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STUDY OF AIR POLLUTION LEVEL IN AN URBAN AREA USING LOW-COST SENSOR SYSTEM ONBOARD MOBILE PLATFORM

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Abstract

The paper aims to assess the air pollution level using one mobile low-cost measurement system versus in situ sensing data from local air quality network stations. The measurements were performed during the winter of 2022 on the main streets of Galați city, one of the largest cities in Romania. The main purpose of the measurements is to use mobile measurements to capture the spatial and temporal distribution of important air pollutants such as NO_2+O_3, CO, SO_2, and PM_{10} in large urban areas. For this study used a mobile air quality monitoring system Sniffer 4Dv1 to record spatial and temporal data on air pollutants on the street of Galati City. The data sets from local RNAQMN (Romanian National Air Quality Monitoring Network) are compared with Sniffer 4Dv1 data to infer various limitations for each of the two data sets.

Key words: *air pollution, air quality, AQS in situ measurements, mobile measurements.*

INTRODUCTION

Over the past few decades, air pollution has become a major environmental concern on a global scale. The most significant sources of air pollution are man-made and include industrial activities, transportation, and energy generation. In general, air pollutants are defined as significant levels of trace gases or particulate matter (PM) compared to natural ones, which can be detected using a variety of methods and tools, each with pros and cons.

Stationary in-situ measurements, such as air quality stations (AQS), can be utilized as a measuring method since they can measure the local variation of air contaminants (Guerreiro, Foltescu and De Leeuw, 2014; Iorga, 2016; Maftei, Muntean and Poinareanu, 2022; Năstase et al., 2018; Voiculescu et al., 2020). Another way of monitoring air pollution is to use mobile measurements to cover broad regions and capture the spatial distribution of pollutants as well as the location of their sources (Constantin et al., 2017; Elen et al., 2012; Roşu et al., 2020; Roşu et al., 2021; Samad and Vogt, 2021).

The most important air pollutants monitored in urban areas are particulate matter (PM) (Hamanaka and Mutlu, 2018; de Miranda et al., 2012), nitrogen dioxide (NO_2) (Meier et al., 2017; Roşu et al., 2020; Roşu et al., 2022), sulfur dioxide (SO_2) (Constantin et al., 2020; Schwela, 2000; Zhao et al., 2018), ozone (O_3) (Bishoi, Prakash and Jain, 2009; Manes et al., 2016), and carbon monoxide (CO) (Al-Ali, Zualkernan and Aloul, 2010; Brienza et al., 2015; Liu et al., 2012).

In recent years a more thorough and up-to-date data about air pollution are required to support policy and public health decisions. This practice led to a grow into the usage of low-cost sensors to monitor air pollution in urban areas. Low-cost sensors are used today to measure air pollutants such as particulate matter, nitrogen dioxide, and ozone for a fraction of the cost of standard air monitoring equipment (including AQS). Research in Delhi, India, for example, discovered that using low-cost sensors helped to detect high-pollution locations and assess the success of pollution-reduction strategies (Gulia et al., 2020). Similarly, research carried out in Los Angeles, California, USA, showed how low-cost sensors may be used to monitor pollution trends and pinpoint their origins, offering useful data to decision-makers and neighbourhood organizations. (Lu, 2022; Lu et al., 2022).

The main objective of the study is to test a low-cost sensor monitoring system in the quantification of the amount and distribution of several air pollutants (NO_2+O_3, SO_2, CO, and PM_{10}) in a large urban area in South East of Romania. Also, we aim to identify the hot spots of the concentration of these air pollutants and identify the emissions sources. Another objective is to evaluate the concentration values recorded with the low-cost air quality system with respect to the measured concentrations for the same air pollutants provided by the national air quality stations located in the same area.

MATERIALS AND METHODS

1.1. Study area and localization

For our study, we performed mobile air quality measurements in the fifth largest city in Romania Galati City (GL), with a population of 217851 (Anon n.d.-b). We choose Galati City because the main emissions sources include local industry, moderate car traffic, and household heating (Roşu et al., 2020; Roşu et al., 2022). The mobile measurements were performed in the afternoon, from 12 -15 local time (LT) on 19 January 2022 on the main streets of Galati city by mounting the low-cost air quality monitoring system Sniffer 4Dv1(SN) on the top of a car (Figure 2).

The measured data were compared with the local AQS data to verify the measurement values. The route of the mobile air quality system is presented in Figure 1 along with the location of the local AQS.

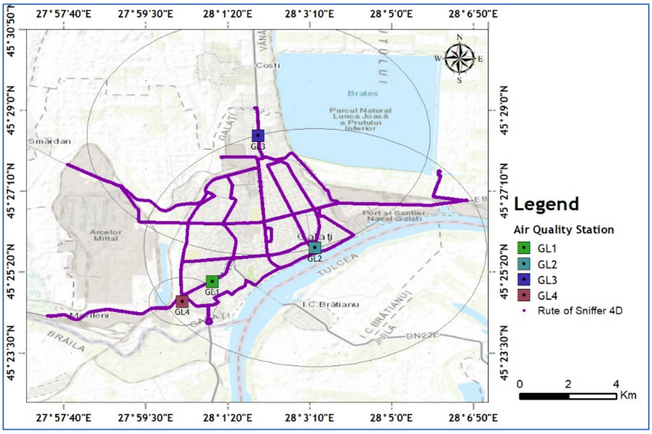

Figure 1. The track of the mobile measurements performed on 19 January 2022 in Galati city with the air quality system Sniffer 4D v1 and the location of the AQS

1.2. Equipment and data used

1.2.1. Air quality stations from Galati City (AQS)

The local air quality monitoring network in Galati City is administrated by the local administrative office of the Environmental Protection Agency from Galati (Agenția de Protecția Mediului din Galați - APM GL). The Galati city monitoring network consists of 4 stationary AQS that are located in different parts of the city (Figure 1). Each AQS is composed of a container that houses monitors and sensors that continuously measures individual pollutants. The list of the parameters measured by each AQS in Galati City includes a large list of air pollutants and meteorological data. The ones that interest us in our study are (including the determination method): particulate matter (PM_{10} - Light Scattering Particle), nitrogen dioxide (NO_2 - chemiluminescence), sulfur dioxide (SO_2 - UV fluorescence analyser), carbon monoxide (CO - Non-Dispersive Infrared), and ozone (O_3 - ultraviolet photometric analyser) (Anon, 2008).

The measurements are made in real time and are transmitted to a central database that is free to use (Anon n.d.-a). Details of the AQS from Galati City are presented in Table 1. In Figure 1 and Table 1 it is presented graphically and numerically the spatial extent of the maximum spatial detection limit buffer of each AQS.

Table 1. Specifications of AQS network from Galati city

AQS type	AQS code	Limit of detection maximum (km)	Limit of detection minimum (km)	Latitude (decimal degrees)	Longitude (decimal degrees)
Traffic	GL1	0.1	0.01	45.41868	28.016577
Urban	GL2	5	1	45.43146	28.054877
Suburban	GL3	5	1	45.47377	28.033728
Industrial	GL4	1	0.01	45.41117	28.005526

1.2.2. Air quality system Sniffer 4Dv1 (SN)

The air quality system Sniffer 4Dv1 is a very lightweight (>350 g), compact, and portable air quality system that uses various determination methods via several sensors that can measure up to nine air quality parameters, including temperature and humidity. The system works using pomp to bring external air to the sensors via the frontal inlet. The sensors can be mounted inside the main body of the monitor in several combinations depending on applications, this include personal exposure monitoring, urban air quality monitoring, and industrial emissions monitoring (Anon n.d.-d). The sensor combination used for this study is presented in Table 2 along with the technical specifications of each sensor.

Table 2. Specifications of sensors of the air quality system Sniffer4D v1 used for the measurements performed on 19 January 2022 in Galati city (Anon n.d.-c)

Sensor type	**High-resolution NO_2+O_3**	**Inhalable Particulate Matter (PM_{10})**	**High-resolution CO**	**High-resolution SO_2**
Pollutant	NO_2+O_3	PM 10 (particle size 0.3~10 µm)	CO	SO_2
Measurement Range	0-11 (ppm)	0-1000 (µg/m3)	0-10 (ppm)	0 -15 (ppm)
Detection Limit:	5 (ppb)	1 (µg/m3)	10 (ppb)	5 (ppb)
theoretical resolution	1 (ppb)	1 (µg/m3)	0.7 (ppb)	0.5 (ppb)
Sensor type	Electrochemical	Laser scattering/Light scattering	Electrochemical	Electrochemical

The air quality system Sniffer 4Dv1 was developed to be used on-board mobile platforms, specifically for UAVs (unmanned aerial vehicles), but for our study we adapted it, so it was mounted on top of our mobile laboratory (Figure 2). In Figure 2 the inlet of the equipment is pointing in the forward direction, so the system will not measure the direct emissions of our auto-laboratory. In Figure 2 it can be noticed that we powered the system via a 6S1P drone Li-Po battery. Also, it can be observed the telemetry antenna which is mounted on the back of the air quality system Sniffer 4Dv1, is used for real-time data transfer, settings, and measurements startup from a maximum distance of 2 km in urban areas (Anon n.d.-c).

Our system houses a combination of several sensors that can simultaneously collect real-time data for NO_2+O_3, SO_2, PM_{10}, and CO.

The data from these sensors is collected and processed using advanced algorithms to provide real-time measurements of air quality. The data is transferred via a 433MHz radio telemetry system to a laptop where the data is recorded, analysed, and visualized in real-time using the software Sniffer4D Mapper (Figure 3).

The general specification of data sampling from AQS and details of the track and sampling specification for the air quality system Sniffer 4Dv1 are presented in Table 3.

Table 3. Sample specifications for AQS and air quality system Sniffer 4Dv1 during the measurements performed between 12 -3 PM on 19.01.2022 in Galati city

Instrument/ AQS Sampling specifications	**Sniffer track and measurements characteristics**	**AQS GL1**	**AQS GL2**	**AQS GL3**	**AQS GL4**
Number of Samples	10309	240	240	240	240
Average Size of the Grid (km2)	0.019	0.031	78.5	78.5	3.1
The total detected area (km2)	11.252	0.00031	78.5	78.5	3.1

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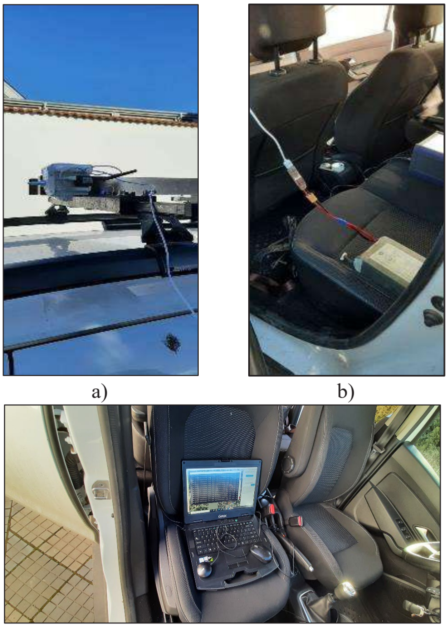

a) b)

c)

Figure 2. The setup of the air quality system Sniffer 4Dv1 mounted on top of the auto laboratory: a) Positioning the system, the power cable, and telemetry antenna b) Connection to the 6SP1 Li-Po battery used as the power source. c) The laptop is used for real-time data visualization and recording

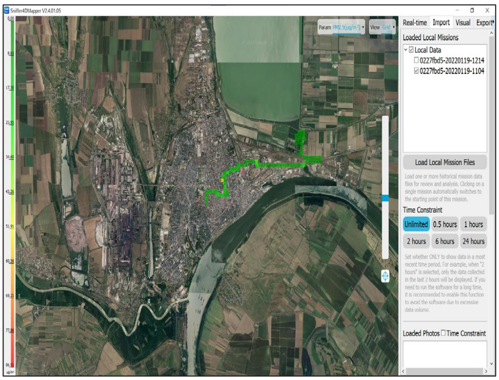

Figure 3. Print screen of the software Sniffer4D Mapper interface during the real-time data recording and visualization for the measurements performed in Galati city on 19.01.2022

For the comparison of AQS with the data from the Sniffer 4Dv1, we summed up the concentration values for O_3 and NO_2 recorded at each AQS from Galați City. Also, we excluded data from Sniffer 4D data for $PM_{2.5}$ because no data was available from all AQS at the time we performed the measurement.

RESULTS AND DISCUSSIONS

Using the coordinates embedded in the Sniffer 4 Dv1 data set we produced maps using Geographic Information System (GIS) software. All the maps of the concentration's distribution of each air pollutant PM_{10}, NO_2+O_3, SO_2, CO, alongside with AQS average hourly mean of the same air pollutant are presented in Figures 4 to 7. The AQS value was produced from all the hourly mean values of each pollutant during the whole time we performed mobile measurements (from 12:00 - 3:00 PM).

Firstly, we can observe in Figures 4 to 7 there is a high difference between the values of SN versus AQS and that could be a cause of the sampling rates of the Sniffer 4Dv1, one determination per second, and the AQS sampling rate of one determination each minute (the result is expressed in hourly mean value). The Sniffer 4Dv1 has a higher temporal resolution and probably this influences the results of the measurements into obtaining more values and thus a higher overestimation of the air pollution. Another cause of the high differences is the determination method but some of the studies presented that for similar sensors the differences between the measured values measured with chemiluminescence and electrochemical sensors are small, especially for CO, NO_2+O_3 (Afshar-Mohajer et al., 2018; Lin et al., 2015; Mead et al., 2013; Spicer et al., 1994).

If we discuss on the area of the sampling of the air pollution detection (pixel sampling size), on the one hand, we can observe in Table 3 that the SN has a sampling area of 0.019 km^2 per measurement(pixel), on the other hand, the AQS sampling area of detection ranges from very narrow pixels (0.031 km^2) to very wide ones (~78.5) km^2. Thus, GL1 and GL4 will detect more localized emissions whereas GL2 and GL3 will detect far-away emissions and will mediate them on the entire surface of the detection limit as we can observe in the pollutants values the maps presented in Figures 4 to 7.

Also, the fact that we capture with our SN more localized hot spots during the mobile measurements could help us understand what the major emissions sources for each air pollutant are and where is concentrated spatially within the Galati city boundary.

The circles represented with the black line in Figures 4 to 7 represent the maximum limit of detection of each AQS (Table 1). For AQS GL1 the spatial buffer (radius around the AQS) is 100 m, that's the reason it is not visible on the map.

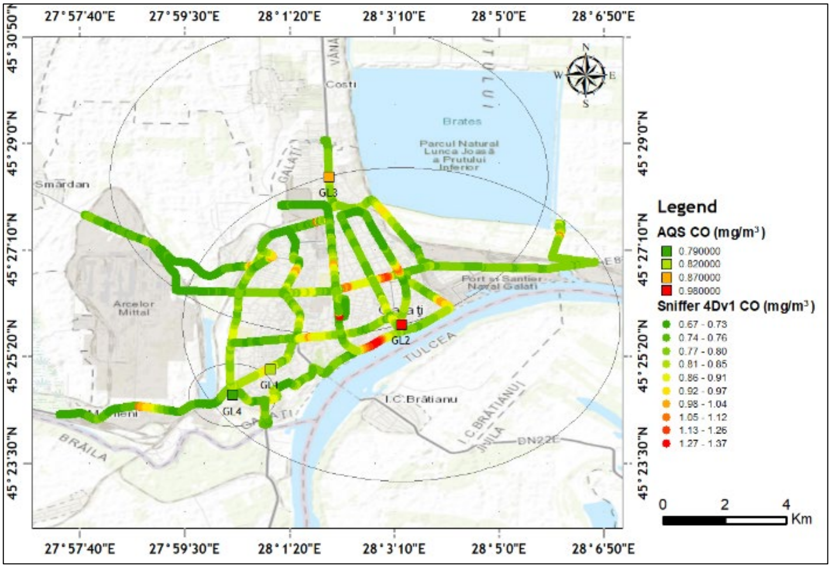

Figure 4. Distribution map of CO concentrations measured with SN and recorded by AQS between 12-15 LT on 19.01.2022 in Galati city

In Figure 4 is observed that CO higher concentrations measured by SN are concentrated in the eastern part of Galati city with values between 1.04-1.37 mg/m^3. The high values can be a cause of traffic agglomeration on the main roads of the city, or we believe it's the wind-driven plume of an oil factory that is located in that part of the city (Roşu et al., 2020).

The fact that we believe it's the oil factory is that a similar value is recorded by the AQS GL2 0.98 mg/m^3 which is located in the same part of the city. Also, we should consider that the AQS GL2 value has resulted from averaging all the concentration values recorded inside its buffer of the detection limit, and this could explain the difference between SN, with most of the lower values along the track and more localized for higher values. We could notice that the value of 0.98 mg/m^3 recorded by AQS GL2, even if it is an average hourly value for the entire period when the mobile SN measurements were performed, is similar to the high values recorded close by the SN system. This could mean that at each passing by the SN, the system measured instantaneous values of the plume that was passing that area and produced the value recorded by AQS GL2.

A similar averaging effect can be seen in the measured hourly value of CO concentrations from all AQS where it can be observed that practically the values measured by each AQS can be described by the SN mobile measurements inside each stations limit of detection buffer trough a spatial mediation effect of the mobile recorded values.

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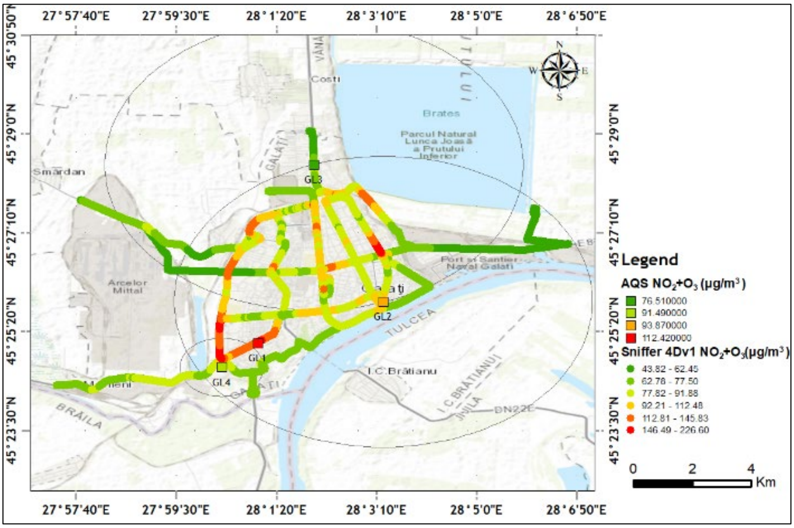

Figure 5. Distribution map of $NO_2 + O_3$ concentrations measured with SN
| and recorded by AQS between 12-15 LT on 19.01.2022 in Galati city

Figure 5 presents the measured values for the sum of nitrogen dioxide and ozone concentrations values recorded by SN and AQS on 19.01.2022 in Galati City. As we can observe the variation of the recorded values is higher than in the case of CO. High values between 92.21-226.60 μg/m³ were measured in the centre of the city and on the main roads with an intensified car or heavy truck traffic, e.g. the ring roads of the city or the highly circulated roads that cross the entire city from one side to another. The AQS GL1 recorded averaged hourly values to a value of 112 μg/m³, a value that is like the ones that SN recorded instantaneously in the same area. The explanation for recording a very similar value is that the AQS averaged all the NO_2+O_3 values within its buffer of the maximum range of detection of 0.01 km. Also, the high values could be explained by the fact that the plume of pollutants NO_2+O_3 remained in the same area, or the area pollution is being caused by high constant car traffic. If we look at the spatial limit of the detection buffer (black line circle) for the AQS GL2 and the average value for 12-3 PM of 93.87 μg/m³we could say that the value is similar to the ones that were recorded by the SN inside the buffer of AQS GL2, most of the value recorded are between 43.82-91.88 μg/m³, followed by the high values between 112.81-226.60 μg/m³, which are less localized and were detected alongside a small portion of the main roads. This could only strengthen the idea that the main source of the recorded values are cars and heavy traffic. In Figure 5 it can be observed that the AQS GL3 recorded a smaller hourly average value of 71.51 μg/m³ since it's a suburban station and as we can observe the extent of the buffer it's more likely to measure the emissions outside the urban agglomeration and only a small portion of buffer covers the city. This can be explained also if we observe the values recorded by the SN we can say that the AQS GL3 only detects the emissions sources (car traffic) that reside in the Northern part of Galati city and the suburban area. The same thing can be noticed for the industrial AQS GL 4 which measured an hourly averaged value of 91.49 μg/m³, where high values measured by SN ranged between 112.81 – 146.40 μg/m³ and covered a small portion of the buffer of the AQS GL4 and most of the buffer was spatially covered by SN instantaneous measured values ranged between 62.78-91.88 μg/m³.

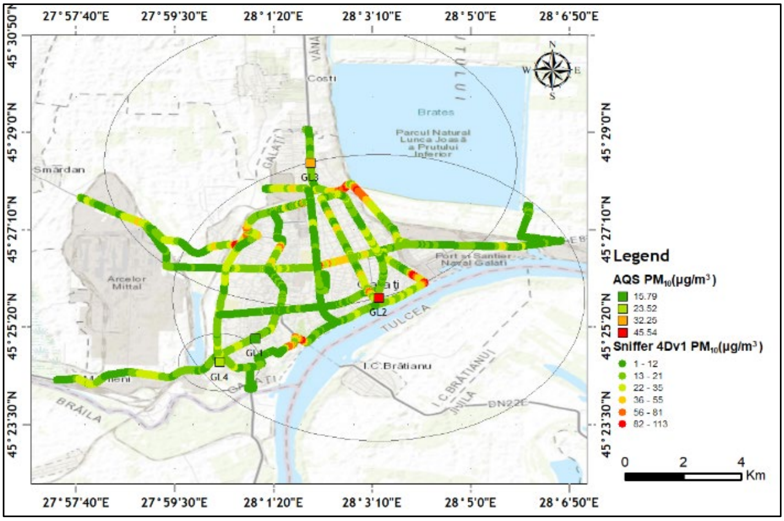

Figure 6. Distribution map of PM_{10} concentrations measured with SN and recorded by AQS between 12-15 LT on 19.01.2022 in Galati city

The values for the measured concentrations of PM_{10} by the SN system along the main streets of Galati City are presented in Figure 6. The values measured ranged from 1-113 µg/m³. High values between 56-113 µg/m³ were measured close to important crossroads or in the areas where heavy traffic is usually present (the North and North-East of Galati City). Similar values of PM_{10} concentrations were recorded by each of the AQS if we consider the spatial limit of the detection buffer and the location of each AQS. Values that are sustained by the measured values with the SN system. The highest hourly average value of 45.54 µg/m³ was recorded by AQS GL2. Also, all high values recorded by the SN system ranged between 36-113 µg/m³ and were measured inside the AQS GL2 buffer. The emissions were measured at the cross of the main roads. This could only indicate that the emissions of PM_{10} are most likely produced by car traffic and heavy traffic.

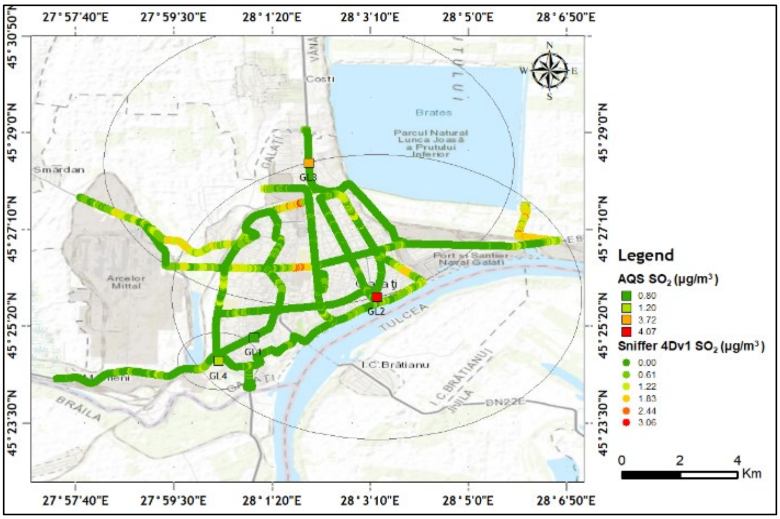

Figure 7. Distribution map of SO_2 concentrations measured with SN and recorded by AQS between 12-15 LT on 19.01.2022 in Galati city

In the case of sulphur dioxide (SO_2), we can observe in Figure 7 that measured concentrations with SN are very low and ranges from 0.00 – 3.06 μg/m³. Similar averaged hourly concentration values of SO_2 were recorded by all AQS. This could only underline that the SN measured values are real and comparable with AQS data if we take into account the spatial distribution of measured values of the SN system concerning the detection limit range of each AQS. Also, it can be noticed that hot spots of SO_2 measured by the SN system are localized in the central area and the north part of Galati City, near rural areas or where more houses with household heating based on fossil fuel burning (wood or coal) are present. Anomalies of measured values can be observed in the remote east part of Galati City, where we believe measured values of SO_2 are errors caused by the presence of high concentrations of H_2S due to a marshy area (Khan, Rao & Li 2019). This finding needs to be further analysed and studied with a sensor of SN that can measure concomitantly the H_2S and SO_2 (Anon n.d.-c).

CONCLUSIONS

The results of the study showed that the Sniffer 4Dv1 is a very complex and useful instrument that can be used for air quality monitoring in urban areas, as we presented in the results of the measurements performed on January 19, 2022, on the main roads of Galati. The main advantage of the SN is that it can detect and measure real-time and simultaneous data for a wide range of air pollutants, including nitrogen oxides, sulfur dioxide, ozone, and particulate matter, which were the main subject of this work. By capturing instantaneous values of the concentration of each air pollutant, we can better observe the dynamics of air pollutants and indicate the main sources, which we found based on SN measurements to be industrial for CO, industrial and car traffic for NO_2 and O_3, car traffic and heavy traffic PM_{10}, and household heating for SO_2.

The comparison with the average hourly data from AQS, for the entire period we performed mobile measurements with SN, showed that the SN system measured more localized concentration values (hot spots) around emissions sources, while the AQS measures values from wide areas to narrow areas (0.031 km^2), integrating and averaging all the values recorded within its detection buffer. However, the spatially compared data recorded at each AQS for each air pollutant showed similar values to those recorded by our SN system inside the buffer of each AQS.

Overall, we believe that the Sniffer 4Dv1 represents an advancement in air quality measurement technology, enabling us to better understand the complex dynamics of air pollution in our urban environments. The Sniffer 4Dv1 is a valuable tool for understanding the sources and impacts of air pollution and for developing effective strategies to reduce exposure and improve public health.

We propose doing more comparative studies to identify the sensibility of the system by measuring each air pollutant in different conditions and with different equipment and different measuring methods. Further studies need to be done to say to validate the data obtained with Sniffer 4Dv1 compared to data from the best available technologies (BAT) implemented at each AQS or by other standardized instruments for air quality measurements. The next studies will include an analysis of time series variation using local long-time measurements near AQS with a long-range spatial limit of detection and AQS with a narrow spatial limit of detection for the same pollutants, this will give us an idea of data consistency over time and on the evaluation of error of detection for each pollutant (factory versus experimental).

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