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Evaluation of volatile organic compounds present in the atmospheres of rural, urban and industrial areas

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Abstract. Romanian legislation regarding the measurement of volatile organic compound emissions provides limits only for benzene and it is recommended to measure other organic compounds (for example: 1-Butene, Isoprene, Ethyl Benzene, Ethane, Trans-2-Butene, n-Hexane, Total non-methane hydrocarbons, etc.), as they can also cause health problems with long-term exposure. The volatile organic compounds (VOCs) are reach the atmosphere as a result of human activities, such as vehicle exhaust emissions, industrial activity, solvent use, waste management and agricultural practices. Among these, emissions of benzene, toluene, ethylbenzene, xylenes and trimethylbenzene from vehicles have a significant impact on air quality. At the same time, VOC concentrations in the environment are also influenced by biogenic emissions and photochemical degradation processes. Atmospheric concentrations of volatile organic compounds were measured in several areas, including rural, urban and industrialized areas located in Hunedoara County. The analyses were performed using gas chromatography-mass spectrometry (GC-MS), which is a powerful and versatile analytical technique that combines two methods gas chromatography (GC) and mass spectrometry (MS). these methods allows the separation, identification and quantification of components in a complex mixture. Following the analysis of the measurements, it results that Toluene and xylenes showed the highest concentrations in industrial areas, which indicates a major contribution from the evaporation of industrial solvents. In urban areas, although the values recorded for toluene and xylene are lower, benzene has a relatively higher presence, most likely as a result of intense road traffic and incomplete combustion of fuels. The highest values for Benzene were recorded in rural areas, which suggests a significant influence of biomass burning, the presence of wood-fired thermal power plants, as well as the use of agricultural machinery and the handling of liquid fuels in rural areas.

1 General information

Volatile organic compounds (VOCs) are organic chemicals that rapidly evaporate into air at normal temperatures, meaning they have a high vapor pressure. These are carbon-containing

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chemical compounds that can exist as gases at typical atmospheric temperature and pressure. VOCs include a wide range of substances such as benzene, toluene, formaldehyde, xylene, and others, which can be released from various sources like chemical solvents, cleaning products, paints, vehicle emissions, and even industrial activities.

Secondary effects of exposure to VOCs include: respiratory tract irritation, headaches, nausea, and skin and eye irritation during short-term exposure. Acute exposure may also lead to fatigue, dizziness, and a general feeling of discomfort. In the long term, VOCs can cause chronic respiratory issues, central nervous system disorders, cancer risks, and damage to the liver and kidneys. Some chemical substances, such as benzene, can affect fertility and may cause birth defects during pregnancy. VOCs can also reduce immune system efficiency and increase sensitivity to allergens.

Volatile organic compounds are generally more concentrated in urban areas than in rural ones. This is because of several factors, including:

- Vehicle traffic: gasoline or diesel-powered vehicles emit significant amounts of VOCs, and cities have high traffic density, leading to higher concentrations.
- Industrial activities: factories, plants, and other types of industrial activities in urban areas also release VOCs, contributing to air pollution [1].
- Construction and renovations: the use of paints, adhesives, solvents, and other chemical products is more frequent in urban areas, also contributing to VOC emissions.
- Indoor sources: in urban environments, people more often use cleaning products, paints, or other chemical substances, that release VOCs, indoors.

In contrast, rural areas have fewer sources of VOC emissions, with much less industrial activity and vehicle traffic compared to cities. However, VOCs in rural areas can originate from natural sources (e.g., plants or forests), but concentrations are generally much lower than in urban environments.

Exposure to VOCs can affect health, including respiratory tract irritation, long-term health issues, and in some cases, cancer risk [1].

Measuring VOCs in the air is essential to identify pollution sources, understand transport mechanisms, and assess health impacts and regulatory compliance. However, studies in rural areas are relatively rare [2].

VOC concentration fluctuations in the air vary over time and space, requiring a dense monitoring network to determine their spatial and temporal distribution [3]. Intensive monitoring using passive samplers provides detailed data on spatial variations that scattered measurement instruments cannot capture. Additionally, the flexibility in placing these samplers makes them ideal for assessing exposure in hard-to-reach locations [4].

The aim of this study was to characterize the presence of VOCs in the Jiu Valley region, where both rural and industrialized areas were identified [5].

To facilitate identification, VOCs in ambient air (monitoring and interpretation) are classified as follows:

- a. BTEX and other volatile aromatics

BTEX are classic indicators of urban pollution and the presence of fuels.

Sources: road traffic, fuel evaporation, gas stations, petrochemical industry.

Role: contribute to the formation of tropospheric ozone and photochemical smog; some are carcinogenic.

Compounds: Benzene (IARC Group 1, strictly regulated in the EU), Toluene, Ethylbenzene, mp-Xylene, o-Xylene, Styrene.

- b. Volatile aliphatic halogenated compounds (industrial solvents/degreasers)

Sources: fugitive industrial emissions, dry cleaning, contaminated soil (evaporation from soil). They are important for monitoring air quality in industrial or peri-urban areas. Some originate as emissions from contaminated soils (through evaporation).

Role: some are persistent in the atmosphere, affect the stratospheric ozone layer, and can form secondary toxic compounds

Compounds: 1,1-Dichloroethene; 1,1-Dichloroethane; cis-1,2-Dichloroethene; trans-1,2-Dichloroethene; Dichloromethane (GR.2B); Chloroform (GR.2B); 111-Trichloroethane; 1,2-Dichloroethane (GR.2B); Trichloroethene (GR.1); Tetrachloroethene (GR.2A); 1,1,2-Trichloroethane; 1,1,2,2-Tetrachloroethane; Carbon tetrachloride (GR.2B).

- c. Volatile trihalomethanes (THMs)

Sources: by-products of water chlorination, evaporation from sewers, cooling towers, chlorination treatments.

Compounds: Bromodichloromethane; Dibromochloromethane; Bromoform; Chloroform

- d. Halogenated aromatics

Sources: chemical industry, solvents, plastics.

Compound: Chlorobenzene.

- e. Biogenic emissions

• Carbon disulfide

Sources: industrial processes, biogenic emissions (swamps, organic decomposition), industrial volcanism.

The chemical industry and the manufacturing of carbon-based products. It mainly originates from: pulp production, chemical manufacturing, petroleum industry, agricultural activities, fungicides and pesticides used in agriculture, or from natural emissions.

- Subgroup 1: Chloroalkanes – saturated compounds (C–C, C–H bonds)

Volatile, used as solvents, sometimes by-products of industrial processes.

• 1,1-Dichloroethane
• 1,2-Dichloropropane (!! IARC Group 1 – carcinogenic)

Source: chemical industry, solvents, legacy contaminants, may appear as vapor from contaminated soils.

Interpretation: industrial solvents / highly volatile intermediates.

- Subgroup 2: Chloroalkenes – unsaturated compounds (C=C bonds)

Volatile, used as fumigants or in polymer synthesis

• cis-1,3-Dichloropropene
• trans-1,3-Dichloropropene
• (Possibly also "cis-13-Dichloropropene", which appears to be a misspelling of the previous two)

Source: agriculture (soil fumigants), plastics industry, evaporation from soil.

Interpretation: fumigants / volatile contaminants in agricultural or industrial areas.

2 Materials and methods

To determine volatile organic compounds, the gas chromatograph coupled with a mass spectrometer (GC-MS) model GCMS-TQ8040 NX, equipped with a multifunctional Autosampler AOC-6000 Plus and a TD-30 thermal desorption system — was used.

Gas chromatography–mass spectrometry (GC-MS) is an analytical technique based on the use of a gas chromatograph coupled with a mass spectrometer. The gas chromatograph separates the compounds present in the sample, while the mass spectrometer acts as a detector. This technique is an advanced method of analysis and allows the identification and quantification of organic substances (including halogenated and non-halogenated volatile and semi-volatile organic compounds, as well as polycyclic aromatic hydrocarbons).

A schematic representation of a GC/MS system includes: a gas chromatograph, a mass spectrometer, and a data collection and analysis system (DataSystem), which together form the system used for qualitative and quantitative analysis and separation of complex mixtures.

The gas chromatograph consists of an injector (autosampler), a column temperature control system, and a transfer line that allows the column effluent to enter the mass spectrometer. The mass spectrometer includes an ionization chamber (ion source), a mass analyser (quadrupole analyser), and an ion detector, all maintained under high vacuum by diffusion pumps supported by molecular pumps.

Calibration curves were drawn using reference materials for each organic compound.

To select the monitoring points for volatile organic compounds, three representative zones were chosen: industrial areas, urban areas, and rural areas.

Industrial areas are designated for industrial activities, i.e., the production of goods or the provision of industrial services. They are usually located on the outskirts of cities or near transportation infrastructure to facilitate the transport of materials and products. These areas host factories, warehouses, distribution centres, and production units. Although industrial areas can have a negative environmental impact, they are essential for the economic development of regions by providing jobs and contributing to goods production.

Urban areas refer to cities and densely populated towns, with complex infrastructure. They are characterized by a high concentration of housing, public services, educational, commercial, and cultural institutions. Urban areas are economic, social, and cultural centres, with well-developed infrastructure such as roads, public transport, water and sewage networks, hospitals, schools, etc. Urban zones can include both residential neighbourhoods and commercial districts, public institutions, and green spaces. Cities are centres of innovation and economic growth, but also face challenges related to pollution, traffic, and resource management, which can impact residents' health and quality of life.

Rural areas refer to less populated regions outside urban centres, often dedicated to agriculture, forests, pastures, or other nature-related economic activities. They are characterized by low population density and extensive natural landscapes. Main economic activities include farming, livestock raising, forestry, and rural tourism. Infrastructure in rural areas is usually less developed compared to urban zones, with reduced transport network and limited public services. Rural areas are important for food production and natural resource supply, and they play a vital role in biodiversity conservation and preservation of natural landscapes. However, they face economic challenges, such as depopulation and lack of employment opportunities.

Key differences between the zones:

- Industrial areas are focused on production, urban areas are economic and cultural centres, and rural areas are oriented toward agriculture and nature conservation.
- Urban zones have the most complex infrastructure, followed by industrial areas, while rural areas have the simplest infrastructure.
- Urban areas have the highest population density, followed by industrial zones, while rural areas are less populated.

All these zones are interconnected and depend on one another for the balanced development of a region or country.

The research was conducted in the southeastern part of Hunedoara County (Fig. 1), an area covering 37 km² in the Petroșani–Petrila–Lonea–Jieț region, mainly consisting of hilly terrain, with an average elevation ranging from 587 m to 740 m [6].

The sampling points were grouped as follows:

- Industrial areas:1 – Petroșani – near E.M. Livezeni, 7 – Lonea – E.M. Lonea
- Urban areas: 3 – Petroșani – Brădet minibus station, 4 – Petroșani – Central minibus station, 5 – Petrila – Republicii St., Bl. 33, 6 – Petrila – Penny Market parking lot, 2 – Petroșani – Colonie, Popa Șapcă St., no. 41.
- Rural area: 8 – Petrila – Jieț, intersection of Jieț Street with DN7A, 9 – Petrila – Jieț, General School no. 4.

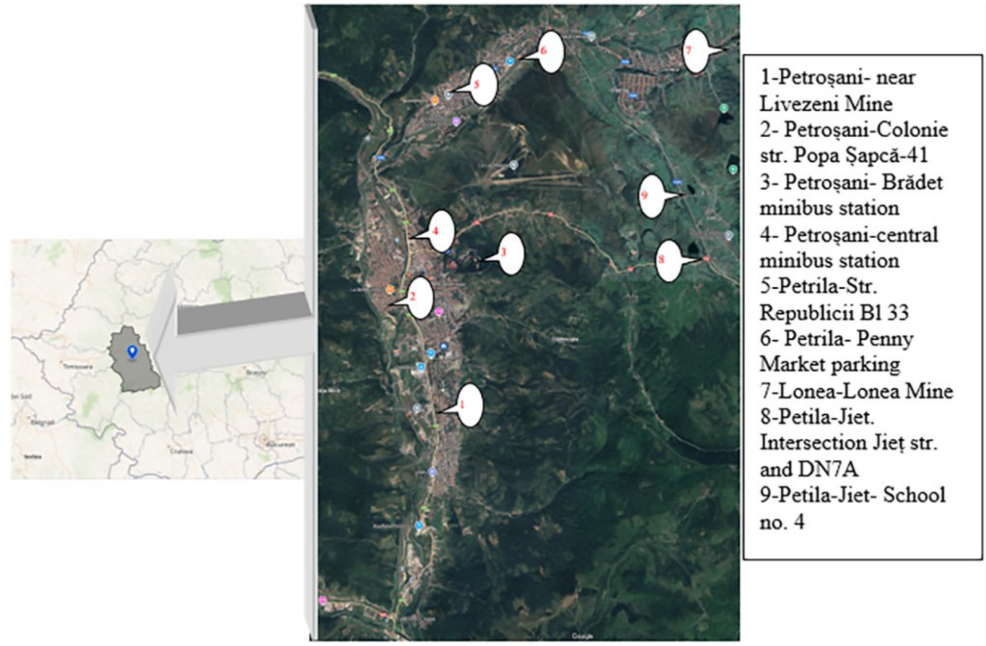

Fig. 1. VOC sampling points

For the sampling campaign, different days were selected over a five-month period, under various weather conditions, during winter and spring.

It is well known that vehicle exhaust gases and industrial sources contribute to ambient VOC levels in urban areas [7]. However, relatively less is known about VOC source characteristics in rural areas [8], mainly due to the lack of field measurements.

An important class of VOCs is the BTEX group (benzene, toluene, ethylbenzene, m/p-xylene, and o-xylene), which has been the focus of many toxicological studies [9]. Ideal regions for studying BTEX emissions and impact include "hotspots", typically urban zones where ambient levels significantly exceed those of the surrounding remote areas. Pollution in developing countries has significantly increased in recent years, and fresh emissions, in particular, are a major health concern for large populations in these areas [10].

BTEX is a critical group of compounds because of their abundance in ambient air, their harmful impact on public health, and their role in atmospheric chemistry [11]. Their sources, including those in this study area, include: vehicles, gas stations, industrial activities, landfills, municipal solid waste (MSW) stations, and combustion for household heating. Previous studies have shown that over 45% of total BTEX emissions, such as benzene and toluene, in Mexico City, the UK, and Los Angeles, originated from gas stations, gasoline evaporation, and vehicle emissions [12].

Regarding health effects, benzene is classified as carcinogenic, ethylbenzene is recognized as a potential carcinogen, toluene and xylene are classified as Group D carcinogens or non-carcinogenic. Benzene also affects blood production, the lymphatic system, and the central nervous system. Toluene can affect the reproductive nervous system. In terms of atmospheric chemistry, photochemical reactions of BTEX pollutants can generate secondary pollutants, such as ozone and secondary aerosols through gas-to-particle conversion processes.

The main component of gasoline is benzene, which is released from gasoline engines. The benzene-to-toluene ratio (B/T) is often used as an index to determine BTEX emission sources. A B/T ratio greater than 0.5 suggests that benzene emissions are not only related to traffic but also come from additional sources.

3 Results and discussions

For the selected areas, several volatile organic compounds (VOCs) were analysed. In the first stage, measurements from the industrial zones were compiled.

Table 1 Average values recorded in the industrial areas, specifically:1 – Petroșani – Near Livezeni Mine, and 7 – Lonea Mine

Measured component	Measuring unit	Sampling date				
		14.11.2024	11.12.2024	17.01.2025	10.02.2025	25.03.2025
Dichloromethane	μg/m³	0,2971	0,3381	0,1886	0,2173	0,2675
Carbon disulfide		0,0212	0,0417	0,0057	0,0201	0,0202
Chloroform		0,0977	0,1114	0,0874	0,0970	0,0879
Benzene		1,5690	1,6100	1,2435	1,4875	1,5394
Carbon tetrachloride		0,3977	0,4387	0,3667	0,3954	0,3681
Trichloroethene		0,0219	0,0287	0,0167	0,0215	0,0170
Toluene		2,3488	2,4144	1,7753	1,9906	2,3014
Tetrachloroethene		0,0905	0,1007	0,0827	0,0899	0,0831
Chlorobenzene		0,0289	0,0348	0,0245	0,0286	0,0247
Ethylbenzene		0,4732	0,5142	0,2252	0,2539	0,4436
mp-Xylene		1,4981	1,5801	0,9246	1,4986	1,4389
o-Xylene		0,5659	0,5795	0,4419	0,4514	0,5560
Styrene		0,1041	0,1109	0,0989	0,1037	0,0991
Bromoform		0,0222	0,0267	0,0187	0,0219	0,0189

Based on the data collected, we created a graph with the average values for each location, taken on different days.

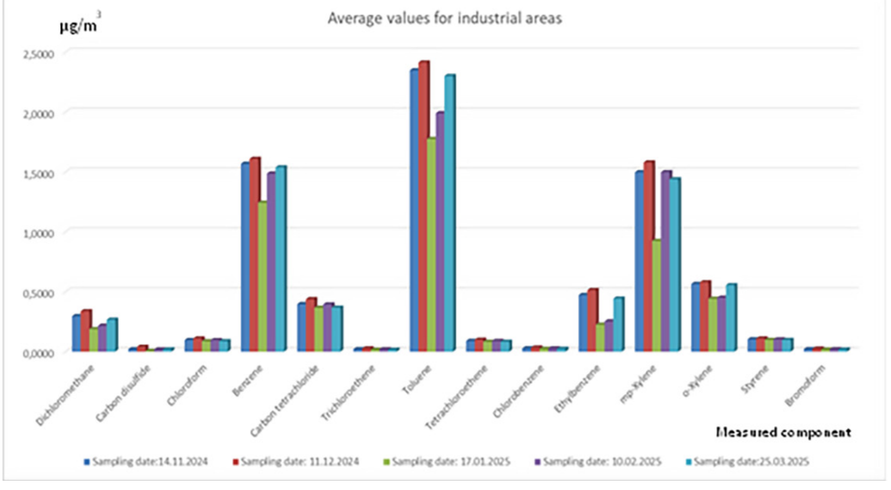

Fig. 2. Average values of volatile organic compounds obtained in different months of the year, for the established locations.

Analysing these results, it can be observed that three components—toluene, benzene, and xylene—present higher values. The maximum value for toluene was 2.41 µg/m³, recorded on December 11, 2024, and compared to the limit value imposed by Law no. 104/2011 (5 µg/m³), it is less than half. It should be noted that the legal limit refers to an annual average, not to a short-term period as in this case.

Anthropogenic sources that may emit benzene, toluene, and xylene (BTX) into the atmosphere include:

- Refineries and the petrochemical industry (oil refining and natural gas processing, processing installations, vapor leaks, industrial ventilation, and liquid handling);
- Evaporation from fuels and solvents at gas stations (gasoline contains between 5–15% toluene, which can evaporate during fuelling, transport, or storage);
- Industrial solvents (paints, varnishes, adhesives, thinners) containing toluene → evaporation during use;
- Incomplete combustion of fuels. Exhaust gases from: cars (especially those without a catalytic converter or with gasoline engines), industrial engines, biomass, coal, or waste burning, thermal power plants.

VOC measurements taken in urban areas are compiled in Table 2.

Table 2 Average values recorded in urban areas, namely: 3 – Petroșani – Brădet minibus station; 4 – Petroșani – Central minibus station; 5 – Petrila – Republicii St. Bl. 33; 6 – Petrila – Penny Market parking lot; 2 – Petroșani – Colonie, Popa Șapcă St. no. 41.

Measured component	Measuring unit	Sampling date				
		14.11.2024	11.12.2024	17.01.2025	10.02.2025	25.03.2025
Dichloromethane	µg/m³	0,3102	0,3348	0,2792	0,2722	0,2759
Carbon disulfide		0,0174	0,0315	0,0076	0,0216	0,0189
Chloroform		0,1167	0,1249	0,1064	0,0969	0,0881
Benzene		1,6513	1,6759	1,6203	1,5895	1,5939
Carbon tetrachloride		0,3266	0,3676	0,2956	0,3938	0,3665
Trichloroethene		0,0425	0,0494	0,0374	0,0201	0,0155
Toluene		1,2274	1,2930	1,1778	1,3031	1,4012
Tetrachloroethene		0,1914	0,2016	0,1836	0,1261	0,1193
Chlorobenzene		0,0198	0,0257	0,0154	0,0235	0,0196
Ethylbenzene		0,2329	0,2739	0,2019	0,1951	0,2546
mp-Xylene		0,6739	0,7559	0,6119	0,8243	0,7677
o-Xylene		0,2604	0,2741	0,2501	0,2692	0,3056
Styrene		0,0934	0,1002	0,0882	0,0911	0,0865
Bromoform		0,0201	0,0247	0,0167	0,0213	0,0182

The average values obtained from measurements carried out in the locations established for urban areas were graphically represented for each measurement period.

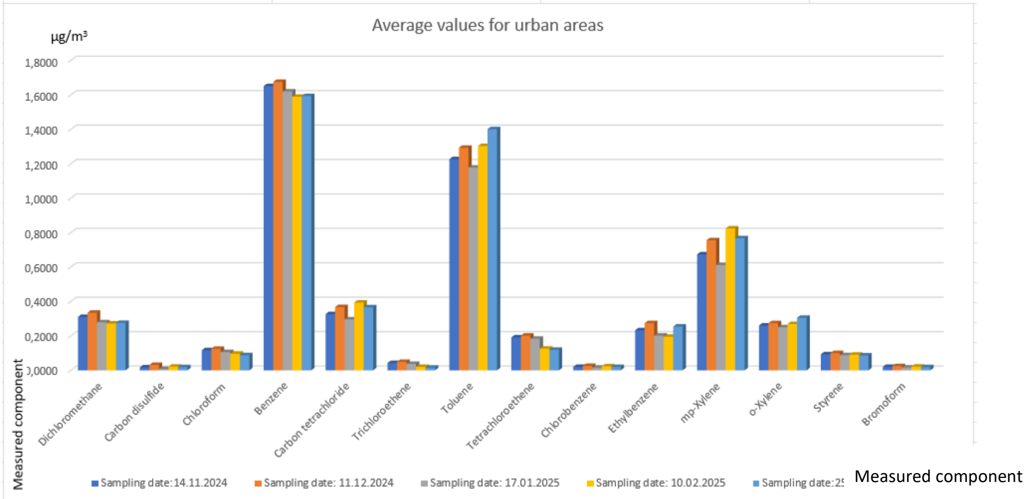

Fig. 3. Average values of volatile organic compounds obtained in different months of the year, for established locations in urban areas.

Analysing these results, it can be observed that there are higher values for three components, namely benzene, toluene, and xylene. The maximum value for toluene was 1.4 µg/m³, recorded on March 25, 2025, which is well below the limit value imposed by Law no. 104/2011 (5 µg/m³), considering an annual averaging period.

It can be noted that in urban areas, benzene concentrations are higher than those of toluene and xylene. This may be due to heavier traffic in urban areas, resulting from the incomplete combustion of fuels (e.g., car exhaust gases, thermal power plants, etc.). [13], [14].

In the final stage of the study, VOC measurements were carried out in rural areas.

Table 3 The average values taken in rural areas, namely: 8-Petila-Jiet. Intersection of Jieț Street with DN7A, 9-Petila-Jiet School no. 4

Measured component	Measuring unit	Sampling date				
		14.11.2024	11.12.2024	17.01.2025	10.02.2025	25.03.2025
Dichloromethane	µg/m³	0,2672	0,3082	0,2362	0,2649	0,2376
Carbon disulfide		0,0120	0,0325	0,0111	0,0254	0,0109
Chloroform		0,0862	0,0999	0,0759	0,0837	0,0764
Benzene		3,5853	2,5603	2,3918	3,1237	3,0081
Carbon tetrachloride		0,3496	0,3906	0,3186	0,3473	0,3200
Trichloroethene		0,0255	0,0323	0,0203	0,0251	0,0206
Toluene		1,1223	1,1879	1,0907	1,1367	1,0749
Tetrachloroethene		0,0667	0,0769	0,0589	0,0661	0,0593
Chlorobenzene		0,0160	0,0219	0,0116	0,0157	0,0118
Ethylbenzene		0,2285	0,2695	0,1975	0,2262	0,1989
mp-Xylene		0,3569	0,4389	0,2949	0,3523	0,2977
o-Xylene		0,1784	0,1921	0,1681	0,1776	0,1685
Styrene		0,2837	0,2906	0,2786	0,2833	0,2788
Bromoform		0,0221	0,0266	0,0186	0,0218	0,0188

Fig. 4 shows the average values measured at the established locations, on different days.

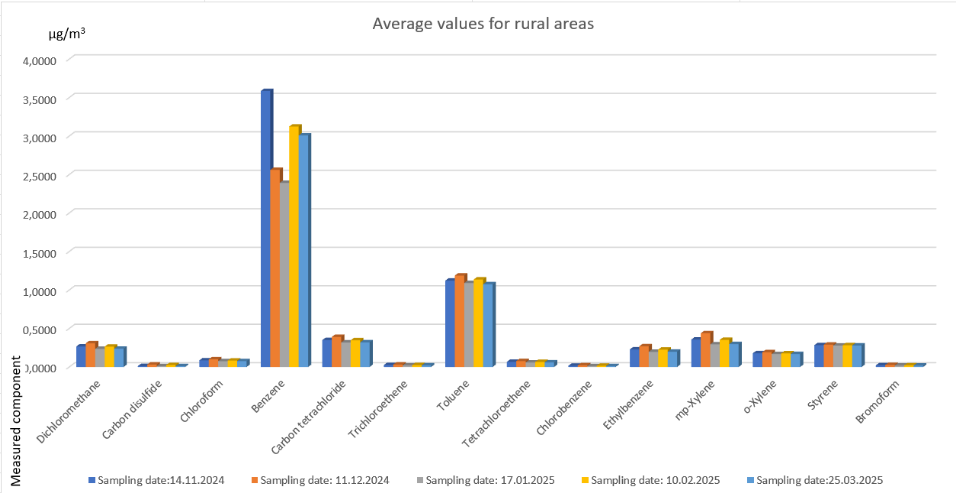

Fig. 4. Average values of volatile organic compounds obtained in different months of the year, for two established locations in rural areas

Analysing these results, it can be observed that higher values were recorded for two components, namely benzene and toluene. The maximum value recorded for toluene was 1.18 µg/m³, measured on December 11, 2024, which is below the limit set by Law no. 104/2011 (5 µg/m³). It should be noted, however, that the legal limit refers to an annual averaging period, not to a short-term measurement like in this case.

In rural areas, the highest concentrations of benzene were recorded. This may because of the following factors:

– Biomass burning (burning wood in stoves for heating, burning agricultural waste such as leaves, straw, and plant debris),
– Emissions from vehicles and agricultural machinery. Even though traffic is lower in rural areas, gasoline-powered vehicles and agricultural equipment (tractors, brush cutters, etc.) can emit larger amounts of benzene due to their higher fuel consumption,
– Use of liquid fuels and solvents. In households or small workshops in rural areas, substances such as gasoline for cleaning, paint solvents, adhesives, varnishes may still be used. The evaporation of these types of substances releases benzene into the air.
– Frequent handling of gasoline (e.g., for generators, pumps, chainsaws, heavy equipment).

To enable comparison of measurement values across different areas, Table no. 4 and Chart no. 5 were created.

Table 4 Average values carried out in industrial, urban and rural areas

Measured component	Measuring unit	Industrial areas	Urban areas	Rural areas
Dichloromethane	µg/m³	0,2971	0,3231	0,2672
Carbon disulfide		0,0212	0,0175	0,0120
Chloroform		0,0977	0,1013	0,0862
Benzene		1,5690	1,5058	3,5853
Carbon tetrachloride		0,3977	0,4083	0,3496

Trichloroethene		0,0219	0,0281	0,0255
Toluene		2,3488	0,9278	1,1223
Tetrachloroethene		0,0905	0,1344	0,0667
Chlorobenzene		0,0289	0,0210	0,0160
Ethylbenzene		0,4732	0,1742	0,2285
mp-Xylene		1,4981	0,4456	0,3569
o-Xylene		0,5659	0,1762	0,1784
Styrene		0,1041	0,0712	0,2837
Bromoform		0,0222	0,0220	0,0221

The measurements taken allowed the drawing of a graph of average values, organized by different locations and different areas.

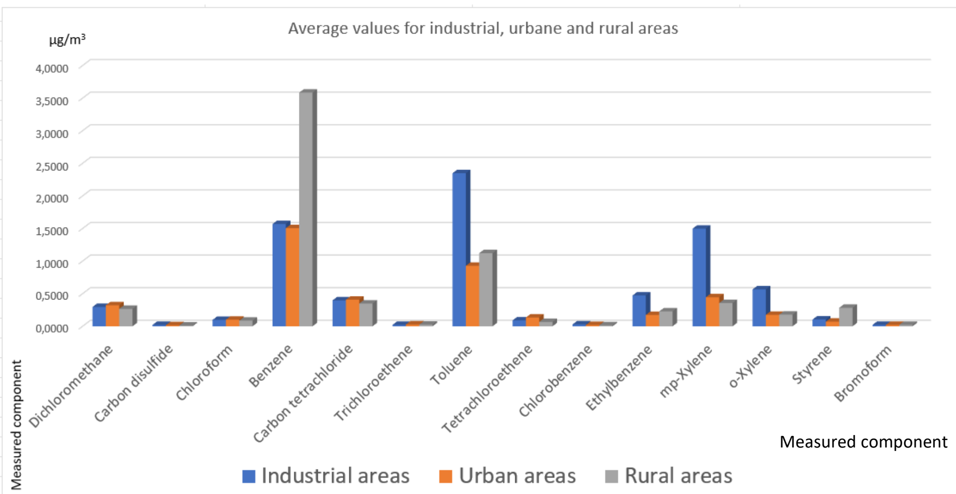

Fig. 5. Average values of volatile organic compounds obtained in different months of the year, for industrial areas, urban areas and rural areas.

Analysing these results, we observe higher values for three compounds, namely: Benzene, Toluene and Xylene. The highest value recorded for benzene was recorded in rural areas, followed by industrialized areas. The value is below the maximum limit of 5 µg/m³ imposed by Law no. 104/2011 (annual average value).

Calculating the percentages for each compound within each area (Industrial, Urban, Rural) indicates:

- Industrial – Toluene dominates (~29%), then Benzene (~29%) and m,p-Xylene (~22%).
- Urban – the distribution is more balanced: Benzene (~28%), m,p-Xylene (~13%), Toluene (~14%).
- Rural – extremely unbalanced: Benzene alone represents over 56%, followed by Toluene (~13%) and m,p-Xylene (~8%).

The highest values of toluene and xylene concentrations were recorded in industrial areas, followed by rural areas.

In conclusion, rural areas have the highest concentrations of Benzene, and industrial areas have the highest concentrations of toluene. Analysing all 5 months (November-March) in which the measurements were made, it can be concluded that in November and February the highest values of VOC concentrations were recorded, this is mainly due to vehicle emissions and biomass burning (burning wood/coal in heating stoves, burning vegetable waste).

Conclusions

This study conducts ambient measurements of BTEX pollutant concentrations in industrialized, urban, and rural atmospheres.

Typically, higher concentrations of volatile organic compounds (VOCs) in urban areas compared to rural ones are driven by traffic density, industrial activities, and frequent use of chemical materials in construction and renovation. These sources, specific to the urban environment, significantly contribute to increased VOC pollution levels.

Exposure to volatile organic compounds (VOCs) can impact health, causing respiratory tract irritation, long-term health problems, and, in some cases, an increased risk of cancer.

It is well-documented that vehicle exhaust and industrial sources significantly contribute to VOC levels in urban environments. However, the source characteristics of VOCs in rural areas remain less understood, mainly due to a lack of field measurement data.

In Romania, legislation on the monitoring of VOC emissions sets limit values only for benzene, while for other compounds, such as 1-butene, isoprene, ethylbenzene, ethane, trans-2-butene, n-hexane, and total non-methane hydrocarbons, monitoring is recommended without the imposition of specific limit values.

The aim of this work is to compare the atmospheric concentrations of volatile organic compounds measured in various areas, including rural, urban, and industrial zones located in Hunedoara County.

For the analysis of VOC emissions, a gas chromatography system coupled with tandem mass spectrometry (GC-MS/MS), model TQ8040 NX, was used, equipped with a multifunctional autosampler AOC–6000 Plus and a thermal desorption system TD–30, ensuring sensitive and selective detection of the targeted compounds. Calibration curves were traced using reference materials specific to each analysed organic compound.

The research was conducted in the southeast of Hunedoara County, an area covering 37 km² in the Petroșani-Petrila-Lonea-Jieț region, mainly composed of hilly terrain, with an average elevation ranging from 587 m to 740 m.

The highest benzene concentration was recorded in rural areas, followed by industrial zones, suggesting a significant influence from biomass burning, the use of agricultural equipment, and handling of liquid fuels in rural environments.

Toluene and xylenes recorded the highest concentrations in industrial areas, indicating major contributions from refineries, the petrochemical industry, and evaporation of industrial solvents.

In urban areas, although recorded values for toluene and xylenes were lower, benzene showed relatively higher levels, most likely as a result of heavy traffic and incomplete fuel combustion.

All recorded values for toluene, benzene, and xylene across the three types of zones are below the legal limit of 5 µg/m³ established by Law no. 104/2011, bearing in mind that this limit applies to an annual average, while the present measurements reflect short-term values.

The highest benzene values were recorded in rural areas, while the highest values for toluene and xylene were found in industrial zones. This pattern may also be influenced by heavier traffic in urban areas, resulting from incomplete fuel combustion (e.g., car exhaust, thermal power plants, etc.).

In conclusion, by analysing all five months (November–March) in which the measurements were carried out, the highest VOC concentrations were recorded during the winter months (November and February), highlighting the seasonal influence of biomass burning for heating and increased vehicle emissions during this period.

Exposure to volatile organic compounds (VOCs) can have a range of adverse health effects. In the short term, it can cause respiratory tract irritation, headaches, nausea, as well as skin and eye irritation. Acute exposure is also associated with fatigue, dizziness, and general discomfort. In the long term, VOCs can contribute to the development of chronic respiratory conditions, affect the central nervous system, increase the risk of cancer, and cause liver and kidney damage. Certain compounds, such as benzene, can negatively affect fertility and may lead to birth defects when exposure occurs during pregnancy. VOCs can also reduce immune system efficiency and increase sensitivity to allergens.

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