs and synergies between air pollution and policies in different areas including climate change, energy, transport and industry.

In the frame of all these requirements of ecological monitoring systems each country in the European Union develops its own systems of monitoring stations for ambient air quality measurements.

In the Bulgarian Danube region, air quality monitoring points are located in Vidin, Montana, Vratsa, Plevna, Lovech, Nikopol, Svishtov, Veliko Tarnovo, Gorna Oryahovitsa, Ruse, Shumen, Silistra, Dobrich, Staro Oryakhovo in Bulgaria. A joint Bulgarian-Romanian air quality control system operates in the twin BG–RO cities of Ruse–Giurgevo, Silistra–Kalarash, Nikopol–Turnu Magurele and Svishtov–Zimnich (see Fig. 3).

According to the requirements of national and European legislation, the territory of Bulgaria is divided into six Regions for quality assessment and management of the quality of atmospheric air - Agglomeration of the Bulgarian capital Sofia, Agglomeration of the city of Plovdiv, Agglomeration of the city of Varna, North Danube region, South-West region and South-East region. Data analysis for the quality of

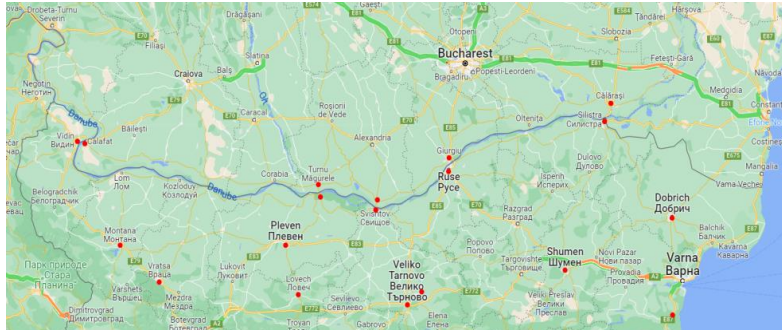


Fig. 3: Map of BG–RO trans-border area with air quality monitoring stations (red points) [1–3].

atmospheric air (AQ) is carried out by regions, taking into account the specifics of each populated place in which control is carried out.

For studying the air quality in BG–RO trans-border area we use the official data from air contaminants concentrations measured in some of the air quality monitoring stations, shown in Fig. 3 and official information from North Danube Bulgarian Region.

This survey is a continuation of our papers [13, 16, 18–22, 25–27, 29–31].

4 STATISTIC STUDY. RESULTS AND DISCUSSIONS

As it was mentioned before, particulate matter (PM), nitrogen dioxide (NO_2) and ground-level ozone (O_3), are now generally recognised as the three pollutants that

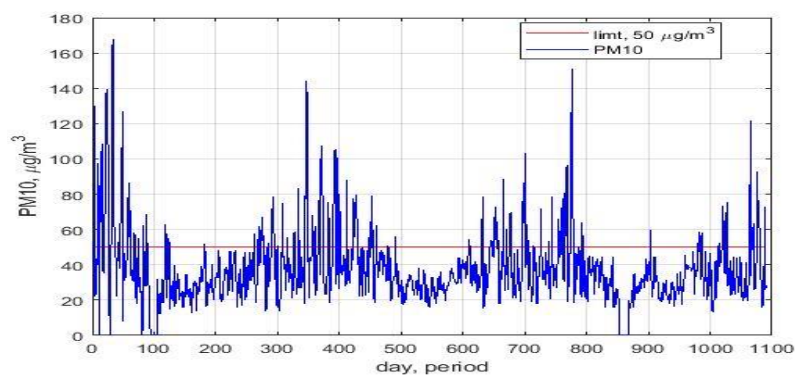


Fig. 4: PM10 measurements for period 01.01.2017 – 31.12.2019 for the city of Ruse, Bulgaria (blue line) and permissible daily limit $50 \mu\text{g}/\text{m}^3$ (red line).

most significantly affect human health. Because of this we will start our study with PM10 contamination in BG–RO trans-border area.

In the next Figs. 4, 5, 6, one can see the graphs of PM10 concentration levels in three Bulgarian towns on Danube river – Ruse, Vidin and Svishtov and in Fig. 7 PM10 concentration levels in the city of Pleven (north Bulgaria) are also shown. It is clear that there are many days with PM10 concentration levels above the daily limit

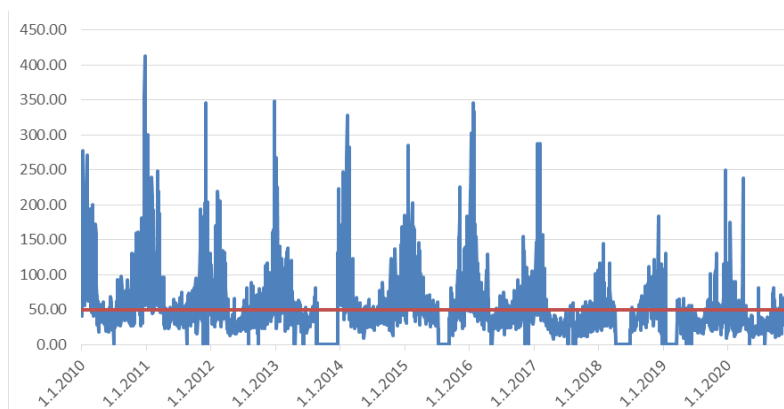


Fig. 5: Average daily values of PM10 levels in the town of Vidin, Bulgaria for the period 2010–2020 (blue line) and permissible daily limit $50 \mu\text{g}/\text{m}^3$ (red line).

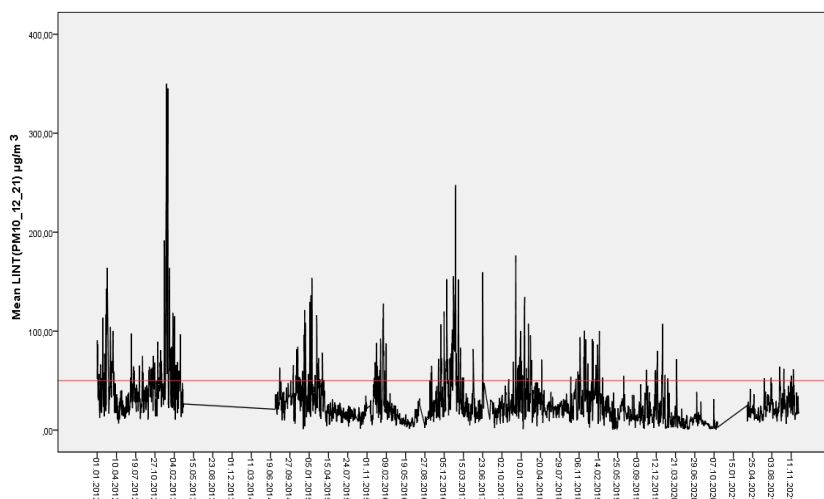


Fig. 6: PM10 concentrations for the period 01.01.2012 – 20.12.2021 for the city of Svishtov, BG–RO trans-border area (black line) and permissible daily limit $50 \mu\text{g}/\text{m}^3$ (red line).

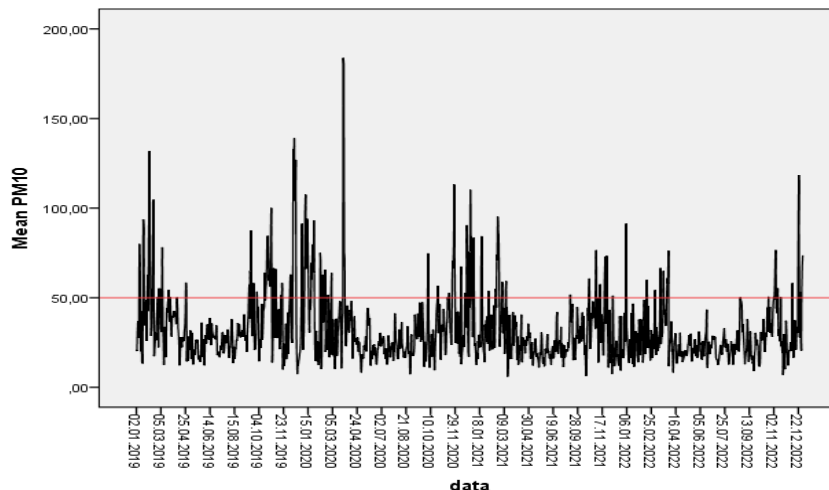


Fig. 7: PM10 concentrations for the period 02.01.2019–30.12.2022 for the city of Plevn, BG–RO trans-border area (black line) and permissible daily limit $50 \mu\text{g}/\text{m}^3$ (red line).

$50 \mu\text{g}/\text{m}^3$. PM10 contamination continues to be a major problem for atmospheric air quality in Bulgaria as a whole and for the BG–RO trans-border area in particular. For 2020 for BG–RO trans-border area the largest number of average daily norms exceedances are measured in Automated Measuring Station (AIS) “Vidin 2” – 77, and in “Nikopol” AIS – 68.

Figures 8, 9 show number of exceedances of the average daily norm and average annual concentration of PM10 for the period 2016–2020, measured in the BG–RO trans-border area, in the point “Ruse-Vazrazhdane” [11]. One could see a clear tendency towards a decrease of the average annual values of the concentration of PM10 and the registered number of exceedances of the daily average norms for PM10 (See



Fig. 8: Number of exceedances of the average daily norm of the PM10 for the period 2016–2020, measured in the city of Ruse, North Danube region, Bulgaria [11].

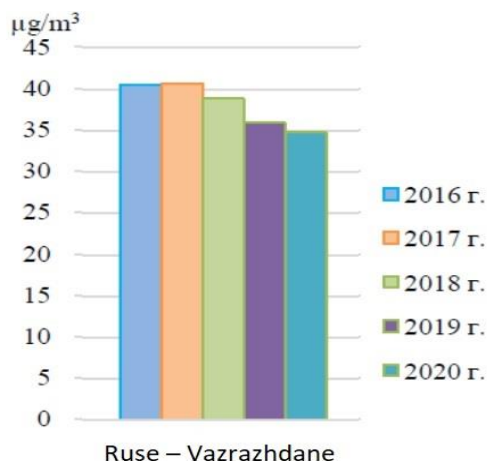


Fig. 9: Average annual concentration of PM10 for the period 2016–2020, measured in the city of Ruse, North Danube region $\mu\text{g}/\text{m}^3$ [11].

Figs. 8, 9). Only in “Ruse-Vazrazhdane” an increase in the average day and night norm of PM10 pollutant in 2020 compared to 2019 can be seen.

PM10 air contamination has a distinct seasonal character. Exceedings of the average daily norm for PM10 are mainly observed during the winter period, due to the use of solid fuels for domestic heating. Adverse weather conditions also affect PM10 concentrations – low wind speed, fogs, temperature inversions. The use of materials for winter road maintenance can also contribute to an increase in the average daily values of the concentration of PM10 during the winter period. Thus main causes of excessive pollution with particulate matter is heating with solid fuel in the winter season and emissions from cars and public transport.

It is known also that in Bulgaria, as a member of EU several strategies and programs are active in the “Transport” sector, which are aimed to reducing emissions of fine particulate matter (PM10) and other air pollutants.

Nevertheless air pollution with fine dust particles still is a major problem for the Republic of Bulgaria and for BG–RO trans-border area. Despite the lowering of the recorded values of the concentration of PM10 in recent years, the air quality according to this indicator is still unsatisfactory. In Bulgaria, the percentage of the population exposed to excessive levels of PM10 is significantly above the average for Europe (10–19% for the period 2015–2019), reaching 60.2% of the population in the country. This is very high percentage (60.2%) and it means that 3.3 million population living in settlements where this pollutant is controlled are exposed on this air contaminaton. The calculations of this percentage were carried out according to the methodology of the European Environmental Agency. According this method-

ology the possible maximum of the possibly affected population is calculated with the following assumption: in each settlement in which it is registered exceeding the norm, the entire population is subjected to the negative influence of dust particles. In 2020, the percentage of the population in Bulgaria affected by abnormal levels of PM10 remained almost unchanged compared to 2019, when it was 60.8. For the period 2000–2019, the largest share of the population of the EU member states (nearly 42%) was exposed to excess pollution with PM10 in 2003.

Next we will examine other type anthropogenic air pollutants in BG–RO trans-border area using official monitoring data.

For the Bulgarian North Danube Region, according the Report [11] during the period 2005–2019, emissions of sulfur (S), nitrogen oxides (NO_x), non-methane volatile organic compounds (NMVOC) and particulate matter with particle diameter less than 2.5 mikrometers (PM2.5) are decreasing. But emissions of PM2.5 increased by 4% from 30.4 kt in 2019 to 31.7 kt in 2020, mainly from household sector emissions. Ammonia emissions have increased by 1.46% from 42.08 kt in 2019 to 42.70 kt in 2020. The main source of ammonia is agriculture. Domestic heating continues to be the main source of PM2.5 for 2020.

For Bulgaria [11] thermal power plants (including refineries) are one of the largest sources of sulfur dioxide (SO₂) – 39% of the total amount emitted in the country. In 2020 sulfur dioxide emissions from all large combustion plants decrease by 7 thousand tons compared to 2019 – from 33.9 kt to 26.9 kt. The main sources of nitrogen oxides are road transport – 39%, thermal power plants (including refineries) – 15%, other transport 13% and rural agriculture (the largest share is the use of inorganic nitrogen fertilizers) – 20%. Agriculture emits 87% of the total amount of ammonia. Another major source are non-fuel production processes – 10%. The main anthropogenic source of NMVOC is domestic combustion – 29% of the total issued quantity for the country. Another major source is used solvents – 19% and agriculture – 19%. Domestic heating is a major source of fine dust particles, with 58% emissions from the total amount of PM10 and 79% of PM2.5 released into the atmosphere. For PM2.5, the other main source is road transport – 7%.

In the next Table 2 one could see emissions of harmful substances in ambient air for Bulgaria for 2020 by groups (in tons per year). Emissions of harmful substances in the atmospheric air from road and other transport in 2020 are shown in the next Table 3 in tons per year.

Figures 10–14 show graphs for different gaseous air pollutants for the period 01.01.2015–20.12.2021 for the city of Ruse, Bulgarian North Danube Region. Figure 10 shows the graph for O₃ (with mean 44.8965 μg/m³, maximum 103.99 μg/m³ and Std. Deviation 19.23307); Fig. 11 shows the graph for SO₂, (with mean 10.2703 μg/m³, maximum 211.85 μg/m³ and Std. Deviation 16.20928); Fig. 12 presents the

Table 2: Emissions of harmful substances in ambient air for 2020 by groups [11]

Emission source groups	SO_x* ×1000 t/y	NO_x** ×1000 t/y	CO ×1000 t/y	PM10 ×1000 t/y	PM2.5 ×1000 t/y
1. Thermal power plants	26.93	13.45	4.47	0.22	0.18
2. Domestic combustion	5.10	2.93	151.35	25.88	25.18
3. Combustion processes in industry (Including energy production)	1.57	2.63	2.18	0.43	0.37
4. Non-combustion production processes	30.83	4.92	19.20	6.70	1.81
5. Extraction and processing of fossil fuels	3.39	1.43	0.496	0.91	0.15
8. Solvent use	0.0028	0.01	0.2455	0.86	0.61
7. Road transport	0.04	35.91	44.83	2.76	2.17
8. Other transport	1.74	12.36	26.88	0.50	0.49
9. Waste treatment and disposal	0.003	0.018	0.10	0.35	0.35
10. Agriculture	0.0002	17.93	0.03	6.14	0.41
Total***	69.60	91.60	249.78	44.75	31.72

* — calculated as sulfur dioxide; ** — calculated as nitrogen dioxide; *** — emissions from the nature sector are not included, due to lack of up-to-date data

Table 3: Emissions of harmful substances in the atmospheric air from road and other transport in 2020, t/y

Groups of emission sources	SO_x* ×1000 t/y	NO_x** ×1000 t/y	CO ×1000 t/y	PM10 ×1000 t/y	PM2.5 ×1000 t/y
Road transport	0.04	35.91	44.83	2.76	2.17
Other transport	1.74	12.36	26.88	0.50	0.49
Total transport	1.77	48.28	71.71	3.26	2.65
Share of transport in national emissions (%)	2.55	52.70	28.71	7.29	8.36

* — calculated as sulfur dioxide; ** — calculated as nitrogen dioxide Source: [11].

graph for NO (with mean $21.3058 \mu\text{g}/\text{m}^3$, maximum $77.82 \mu\text{g}/\text{m}^3$ and Std. Deviation 10.27385); Fig. 13 shows the graph for CO (with mean $9.6385 \mu\text{g}/\text{m}^3$, maximum $65.57 \mu\text{g}/\text{m}^3$ and Std. Deviation 3.68259); and Fig. 14 shows graph for NO₂ (with mean $0.4296 \mu\text{g}/\text{m}^3$, maximum $3.54 \mu\text{g}/\text{m}^3$ and Std. Deviation 0.29168).

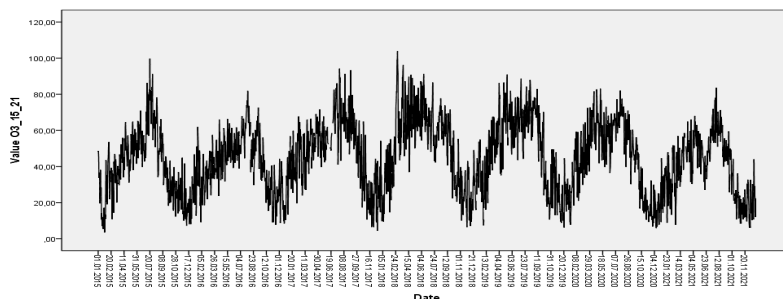


Fig. 10: Graph for O₃ concentration levels for the period 01.01.2015–20.12.2021 for the city of Ruse, North Danube region, Bulgaria.

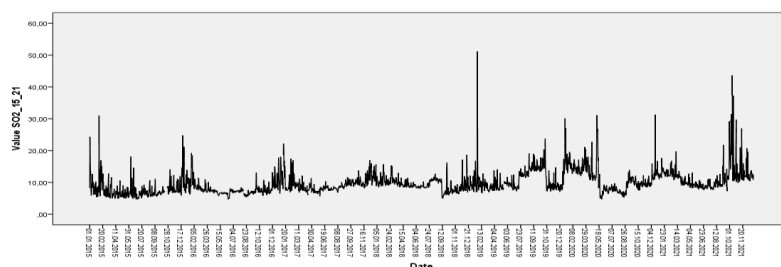


Fig. 11: Graph for SO₂ concentration levels for the period 01.01.2015–20.12.2021 for the city of Ruse, North Danube region, Bulgaria.

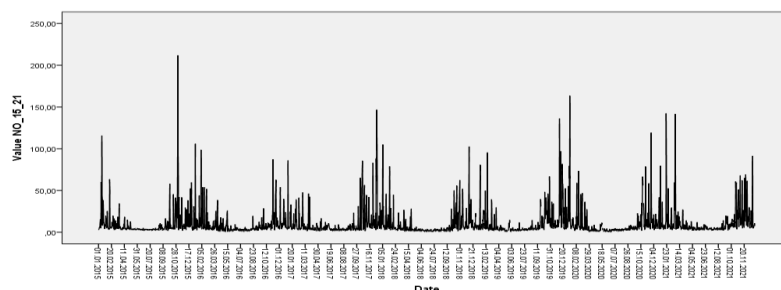


Fig. 12: Graph for NO concentration levels for the period 01.01.2015–20.12.2021 for the city of Ruse, North Danube region, Bulgaria.

Limits of gaseous pollutant concentrations according EU law are as follows: for Sulphur dioxide (SO₂) concentration for 1 hour mean of 350 $\mu\text{g}/\text{m}^3$ and for 24 hours mean – 125 $\mu\text{g}/\text{m}^3$; for Nitrogen dioxide (NO₂) concentration for 1 hour mean of 200 $\mu\text{g}/\text{m}^3$ and for 1 year mean – 40 $\mu\text{g}/\text{m}^3$; for Carbon monoxide (CO) concentration: Maximum daily 8 hour mean of 10 $\mu\text{g}/\text{m}^3$ and for Ozone O₃ Maximum daily 8 hour mean of 120 $\mu\text{g}/\text{m}^3$.

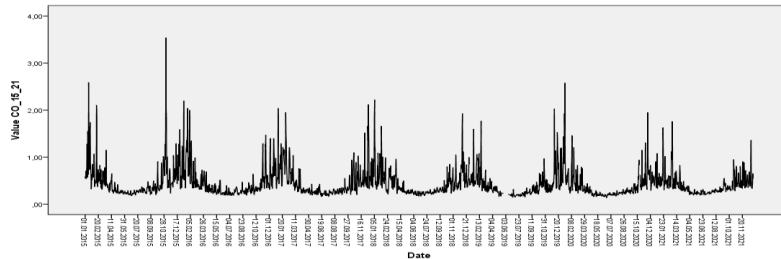


Fig. 13: Graph for CO concentration levels for the period 01.01.2015–20.12.2021 for the city of Ruse, North Danube region, Bulgaria.

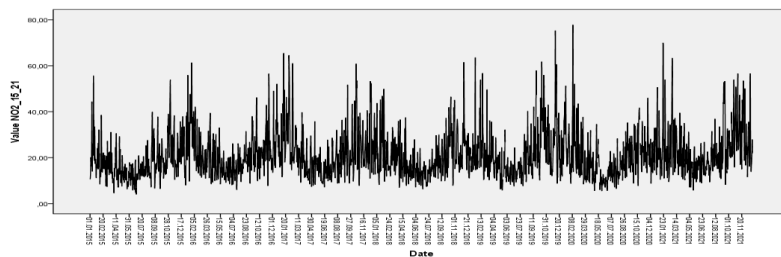


Fig. 14: Graph for NO₂ concentration levels for the period 01.01.2015–20.12.2021 for the city of Ruse, North Danube region, Bulgaria.

In 2020, no exceedances of the average annual norm for PM_{2.5} are registered. The 2020 PM_{2.5} average population exposure indicator is decreasing from 20.74 µg/m³ in 2019 to 18.84 µg/m³ in 2020. Average annual concentrations of PM_{2.5} recorded in 2020 in the city of Ruse, North Danube region, can be seen in Fig. 15 [11]. This PM_{2.5} concentration is lower than the norm.

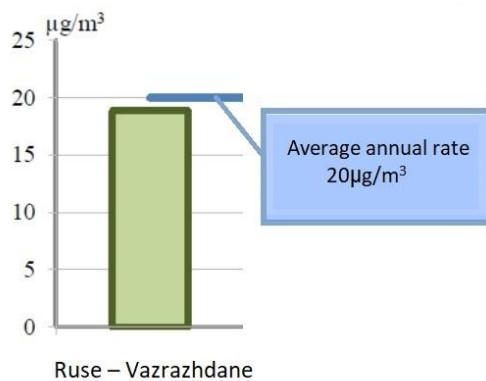


Fig. 15: Average annual concentrations of PM_{2.5} recorded in 2020 in the city of Ruse, North Danube region, µg/m³ [11].

In 2020, the population in Bulgaria and in BG–RO trans-border area is not exposed to ozone levels above the short-term target norm (See Table 4), while for the EU member states the share of the population living with above-normal ozone levels is from 12% to 34% for the period 2015–2019. It should be noted that people in non-urban areas are exposed to higher levels of ozone than people living in cities. In cities, part of the ozone is depleted due to oxidation of nitrogen oxide to nitrogen dioxide, which explains its lower content [11].

About 68% of the population in Bulgaria and in BG–RO trans-border area lives at pollution levels above the target norm for benzo(a)pyrene, while for EU countries the percentage is 14–17% for the period 2017–2019.

The percentage of the affected population indicated in the Table 4 is estimated for 13 cities in the Northern Danube region.

Table 4: Percentage of the population affected by the levels of PM10, O₃, NO₂, PM2.5 and SO₂ for Bulgarian North Danube region according to the Report [11]

Bulgarian Region	PM10, %	O₃, %	NO₂, %	PM2.5, %	SO₂, %
North Danube	58.1	0	0	0	0

In 2020, the population in Bulgaria and in BG–RO trans-border area was not exposed to levels of sulfur dioxide above the permissible average daily norm (See Table 4). In Europe, there is no population (below 0.1%) living with pollution levels above the norm. It is important to note that the monitoring stations used for the calculations are urban and non-urban background and transport (industrial sites are considered to be affected by other local emissions and are not representative of residential areas).

Recently different mathematical models of the air pollutant data are developed to forecast future contamination of the air [13–31]. Some of these are for trans-border BG–RO area [13, 16, 18–22, 25–27, 29–31]. These mostly statistic models take into account many parameters such as seasonality, atmospheric characteristics, interaction with other type of air pollutants and so on. Many of them are good enough to predict future air contamination. Nevertheless PM10 concentration levels for BG–RO trans-border area remain relatively high and this means that ecological situation in the area still need to be improved.

5 CONCLUSIONS

Ambient air quality in the BG–RO trans-borer area is better today than it was two decades ago, but despite improvements, pollutant levels still show significant adverse effects on human health and the environment. The effects from air pollution are felt most strongly in urban areas where people experience significant health problems,

and ecosystems where growth is impaired of vegetation, and eutrophication has led to the loss of biodiversity. Among the main anthropogenic sources of air pollution are automobile transport, production of electricity and thermal energy, industry, agriculture and domestic heating.

To improve air quality in the future, it will be necessary to increase the use of “green” and more efficient technologies in terms of thermal insulation of buildings, as well as the use of alternative sources of fuel in the household and transport, use of best available technology in the industry and more. One of the possible air quality improvement in BG–RO trans-border area is investing in a new electric city buses and trolleybuses in the major cities, improvement of catalytic devices in internal combustion cars, replacement of outdated vehicles that do not meet environmental standards, waste-free technologies, use of eco-fuels, increase of the afforestation of large areas of the urban environment and construction of new road arteries to ease traffic. Other measures to prevent high concentrations of PM10 in BG-RO trans-border area are: reducing the amount of heating with solid fuels; reducing the amount of coal burned in the thermal-electric plants; regular cleaning of the road surface in the cities; reducing the intensity of car traffic in the central parts of the cities, as well as the places with ongoing repair “Water and Sewerage” work; reducing the traffic of TIR vehicles on the main roads of the cities. Another possibility to reduce air pollutants concentrations are so called “green roofs” in the urban zones. It is known according to scientific data, that over 43% of total CO₂ emissions are released by buildings - cooling, heating, etc. Green roofs reduce the need for air conditioning while helping to use less heat in the winter. Green roof plants and plant carpets filter particles from the air and convert CO₂ into oxygen. They also help reducing the amount of dust in the air. Green roofs contribute to air purification and save nature. Thus green roofs have several social, economic and environmental benefits that contribute positively to limiting climate change, preventing floods, increasing green spaces in the urban environment and protecting biodiversity.

The mentioned recommendations would improve the quality of the atmospheric air in Trans-border BG-RO area, but the results will be able to be visualized and evaluated through more precise mathematical modeling of the data series, which take into account more factors.

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in Mathematics with specialization “Fundamentals of cybernetics and management theory” I received an invitation from Prof. Zapryanov to join the team of the newly created “Fluid Mechanics” sector at the Unified Center for Mathematics and Mechanics (UCMM), of which he was the head. At that time, the unified centers united the respective faculties of the Sofia University and the scientific institutes of Bulgarian Academy of Sciences (BAS). Thus, on November 3, 1976, my journey as an university lecturer and researcher in the “Fluid Mechanics” sector began. Later, in 1984, I defended my PhD thesis on “Numerical and asymptotic studies of helical multiphase motions”. My supervisors were Prof. V.P. Stulov from Moscow State University and Prof. Z. Zapryanov, and reviewers – Academician R.I. Nigmatulin from Moscow State University and Prof. St. Radev from UCMM. Thus, under the guidance of Prof. Zapryanov, I became involved in the scientific topics related to the study of movement and heat and mass transfer of viscous and multiphase fluids, with mathematical modeling and applications of mathematics in various chemical-technological and environmental problems. Later on, in 2015, I successfully defended my second (DSc) dissertation on “Mathematical modeling of hydrodynamics and heat and mass transfer in chemical technological processes” and became a doctor of mathematical sciences. Now, after more than 40 years of scientific and teaching activity, I would like to express my deep gratitude to Prof. Zapryanov for inviting me to contribute to these important and dynamic scientific fields of fluid mechanics and mathematical modeling, for inspiring me to pursue these topics and continue to do this so long up today. Thank you, Prof. Zapryanov! I wish you many more years of happy, fulfilling and peaceful life among the people who love you and are grateful to you!

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