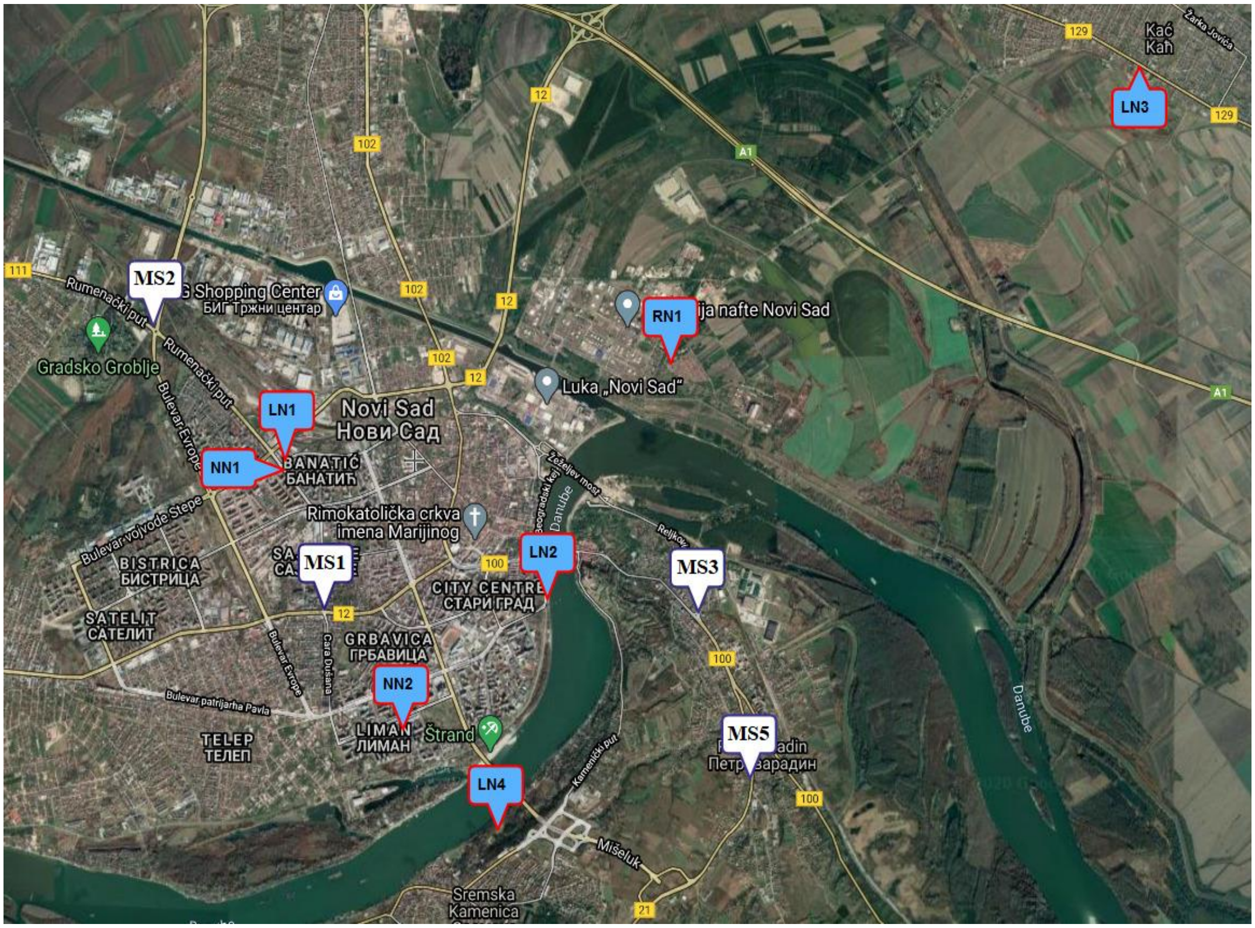

Analysis of the correlations between the COVID-19 pandemic and air quality

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Highlights

- Changes in air pollution in the region of the city of Novi Sad due to COVID19 induced state of emergency (period of ‘lockdown’) was assessed using data from Air quality monitoring stations that belong to national, regional, and local networks as well as to additional measuring sites being part of an ongoing research study aimed at data acquisition for purposes of creation of air pollution maps for Novi Sad
- Assessment provided following key findings: Fine and coarse particulate matter as well as SO_2 levels did not change significantly with the lockdown;
- On March 27th and 28th whole region and country were under particulate matter pollution episode with the source of which was traced back to the far Aralkum Desert, that makes difficulty in the characterization of the impact of the lockdown on particulate pollution by comparing observations before and after the lockdown. This episode highlights the difficulty to quantify the impact of the lockdown on particulate pollution by comparing observations before and after the lockdown;
- There is moderate evidence of O_3 concentration increase after the lockdown;
- There is strong evidence for reductions of NO_2, NO and NOx after the lockdown;
- Daily profiles of particulate matter during the first ten days of state of emergency mainly show lower levels during working hours and higher levels during the night and early morning compared to the days before the lockdown;
- Daily profiles of NO_2, NO and NO_X during the first ten days of the state of emergency prove lower levels during working hours as well as during night hours and early morning compared to
2 the days before the lockdown;
- Daily profiles of CO during the first ten days of state of emergency mainly prove lower level during night compared to the days before the lockdown;
- Pollutants dominantly originating from transport exhibited a decrease in the level;
- Pollutants originating from domestic heating mostly exhibited a constant level;
- Taking into account local sources of air quality in the region of Novi Sad, slight improvement was observed after the lockdown in comparison with days before.

1. Introduction

Both short-term and long-term exposure to air pollution is considered a significant public health concern. Long-term exposure to air pollution has been related to overall mortality and various diseases such as respiratory and cardiovascular diseases. Short-term exposure may contribute to complications of atherosclerosis and acute ischemic events. Due to the high spatial variability of air pollution concentrations, assessment of individual exposure to air pollution requires spatial datasets of high resolution.

This report is a part of a more extensive research study performed in cooperation between a team of researchers from Vinča Institute of Nuclear Sciences, University of Belgrade, National Institute of the Republic of Serbia and Faculty of Technical Sciences, University of Novi Sad. During the heating season (February-March 2020), the campaign's main objective was to collect particulate matter using reference gravimetric pumps and low-cost sensors in the wider area of the city of Novi Sad. An additional goal of this larger study is to analyse spatial and temporal data variability and generate PM2.5 pollution data that are necessary for creating particulate matter air pollution maps with high spatial and temporal resolution.

Measures to control the COVID-19 outbreak, commonly named lockdown, were used as an opportunity to conduct an additional experiment, in which preliminary results about possible relation between massive change of general population daily habits, change in traffic and industrial emissions on one side and air pollution on the other. Several case studies already conducted in COVID-19 struck regions with similar premises showed the following results. The lockdown interventions led to a reduction in population-weighted PM2.5 of 14.5 μg/m³ across China (–29.7%) and 2.2 μg/m³ across Europe (–17.1%) (Giani, 2020). Air quality was improved in some areas due to the lockdown measures, while other areas have only negligible improvements despite the extensive lockdowns.

In addition to the $PM_{2.5}$, main air pollutants namely: PM_{10} and following gaseous pollutants NO_2, SO_2, CO and O_3 in the region of Novi Sad were analysed using available data collected at national, regional and local monitoring stations in the period of the primary planed campaign. It is evident that NO_2, NO_X and NO significantly decrease, O_3 increase while $PM_{2.5}$ and PM_{10} stay about the same (mixed decrease/increase) during the lockdown. Situation regarding PM levels in Novi Sad was similar as in several other cities in region (Copernicus Europe`s eyes on Earth, 2020).

2. Materials and methods

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Study area

Novi Sad represents an urban-industrial agglomeration, and is a second largest city in Serbia. The city is situated at about 80m above sea level, and experiences regional climate from moderately continental to continental. Regarding wind conditions, in terms of frequency, winds that prevail in Novi Sad are north, north-east, and north-west. The speed of all recorded winds is mostly between 2.2 and 3.1 m/s (Petrovic, 2017). The main sources of outdoor air pollution in Serbia include the energy sector, the transport sector, waste dump sites, and industrial activities, while the specific sources of air pollution in Novi Sad include the petrochemical industry complex and increasing road traffic (WHO, 2019).

Sampling campaign

Particulate matter sampling of $PM_{2.5}$ μm, in the ambient air of Novi Sad, was conducted during February and March. Sampling was carried out on four measuring sites (MS), namely: MS1 (Hajduk Veljkova 4, from 2020-03-08 to 2020-03-24), MS2 (Rumenački put 20, from 2020-03-08 to 2020-03-24), MS3 (Reljkovićeva 2, from 2020-03-08 to 2020-03-24), MS5 (Račkog 78. from 2020-02-06 to 2020-02-23 and from 2020-03-18 to 2020-03-26). All four localities can be characterized as traffic sites since they are situated in the vicinity of traffic intersections and streets with a high or medium volume of traffic (Figure 1). Discontinuous numbering of measuring sites is because they are a subset of about 20 measuring sites for which a larger campaign was planned, and MS1, MS2, MS3 and MS5 were suitable for sampling during COVID-19 measures of the state of emergency.

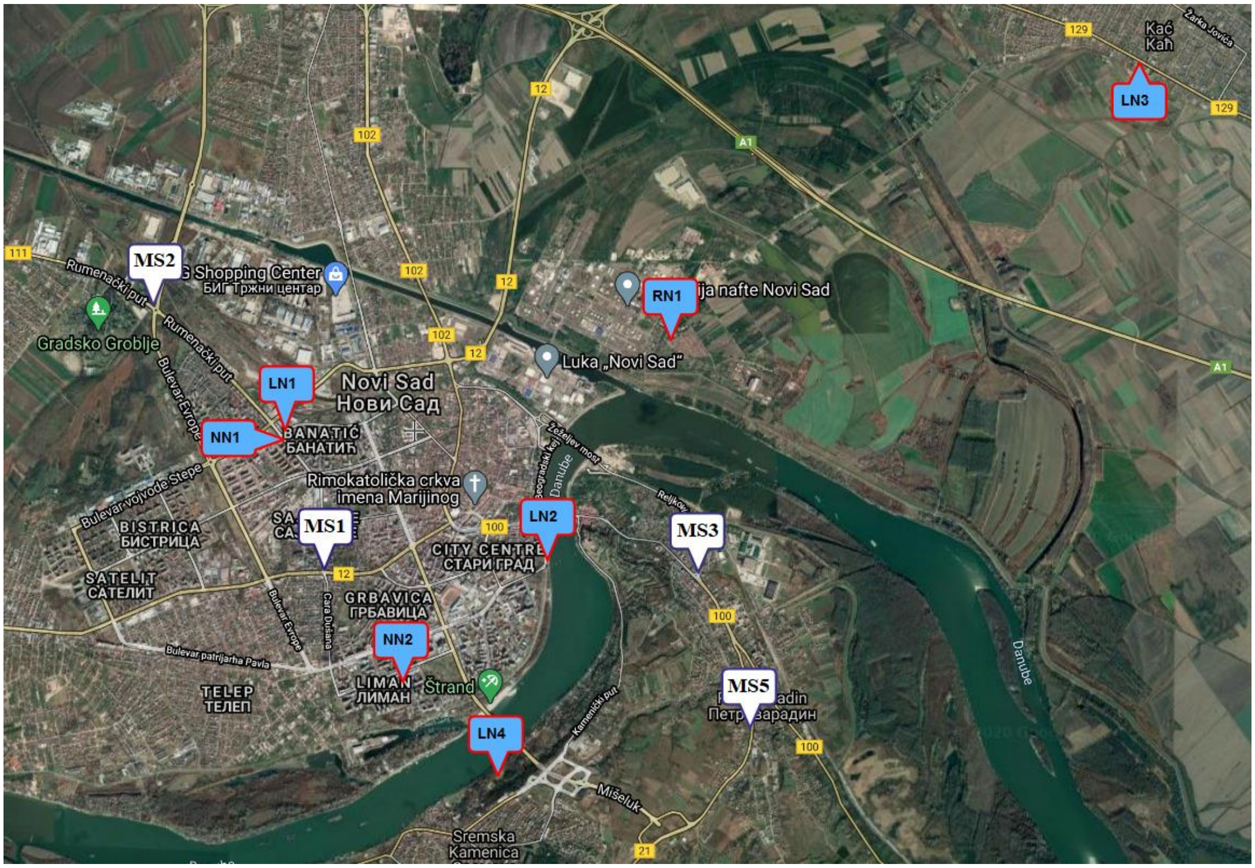

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Figure 1. Map with location of measuring sites (MS1, MS2, MS3, MS5) and monitoring stations at national (NN), regional (RN) and local level (LN)

Considering MS positions, possible sources of $PM_{2.5}$ in the ambient air at all four localities include traffic, along with households and facilities in the vicinity that are using natural gas and other fossil fuels as a heating source. GPS coordinates and more information about each location is given in Table 1.

Table 1. Measuring station description and GPS coordinates

MS	Measuring station	Coordinates
1	• Measuring station one (MS1) was located in a narrow city centre, at a distance of 50 m from the intersection of Futoški put, Hajduk Veljkova, and Cara Dušana Street. • Possible sources of PM2.5 beside traffic could be residential heating small boilers and stoves for individual households in the surrounding area. Types of vehicles passing the intersection are light vehicles and public transportation (busses). • In the vicinity of about 1 km, a small heating plant is placed. • The measuring instruments were set at the height of 3 m.	45.24968, 19.82467
2	• Station two (MS2) was located in the Industrial Zone South, at the very border with the residential area in the Rumenačka 20 street. • Measuring instruments were located at the height of about 2.5 m next to a very busy roundabout, within the courtyard of the	45.27573, 19.80066

	Veterinary Institute in Novi Sad. The distance between the roundabout and measuring place was about 30 m. ● The traffic at MS2 consists mainly of light and heavy trucks and buses, since the roundabout represents the main way that leads to the highway in that city area. ● The rest of the Industrial zone consists of a couple of industrial plants whose production capacities are very low, so the main source of suspended particles at this location is traffic.	
3	● The third measuring station, MS3, was situated in Petrovaradin, associated municipality of Novi Sad. ● Instruments were placed at the height of 3 m, near the intersection of Reljkovićeva and Preradovićeva Street, which can be considered as one of the busiest intersections in Petrovaradin municipality. The distance between measuring place and Reljkovićeva Street was 5 m, and the distance to the intersection was 60 m. ● Reljkovićeva Street is the main street of heavy traffic that passes through Petrovaradin from Novi Sad. Traffic mainly consists of trucks and cars and, to a lesser extent, of bus traffic. ● Sources of PM2.5 at the measuring site beside traffic are residential heating.	45.2494, 19.87729
5	● The fifth station, MS5, was placed like MS3 in Petrovaradin. ● Račkog Street served as transportation hubs in the vicinity of the intersections of regional roads. It is the busiest street in Petrovaradin, where there is a high intensity of both, heavy vehicle and light vehicle traffic. The major part of heavy transportation from Reljkovićeva Street passes through this street. ● The measuring instruments were set on the height of 3 m, at the distance of 12 m from the street. ● At this site, particulate matter can be emitted mainly by traffic and by residential heating boilers.	45.23406, 19.88453

The instruments were situated within 1m of each other, and no additional inlets were used in order to minimize particle losses.

At measuring sites, the instrumentation was at about 2-3 meters above the ground. It included one low-cost sensor suite (LCS) (ekoNET made by Dunavnet with PMS7003 particulate matter sensor) and a reference pump (Leckel Model LVS3) with $PM_{2.5}$ standard inlet (RFP).

The sampling campaign was carried out at all 4 measuring sites continuously, 7 days before the measures of the state of emergency (abbreviation BEMS in further text) and 8 days during the state of emergency (abbreviation EMS in further text) that was declared due to COVID19 in Serbia. Quartz fibre filters used for sampling the particles were replaced every 48 hours.

a) M1, frequent traffic (light vehicles and buses for public transport) and residential heating (gas, coal and wood)

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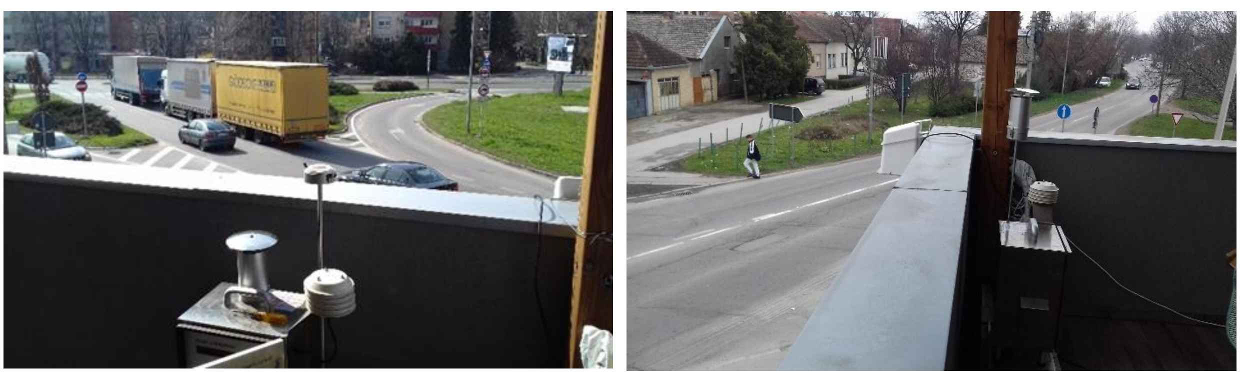
b) MS2, Traffic light and heavy trucks and buses and low-capacity industry



c) MS3, Traffic mainly consists of trucks and cars and residential heating

7 d) MS5, the busiest street in Petrovaradin, where there is a high intensity of both, heavy vehicle and light vehicle traffic

Figure 2. Depiction of measuring station during COVID-19 measuring campaign a) MS1, b) MS2, c) MS3 and d) MS5. Discontinuous numbering of measuring sites is due to them being a subset of about 20 measuring sites for which a larger campaign was planned, and MS1, MS2, MS3 and MS5 were suitable for sampling during COVID-19 measures of the state of emergency.

3. Air pollution monitoring at national, regional and local networks at Novi Sad

Monitoring of outdoor ambient air quality is usually done via networks at the national and local level. However, despite having high quality of instrumentation these kinds of networks are usually very sparse, may not monitor all interest parameters, and give little insight into personal exposure. For rapid deployment and increased temporal resolution IOT enabled low-cost sensors may be of greater interest.

In the city of Novi Sad there are three main groups of monitoring stations: stations that belong to national networks, stations in the regional network and stations in the local monitoring networks.

National Network, (website http://www.amskv.sepa.gov.rs/pregledstanica.php)

- NN1, Novi Sad-Rumenačka (air quality variables that are monitored: SO2, NO2, CO, PM10, PM2.5)
  type of station: traffic (45.262626, 19.819016)
- NN2, Novi Sad- Liman (air quality variables that are monitored: SO2, O3, NO2, CO)

type of station: background (45.238642, 19.835704)

Regional Network, (website http://www.amskv.sepa.gov.rs/pregledstanica.php),

- RN1, Novi Sad - Šangaj (air quality variables that are monitored: BTEX, H_2S,SO_2, t, RH, w_d, w_s), basic according to Regional Secretary of Urbanism and Environmental Protection industrial according to SEPA, 45.27237, 19.873331

Local network, (website https://environovisad.rs/air_points/mm3)

- LN1, Novi Sad-Intersection of Rumenačka Street and Bulevar Jaše Tomića
- LN2, Kać - King Petar 1
- LN3, Novi Sad- Sunčani kej 1
- LN4, Sremska Kamenica, Kamenički park 1-14

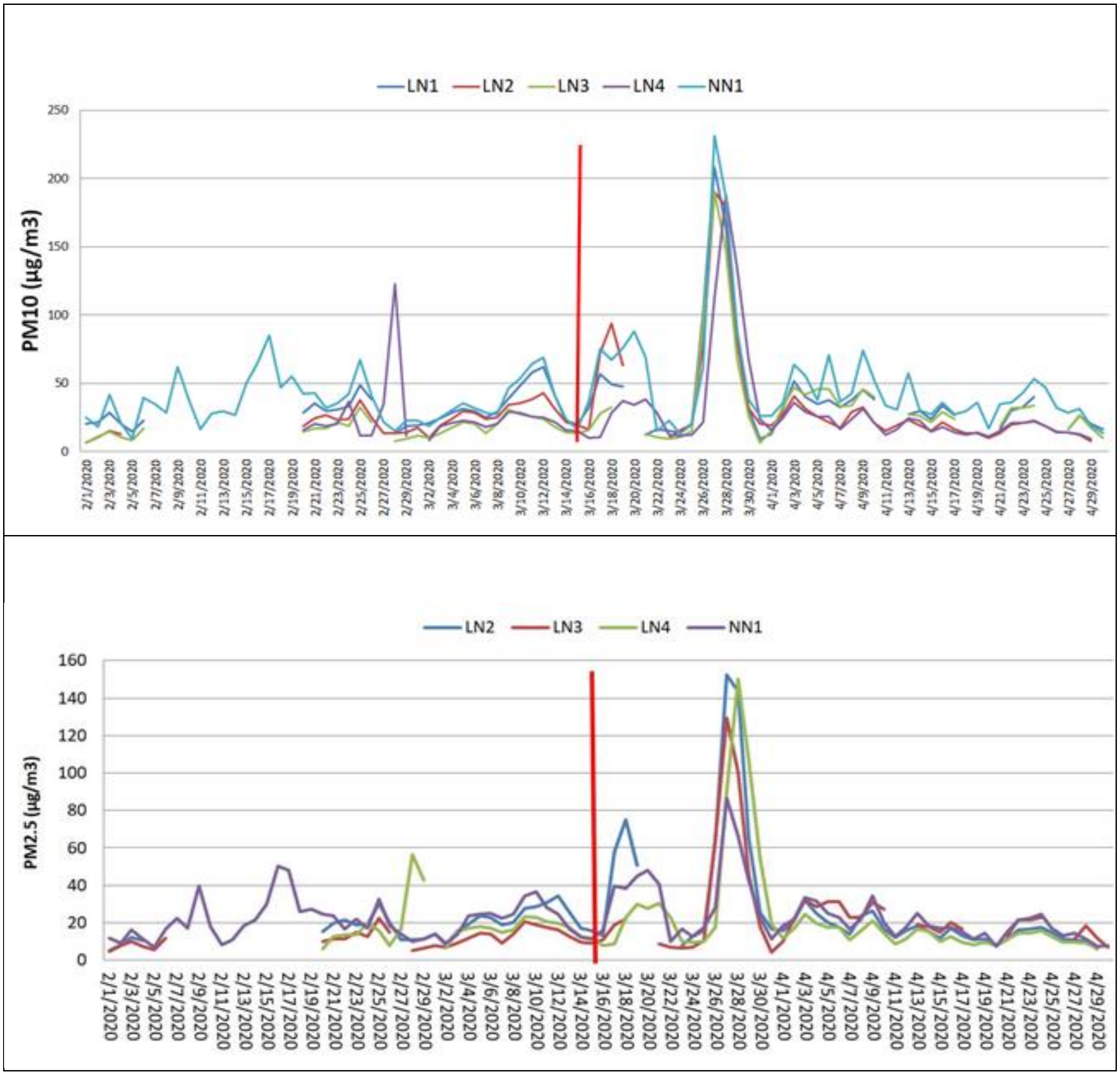
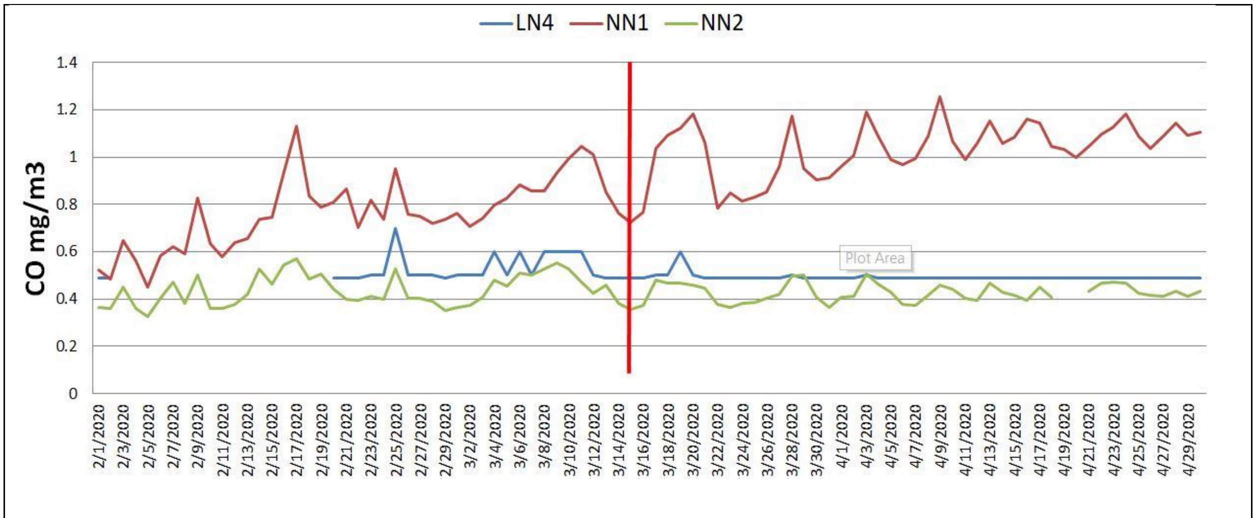
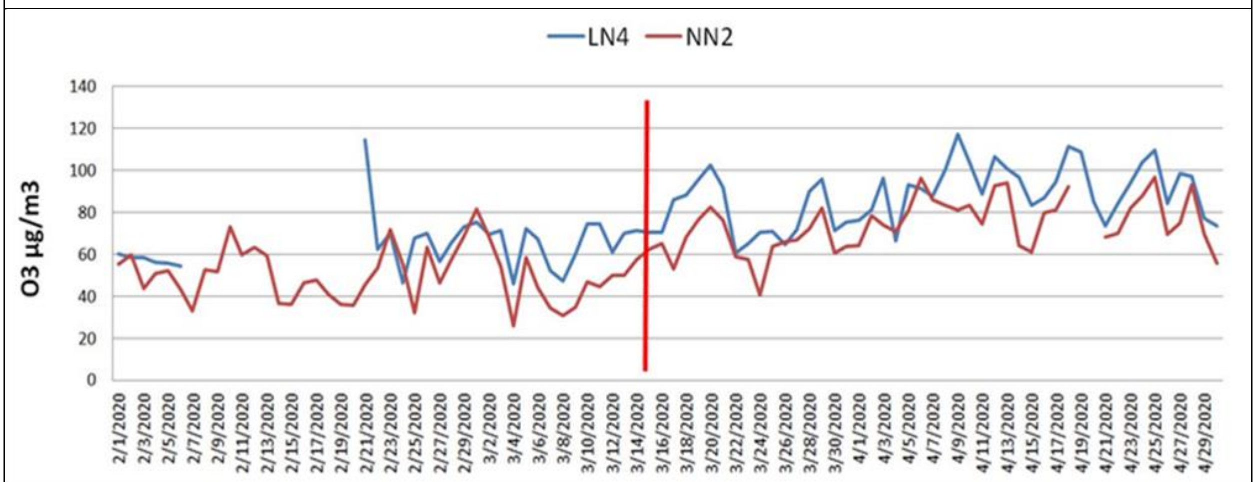
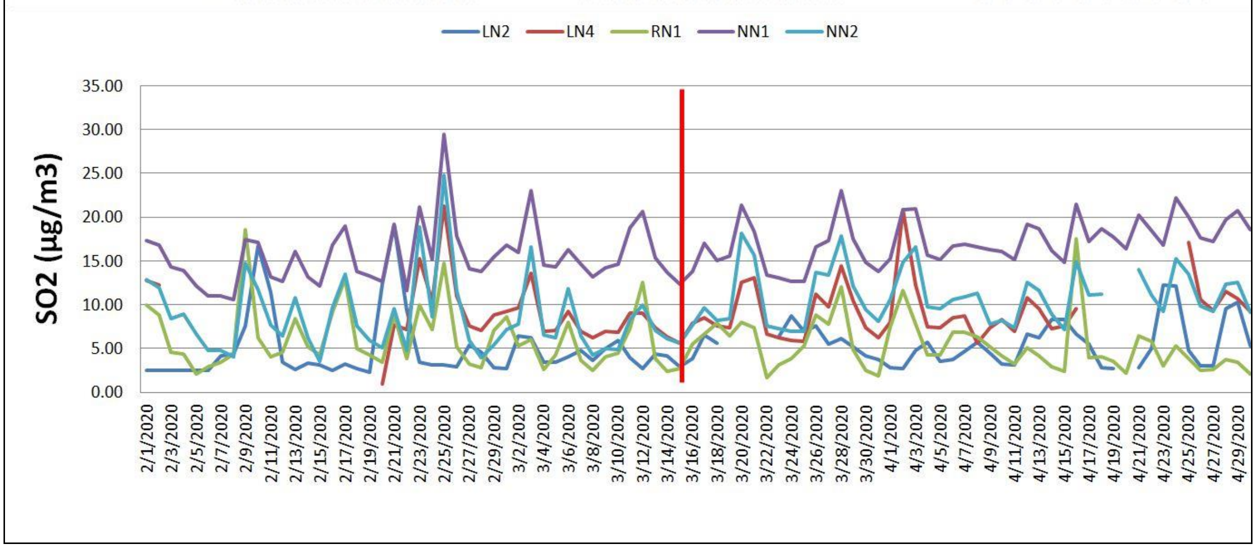


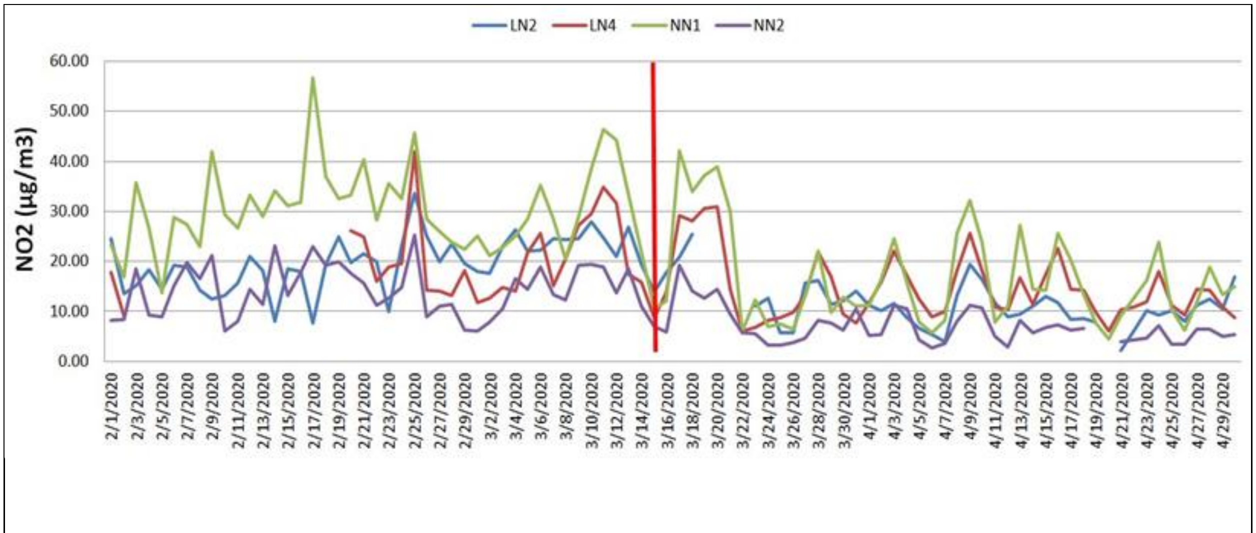
Figure 3. PM_{10} and $PM_{2.5}$ daily concentrations at national and local monitoring network sites during the measuring campaign and a few weeks before and after lockdown

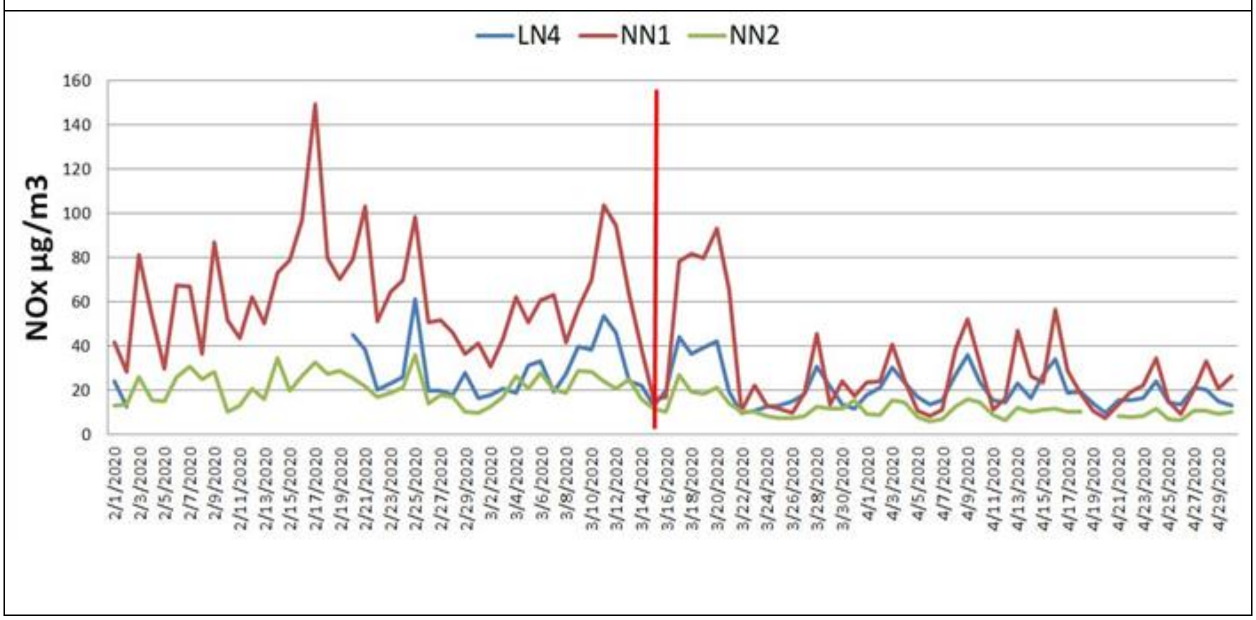

LN4
NN1
NN2
CO mg/m3
Plot Area


LN4
NN2
O3 µg/m3

9


LN2
LN4
RN1
NN1
NN2
SO2 (µg/m3)





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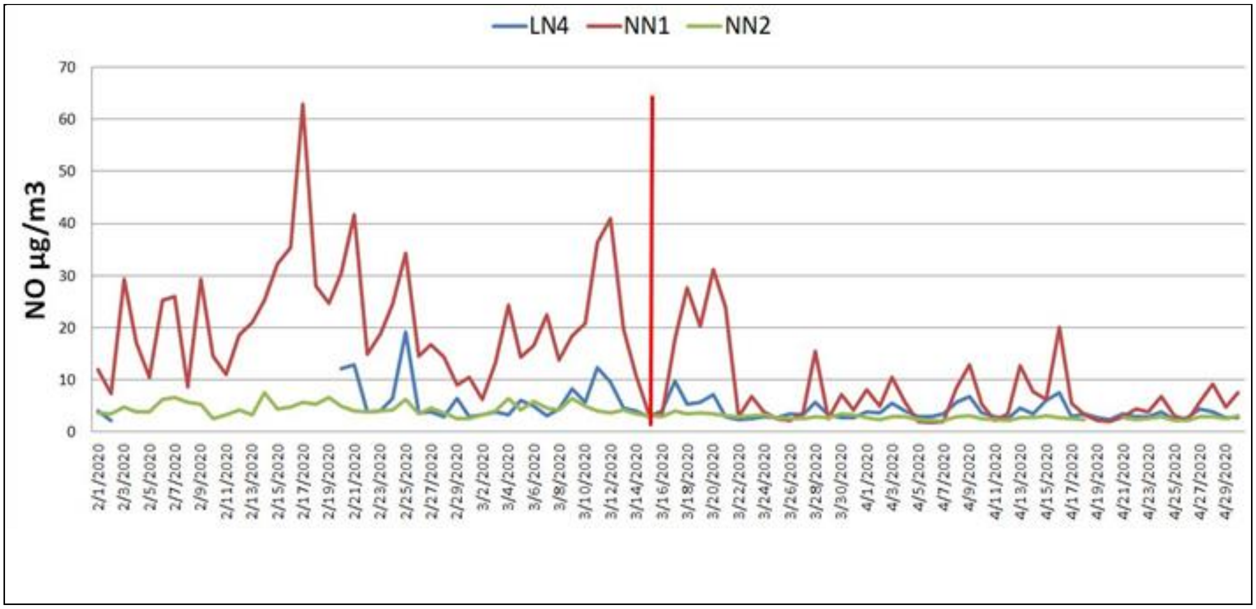

Figure 4. CO, O_3, SO_2, NO_2, NO_x and NO daily concentrations at national and local monitoring network sites during the measuring campaigns and a few weeks before and after lockdown

Figure 5 shows the Back-trajectory calculated using Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) transport and dispersion model. The air mass back trajectory was calculated at 270 m above the ground, on 27th March, when the maximal concentration of PM10 was measured at Novi Sad's national and local network sites. In Figure 3. and Figure 4. extremely high concentrations of both coarse
11 and fine particulate matter on March 27th and 28th can be noticed. For both days, the daily levels of PM10 and $PM_{2.5}$ were approximately 250 µg/m^3 and 100 µg/m^3 respectively. Extremely high concentrations of particulate matter were recorded at automatic monitoring stations in the whole of Serbia and surrounding countries. The minute concentrations of PM_{10} in some cities in Serbia were up to 600 µg/m^3. Based on the back-trajectory analysis, the presence of a possible source of non-local air pollution can be inferred. The Aralkum desert was pointed out as the external source of a high increase in PM. This source of dust was confirmed via back trajectory tracing to the Aralkum Desert that is located on the Kazakhstan and Uzbekistan border.

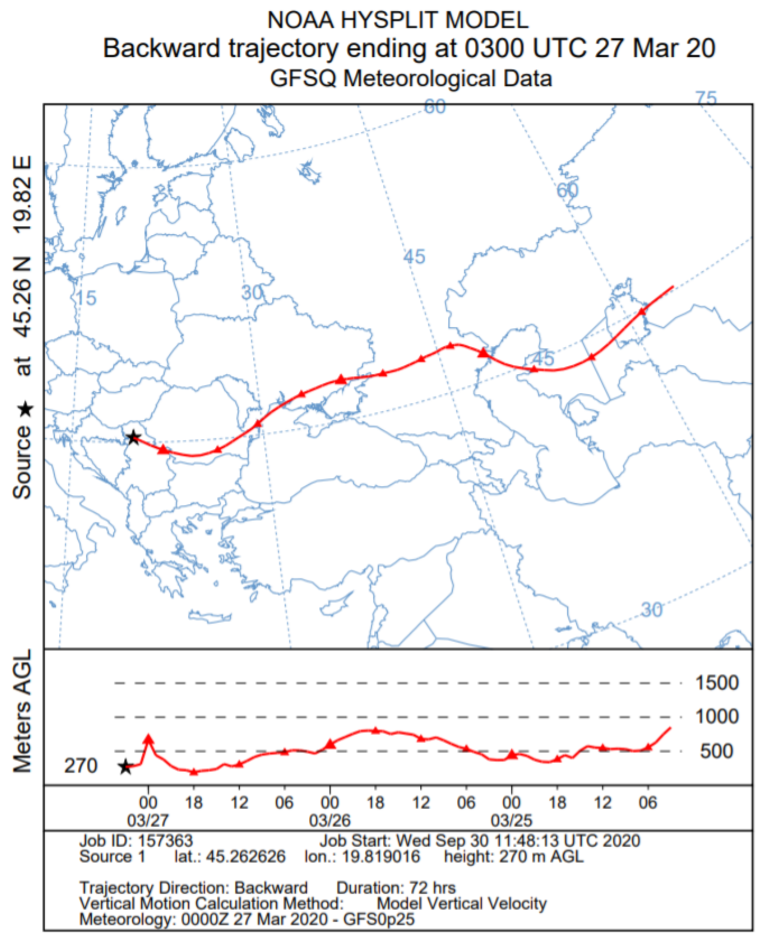

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Figure 5. The air mass back trajectory on 27th March at the city Novi Sad

Table 1. Descriptive statistics for PM10 data collected via national and local network for air pollution monitoring in Novi Sad for period of BEMS and EMS campaign cations in Novi Sad

BEMS (07.03-15.03), EMS (16.03.-26.03)

	LN1 Rumenačka		LN2 Kać		LN3 Vodovod		LN4 Sremska Kamenica		07NN1 SPENS	
Campaign	BEM	EM	BEM	EM	BEM	EM	BEM	EM	BEM	EM
Mean	39.88	44.60	31.00	66.00	22.00	31.44	22.75	35.18	42.81	49.76
St.dev.	17.28	41.90	10.07	44.42	7.01	39.54	6.14	44.39	19.14	28.03
Median	37.50	28.50	30.00	64.00	24.00	19.00	25.00	19.00	43.90	61.28
MIN	22.00	13.00	19.00	14.00	10.00	6.00	14.00	4.00	16.46	13.20
MAX	62.00	150.00	44.00	122.00	33.00	134.00	30.00	163.00	69.14	88.30

Table 2. Descriptive statistics for PM2.5 data collected via national and local network for air pollution monitoring in Novi Sad for period of BEMS and EMS campaign cations in Novi Sad

BEMS (07.03-15.03), EMS (16.03.-26.03)

	LN2 Kać		LN3 Vodovod		LN4 Sremska Kamenica		NN1 SPENS	
Campaign	BEM	EM	BEM	EM	BEM	EM	BEM	EM
Mean	24.80	28.80	14.95	14.79	18.20	20.78	23.60	22.90
St.dev.	8.06	35.54	4.77	26.88	4.91	26.62	9.50	14.27
Median	24.00	51.20	16.30	12.90	20.00	15.20	24.76	28.06
MIN	15.20	11.20	8.80	4.10	12.00	3.20	11.39	9.98
MAX	35.20	97.60	22.40	91.10	24.00	99.00	36.46	48.24

Data from EU member countries are published by EEA, https://www.eea.europa.eu/themes/air/air-quality-and-covid19. Data show, as in the city of Novi Sad, that NO_2, a pollutant mainly emitted by road transport, has decreased in many European cities where lockdown measures have been applied. Changes in levels of PM2.5 may also be expected due to lockdown measures, however a consistent reduction cannot yet be seen across European cities, as is the case in Novi Sad. This is likely due to the fact that the main sources of this pollutant are more varied, including at European level the combustion of fuel for the heating of residential, commercial and institutional buildings, industrial activities and road traffic. A significant fraction of particulate matter is also formed in the atmosphere from reactions of other air pollutants, including ammonia — a pollutant typically emitted from the application of agricultural fertilizers at this time of year.

Other factors, such as weather conditions, may also significantly contribute to the changes seen in pollutant concentrations. Conversely, changes in meteorology can also lead to increased air pollution, and coupled with the often non-linear relationships between changes in emissions and changes in concentrations, also explain why lower air pollution may not occur at all locations.

4. Spatial correlation of PM2.5 concentration in Novi Sad

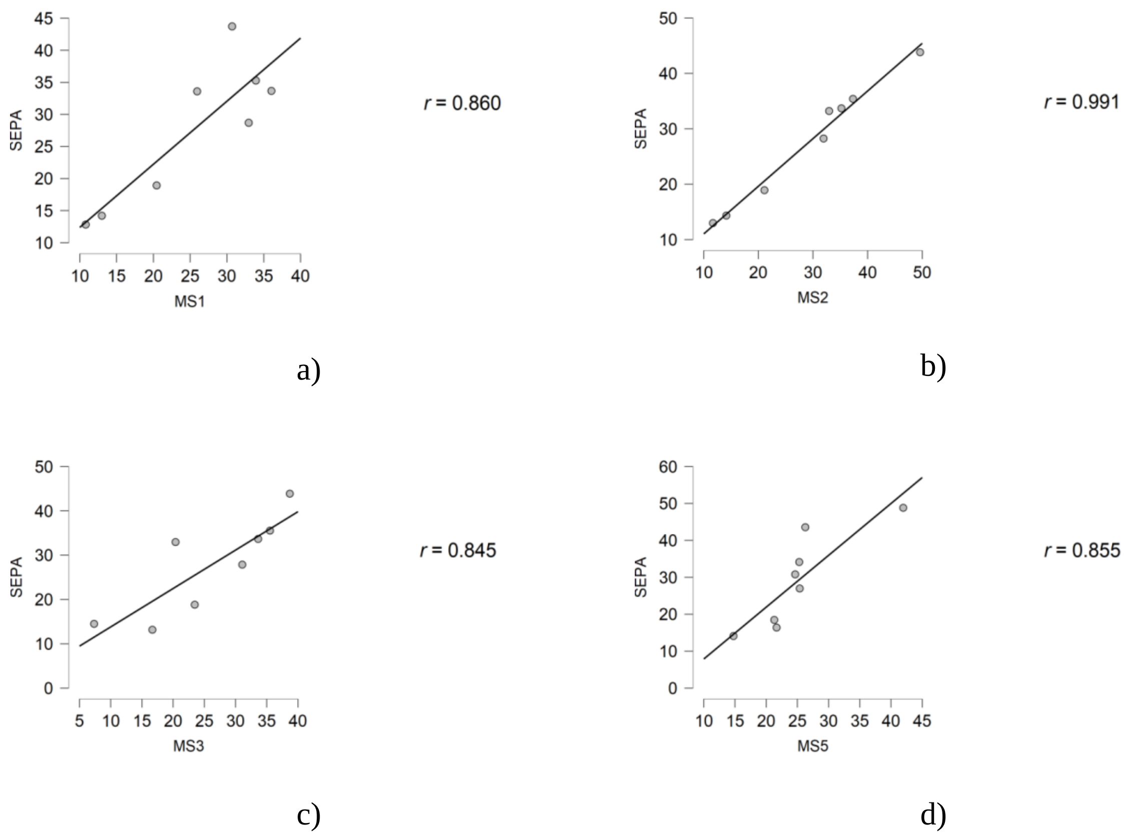

Figure 6. PM2.5 correlation: a) MS1 site reference pump vs. SEPA equivalent instrument b) MS2 site reference pump vs. SEPA equivalent instrument c) MS3 site reference pump vs. SEPA equivalent instrument d) MS5 site reference pump vs. SEPA equivalent instrument

Pearson's correlation coefficient between 48 h concentrations measured at the site that belongs to the national network of air quality monitoring NN1 collected with equivalent monitor GRIMM EDM 180 (https://www.grimm-aerosol.com/products-en/environmental-dust-monitoring/approved-pm-monitor/edm180-the-proven/) and concentrations measured using reference gravimetric pumps LVS Sven Leckel (https://www.leckel.de/) at MS1, MS2, MS3 and MS5 site vary between 0.85 and 0.99. The highest Pearson's correlation coefficient was identified, not surprisingly, between sites that are situated along the same street, Rumenačka, at the distance of about 2.7km. High correlation despite the relatively large distance between the sites indicates that sources of pollution covary, most probably due to traffic consisting of mainly light and heavy trucks and buses, since the roundabout represents the main way that leads to the highway in that city area. Pearson's correlation coefficient was also high for the other three sites, approximately 0.86 for the MS1 site and 0.85 for the other two sites located at the other side of the Danube river at Petrovaradin.

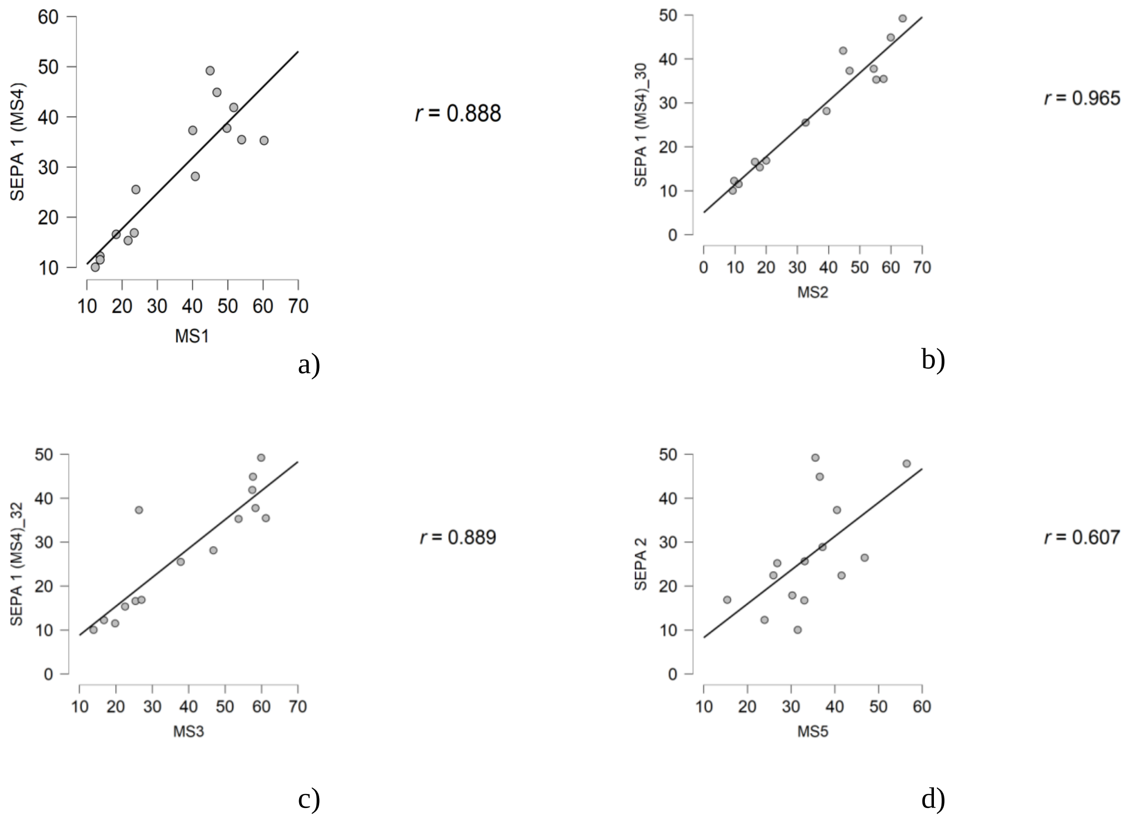

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Figure 7. PM2.5 correlation: a) MS1 low-cost sensor vs. SEPA equivalent instrument b) MS2 low-cost sensor vs. SEPA equivalent instrument c) MS3 low-cost sensor vs. SEPA equivalent instrument d) MS5 low-cost sensor vs. SEPA equivalent instrument

Pearson's correlation coefficient between 1 h concentrations measured at the site that belongs to the national network of air quality monitoring NN1 and concentrations measured using low-cost sensors at MS1, MS2, MS3 and MS5 vary between 0.61 and 0.97. The highest Pearson's correlation coefficient can be noticed between the sites at the same street, Rumenačka, at a distance of about 2.7 km, r=0.97. Pearson coefficient correlation of 0.89 is identified between NN1 measured with equivalent instrument Grim and Dunavnet ekoNET device equipped with PMS7003 low-cost sensor located at MS1 and MS3. Pearson correlation coefficient that is lower is identified between the equivalent device at NN1 and low-cost device at MS5. The possible reason for the lower coefficient correlation between NN1 and MS5 is probably due to differences in particulate matter levels and content as well as local meteorological conditions at two locations.

5. Field calibration of PM2.5 low-cost device performed via collocation with reference pump

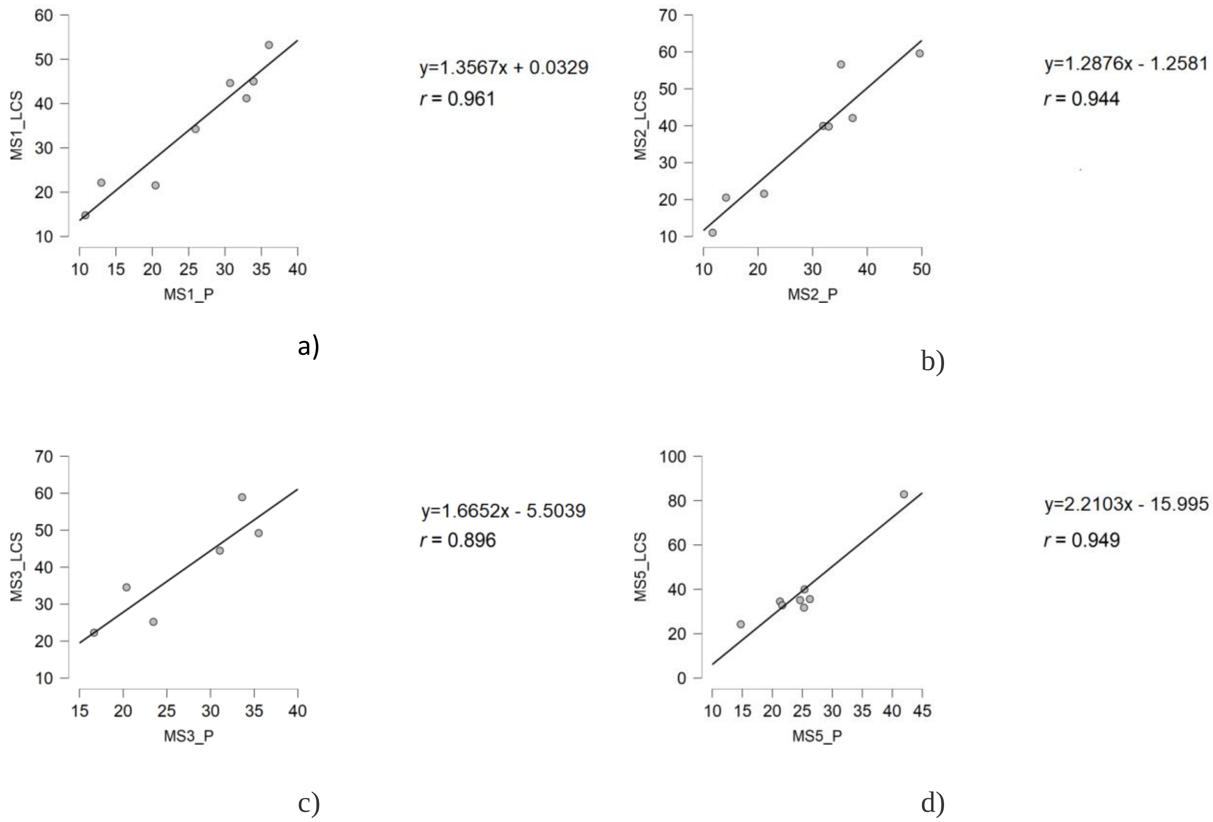

Figure 8. PM2.5 correlation: a) MS1 site reference pump vs. low-cost device b) MS2 site reference pump vs. low-cost device c) MS3 site reference pump vs. low-cost device d) MS5 site reference pump vs. low-cost device

As our extensive descriptive data analysis has shown, low cost PM2.5 devices are suitable for giving insights into trends of air pollution, which can be confirmed via strong correlation that exists between low cost device readings and data obtained from national network. However, despite this and despite the fact that the low-cost devices have gone through initial calibration, in order to avoid mismatch between calibration location and deployment location, low cost sensors were additionally calibrated, by collocating them with the reference gravimetric pumps at their deployment location. Calibration curves are shown in Figures 8, along with Pearson correlation coefficient and calibration equations. Only the data points that were obtained from unscathed filters were used for calibration purposes.

It can be concluded that in order to obtain useful results from low cost sensors, additional round calibration at the deployment location is a desirable and necessary step. All results and data reported in this study, originating from low cost sensors, are calibrated using deployment location calibration.

6. Descriptive statistic of PM2.5 levels before and at the beginning of emergency measure state

Table 1. Descriptive statistics for data collected via low cost sensors, at 4 different locations in Novi Sad

	MS1		MS2		MS3		MS5	
Campaign	BEM	EM	BEM	EM	BEM	EM	BEM	EM
Mean	24.05	25.85	26.79	31.02	26.27	28.72	23.50	21.31
St.dev.	17.70	16.71	20.94	23.54	16.14	16.86	15.50	6.38
Median	21.46	22.13	22.54	23.61	26.61	24.02	20.01	21.11
MIN	2.56	6.37	1.90	4.47	6.50	8.28	7.99	11.49
MAX	74.21	74.26	78.84	88.54	66.34	75.64	61.83	39.14
25th perc.	8.73	13.24	7.97	12.15	11.03	16.34	12.59	17.08
75th perc.	34.52	35.26	40.81	47.50	36.07	38.12	30.13	24.70

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Table 1 shows descriptive statistics for data collected via low cost sensors, at 4 different locations in Novi Sad. For each measuring spot, two columns are given, first referring to the period before the emergency state, and second referring to the period after the emergency state. For measuring sites MS1, MS2 and MS3 these periods are identical going from 2020-03-08 to 2020-03-15 for the BEMS period, and from 2020-03-16 to 2020-03-24 for the EMS period. From MS5 site, BEMS period data was collected somewhat earlier from 2020-02-06 to 2020-02-23, while the EMS period mostly coincides with the EMS period for the remaining sites, going from 2020-03-18 to 2020-03-26.

Median of PM2.5 concentration was similar in the BEMS and EMS period for all sites, a slight decrease of median was observed only for MS3. Maximum values of PM2.5 pollution (98th percentile) increased for MS2 and MS3 sites, remained the same for MS1, and decreased for MS5 site. Another interesting aspect is standard deviation of the pollution, which may signal change in pollution sources and their distribution: it remained the same at MS1 and MS3 sites, and showed a significant decrease at MS5 site. More insight into PM2.5 pollution and change that occurred during EMS at these sites is possible via time series and 24h box plots which are shown in further text.

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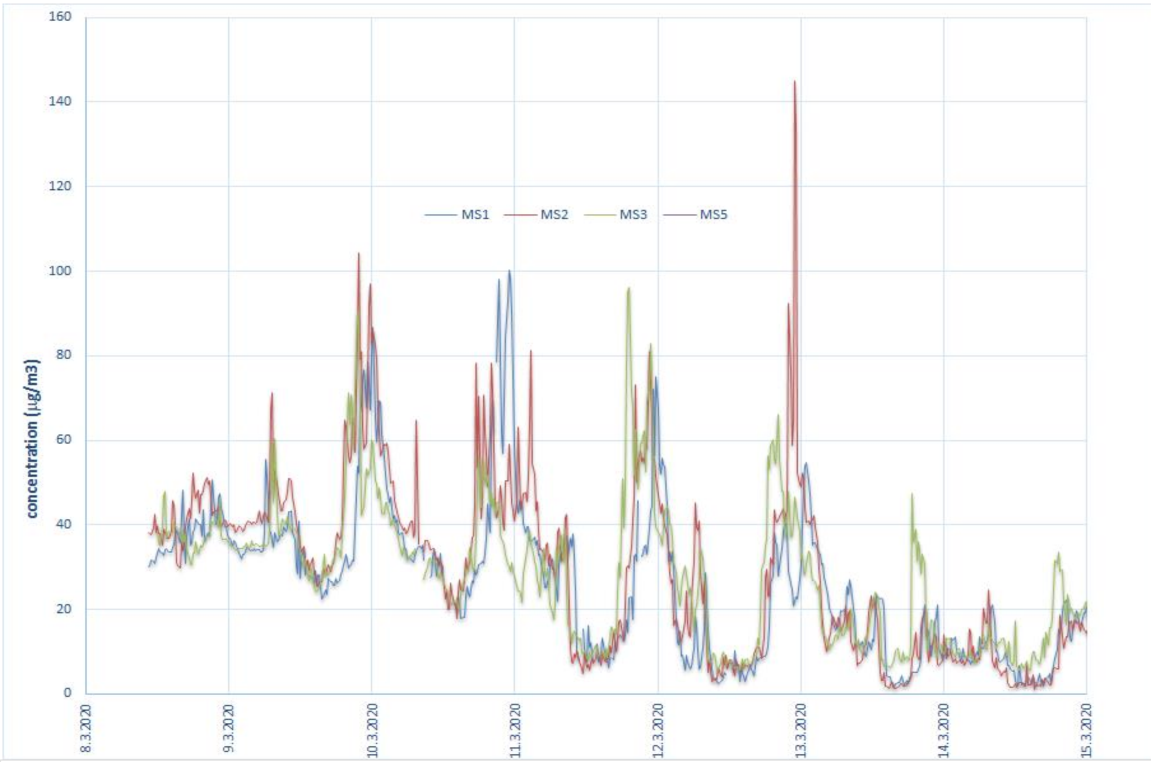
7. Time series of PM2.5 at sampling sites MS1, MS2, MS3, MS5 and SEPA during the measuring campaign



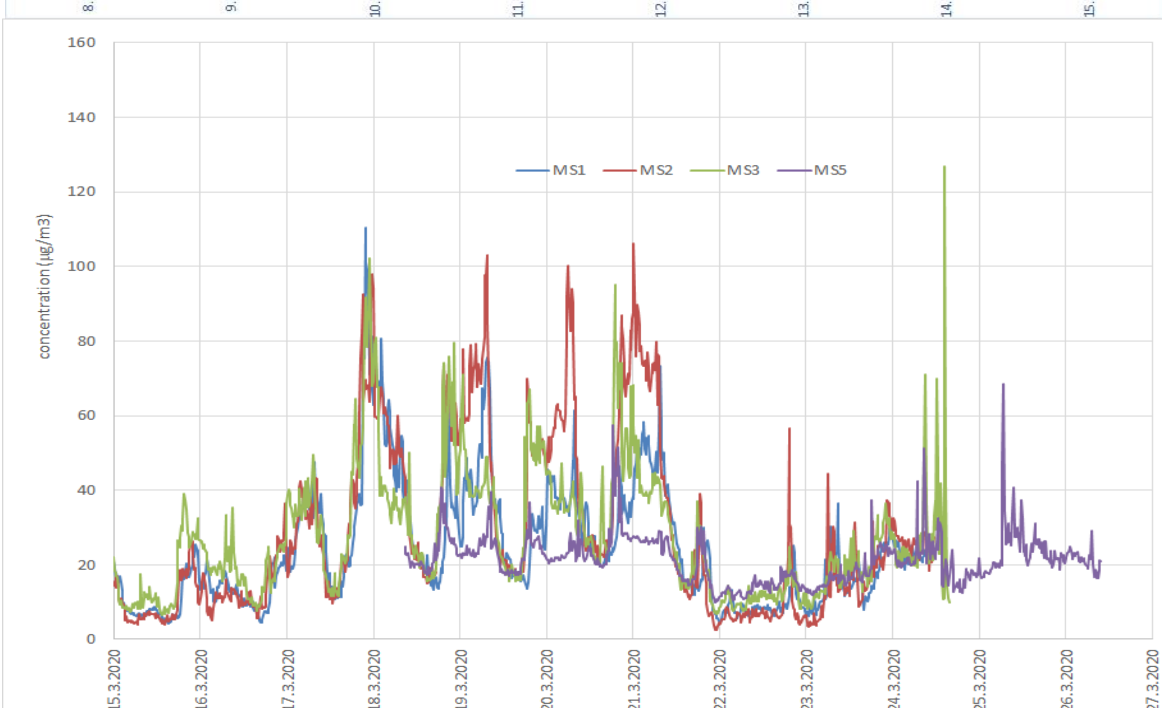
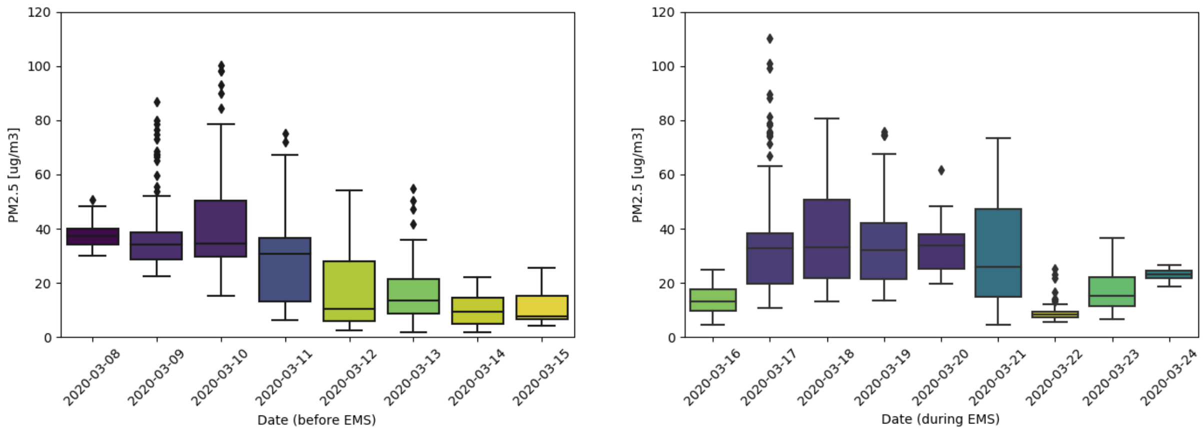
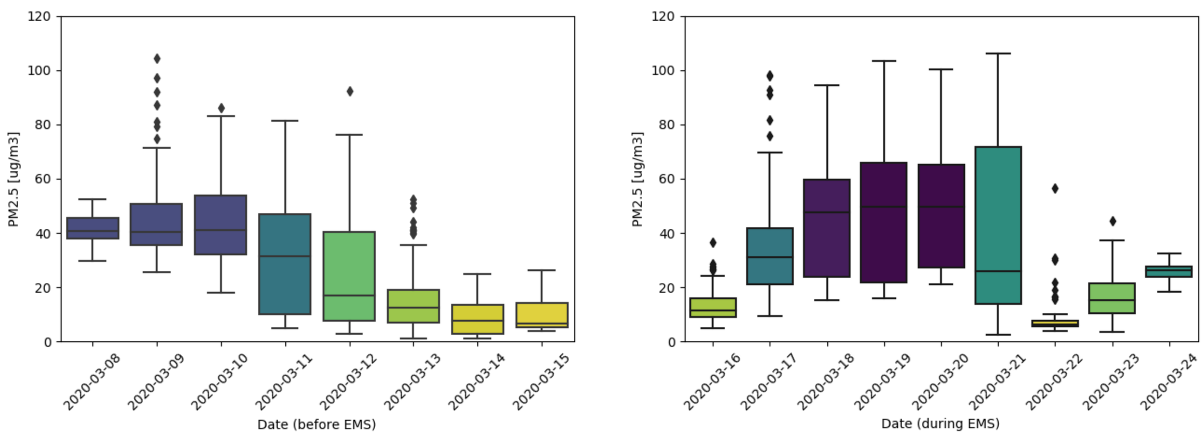


Figure 9. Time series of PM2.5 levels before and during emergency measures state



a) MS1



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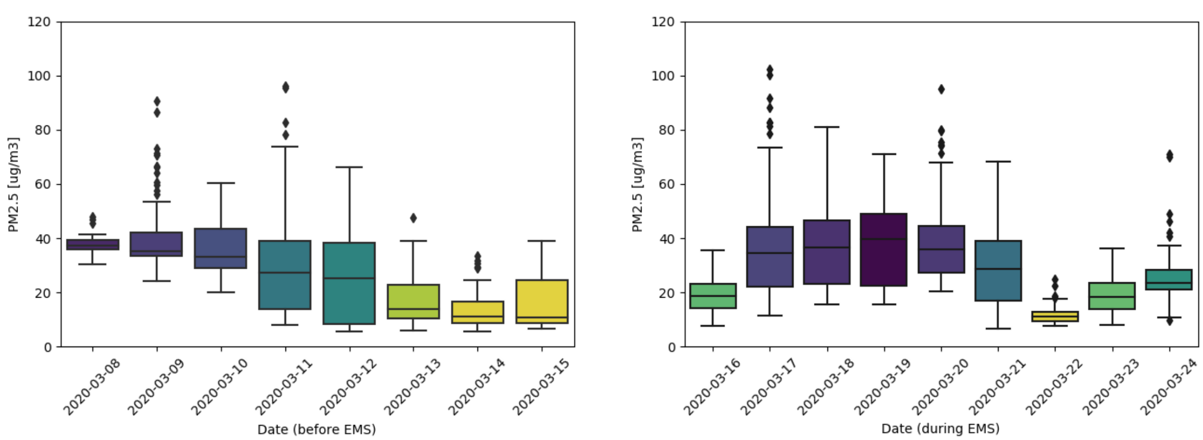
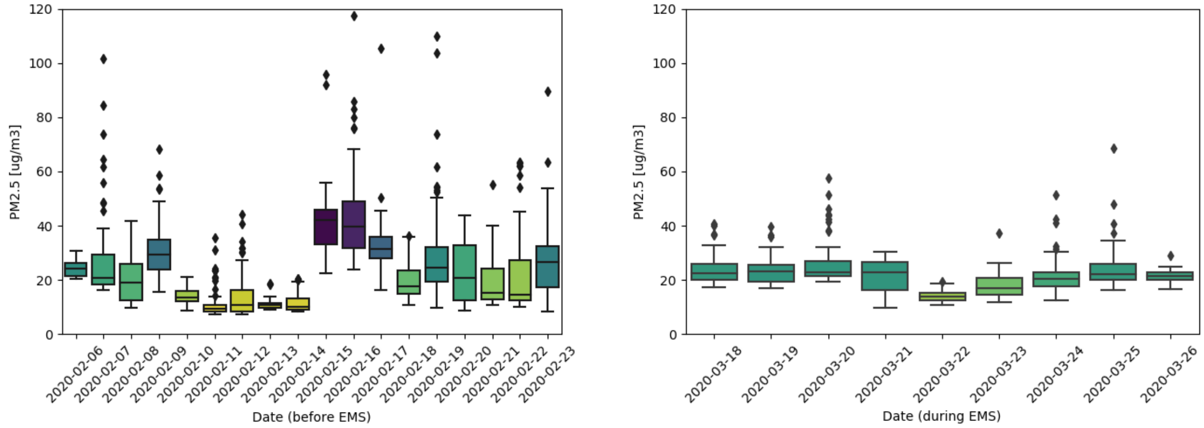
b) MS2



c) MS3

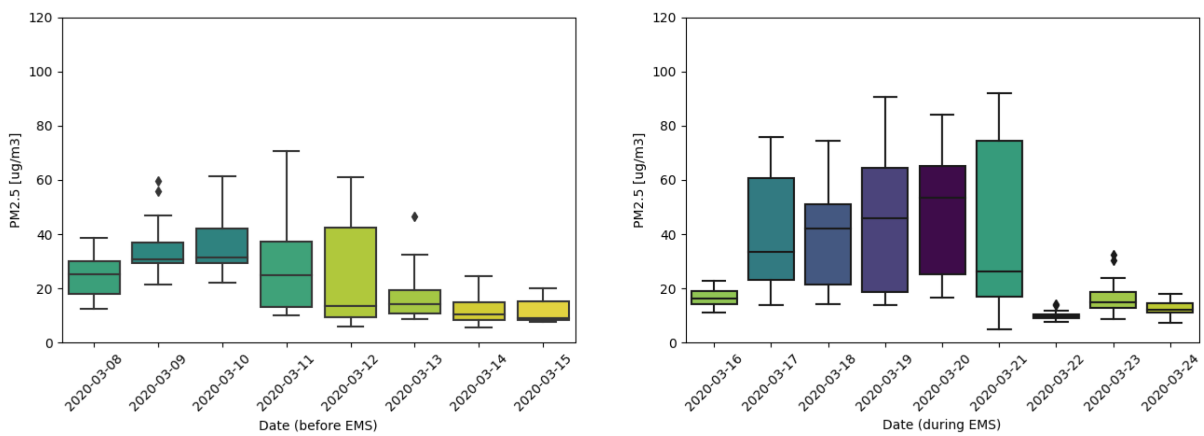


d) MS5

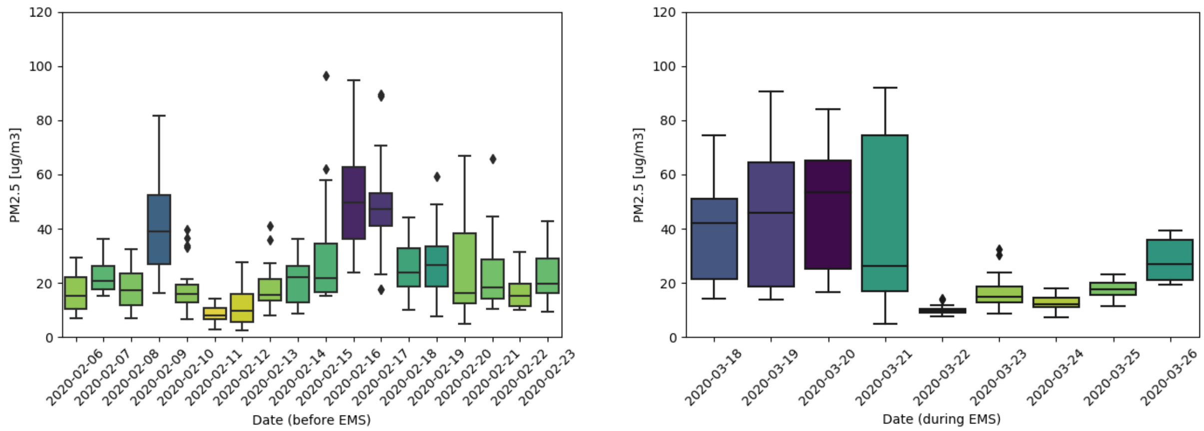
Figure 10. Box-plot of PM2.5 concentration using deployment location calibrated low-cost device before and during measures of the state of emergency a) MS1 b) MS2 c) MS3 d) MS5

Spontaneous reduction and change in human mobility during the day before the emergency state measures announcement, weekend on 14.03 and 15.03 could also influence air pollution emissions, particularly due to lower traffic in the intracity area of Novi Sad. For this period, there are no openly accessible data about traffic volumes within residential areas of Novi Sad.

20



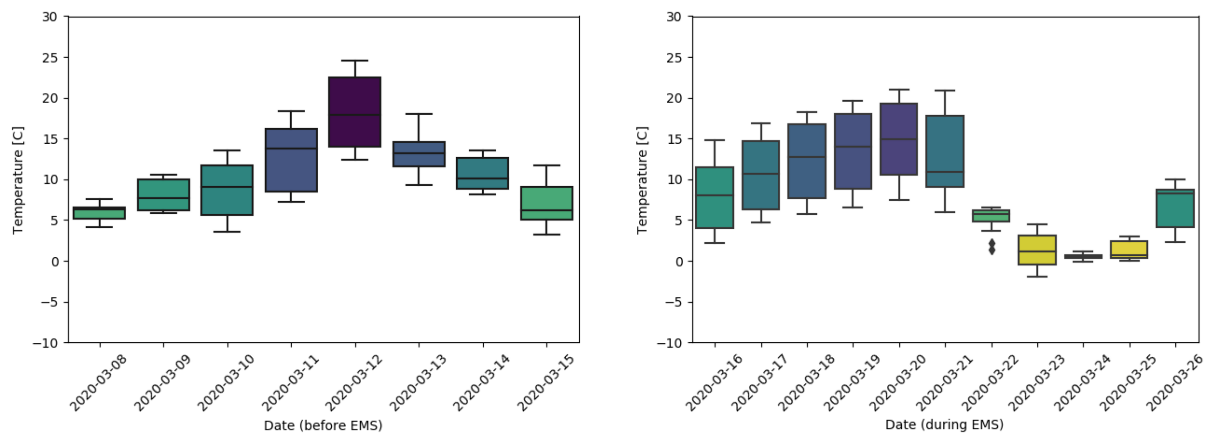
(a)



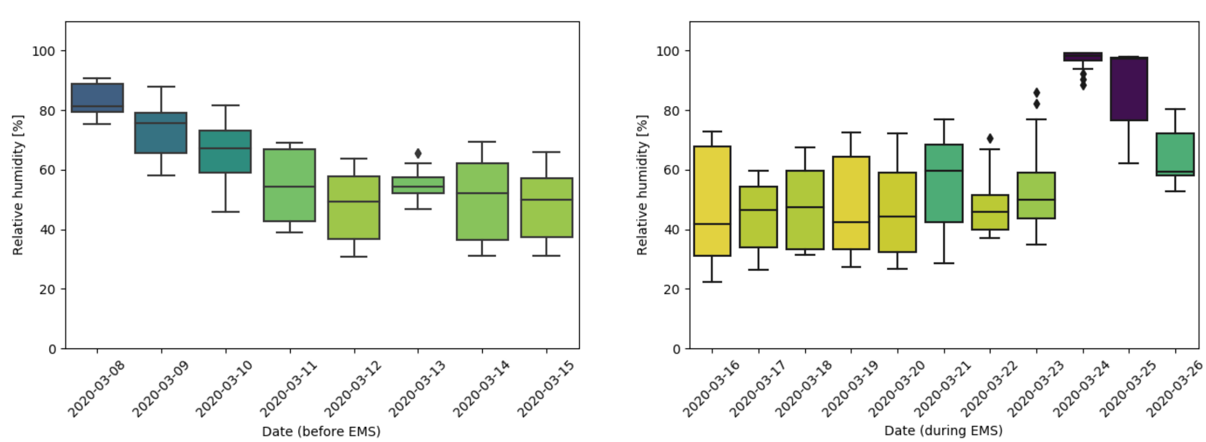
(b)

Figure 11. Box-plot of PM2.5 concentration measured by SEPA station during time period corresponding to BEMS and EMS measured by (a) MS1, MS2 and MS3 (b) MS5

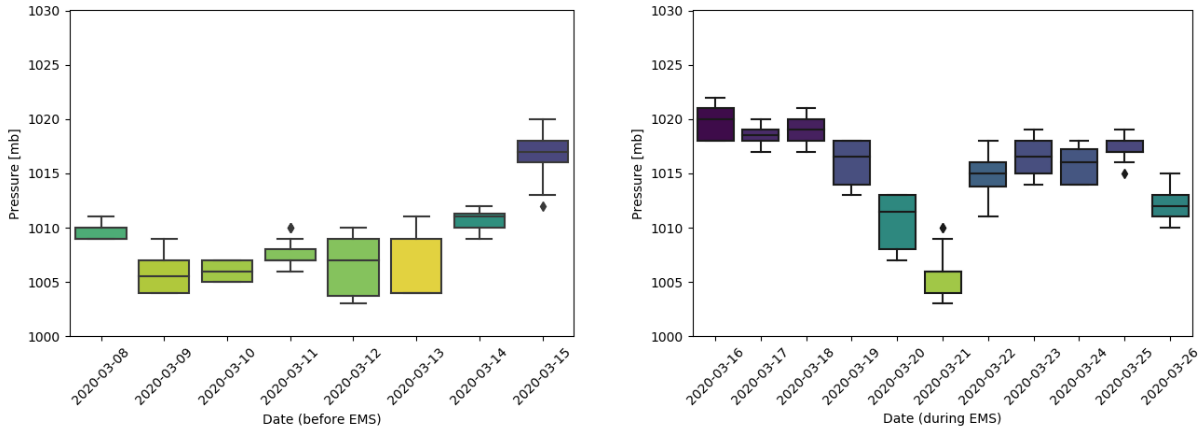
21



(a)

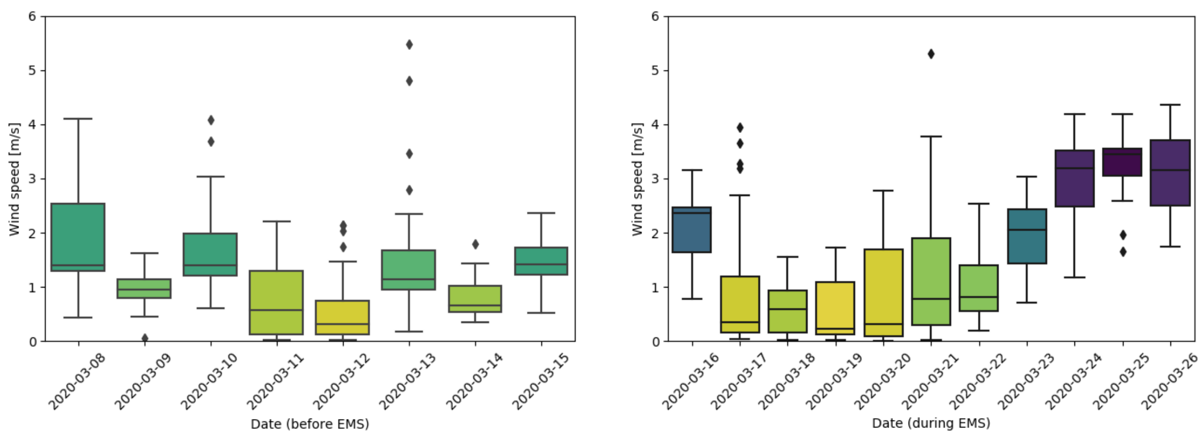


(b)



(c)

22



(d)

Figure 12. Box-plot of meteorological data measured by SEPA station during the time period corresponding to BEMS and EMS as measured by MS1, MS2 and MS3. (a) Temperature (b) Relative humidity (c) Pressure (d) Wind speed

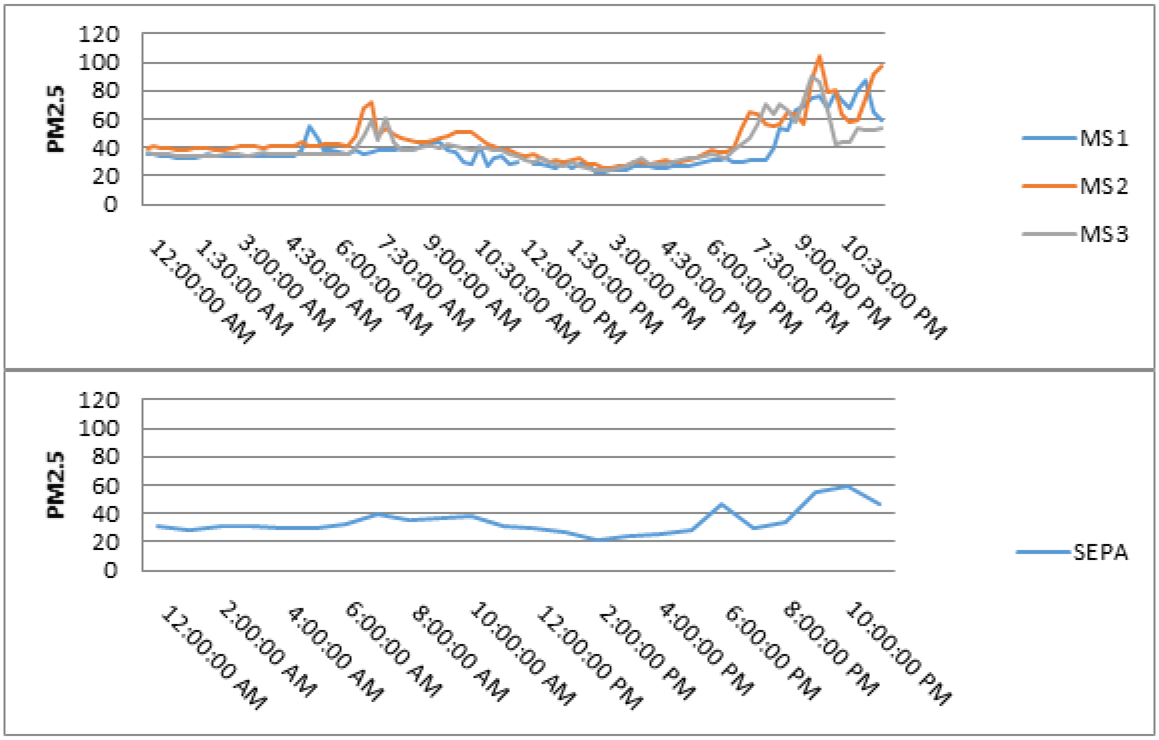
Meteorological conditions such as wind speed, wind direction, and air temperature gradients in interaction with the landscape's physical features are key factors that influence the movement and dispersal of air pollutants, including particulate matter pollution. Sampling campaign in both BEMS and EMS period was conducted during the heating season in the Republic of Serbia, lasting from October 15th till April 15th. It is well known that coarse and fine particulate matter concentration positively correlates with temperature and relative humidity, respectively, and strongly negatively correlates with wind speed (Wang & Ogawa, 2015). This means that wind speed and relative humidity are two key factors affecting PM2.5 and PM10 concentration distributions.

During the BEMS period of the campaign, for period 9.03.-12.03.2020. when higher PM2.5 daily levels were observed, the median value of wind speed was less than 1m/s. During the EMS period, PM2.5 daily level was higher in period 17.03-21.03.2020. when daily median levels of wind speed were also very low, less than 1m/s.

8. Variation of PM2.5 at sampling sites MS1, MS2, MS3, MS5 and SEPA for each day of measuring campaign before and during emergency state

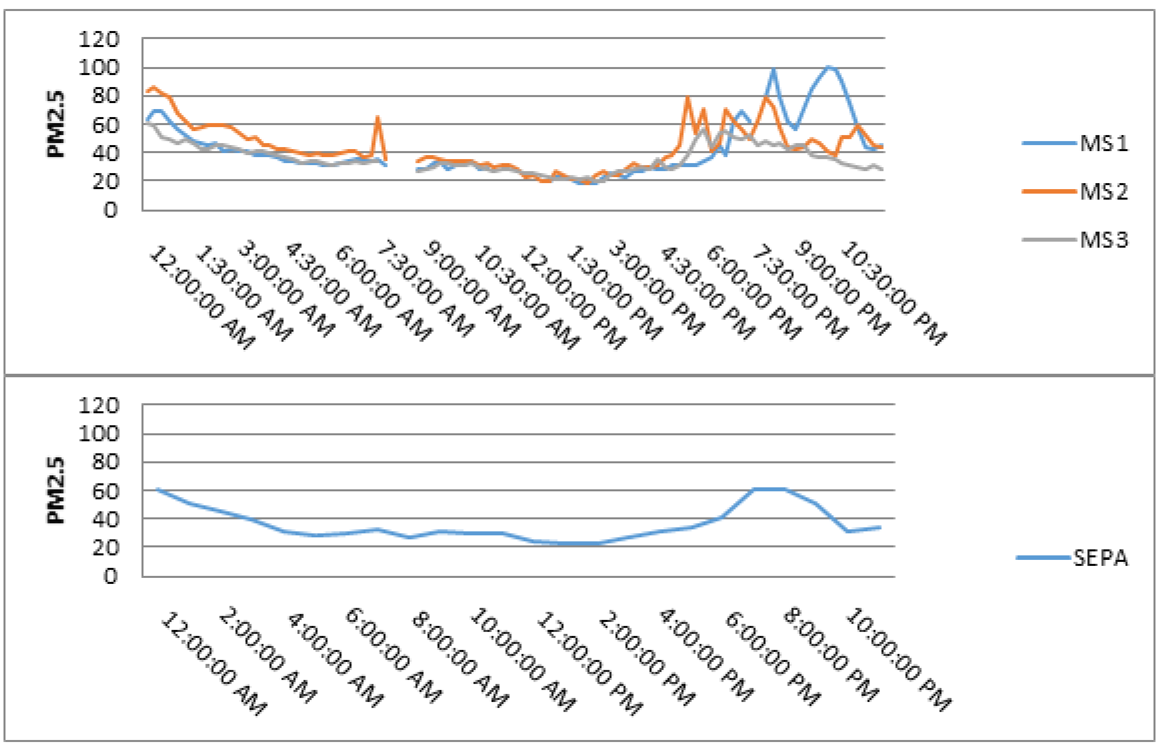
23

a) Daily variation of PM2.5 on 8 March 2020 at MS1, MS2 and MS3 and SEPA

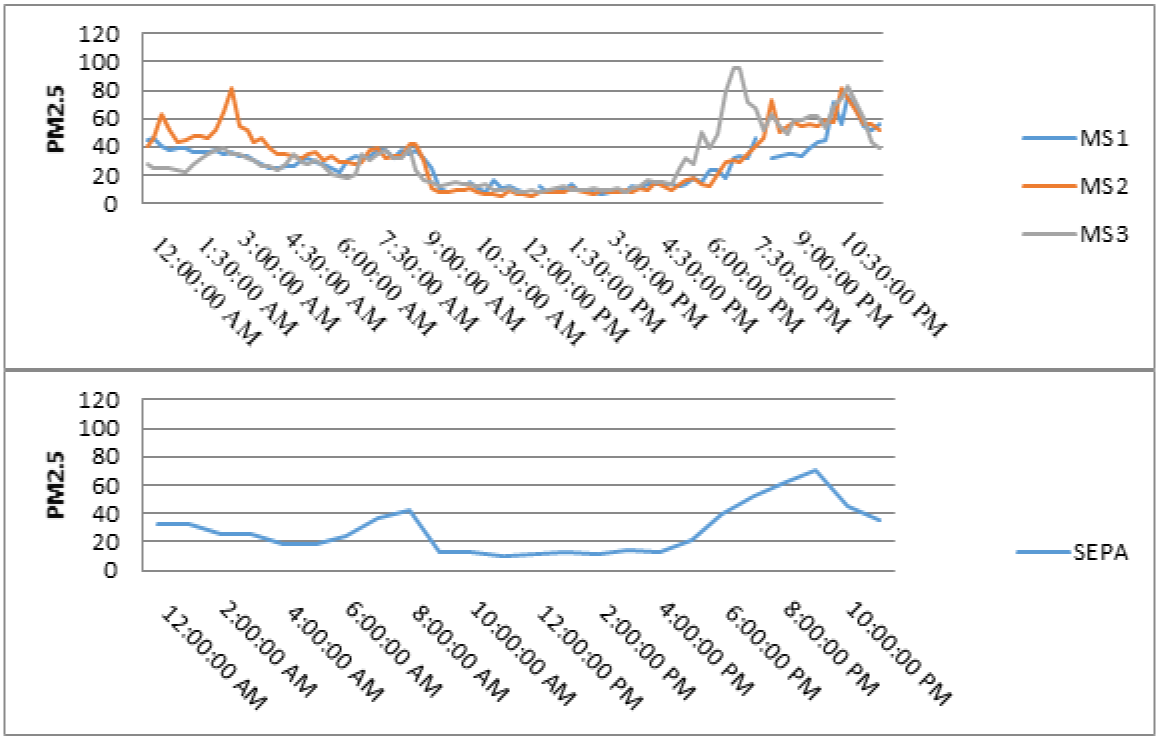


b) Daily variation of PM2.5 on 9 March 2020 at MS1, MS2 and MS3 and SEPA

24

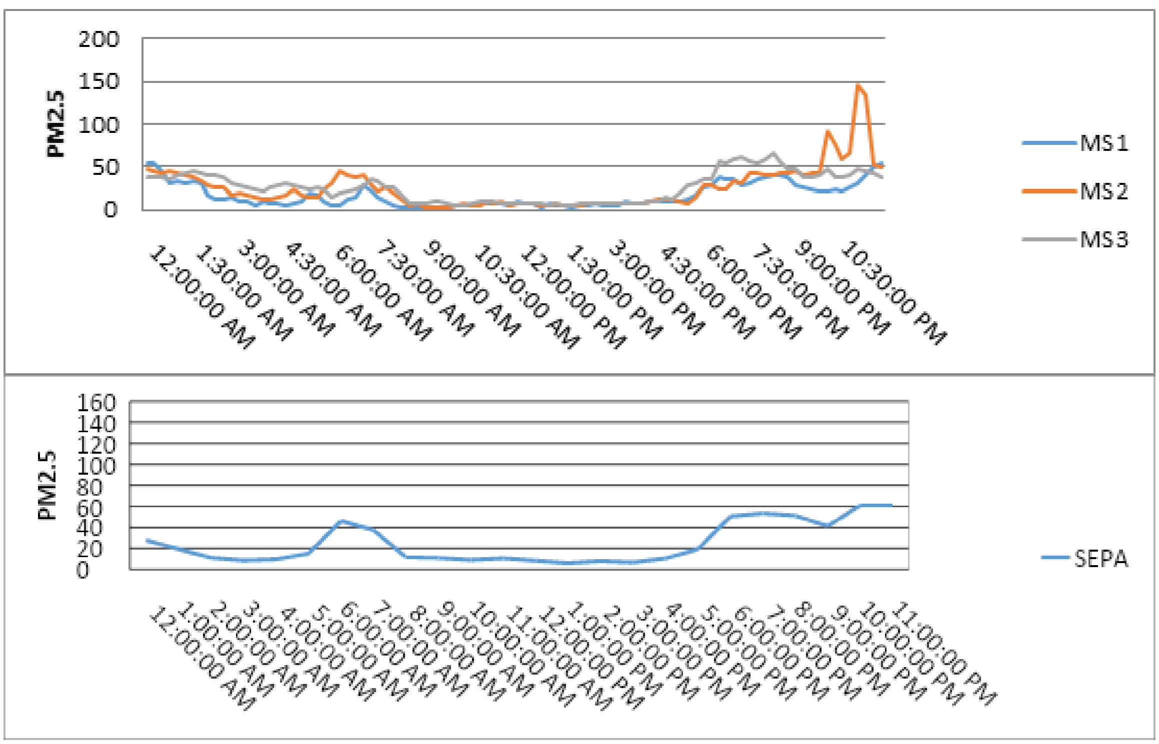


c) Daily variation of PM2.5 on 10 March 2020 at MS1, MS2 and MS3 and SEPA

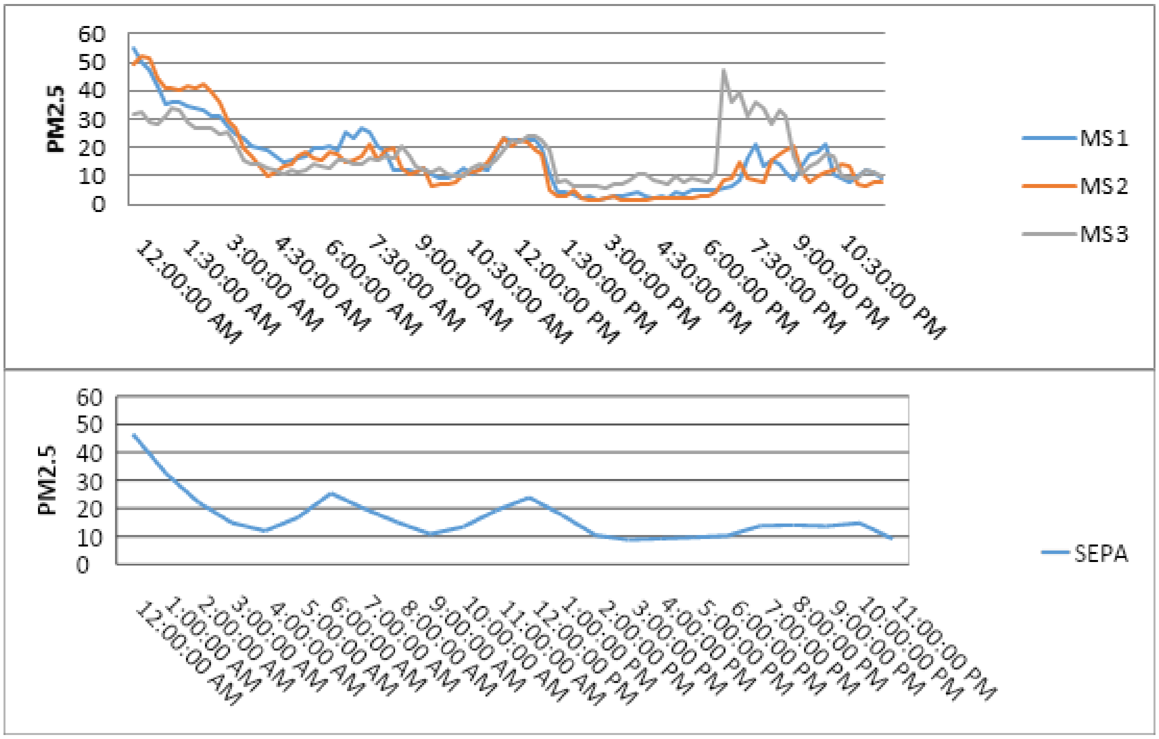


d) Daily variation of PM2.5 on 11 March 2020 at MS1, MS2 and MS3 and SEPA

25

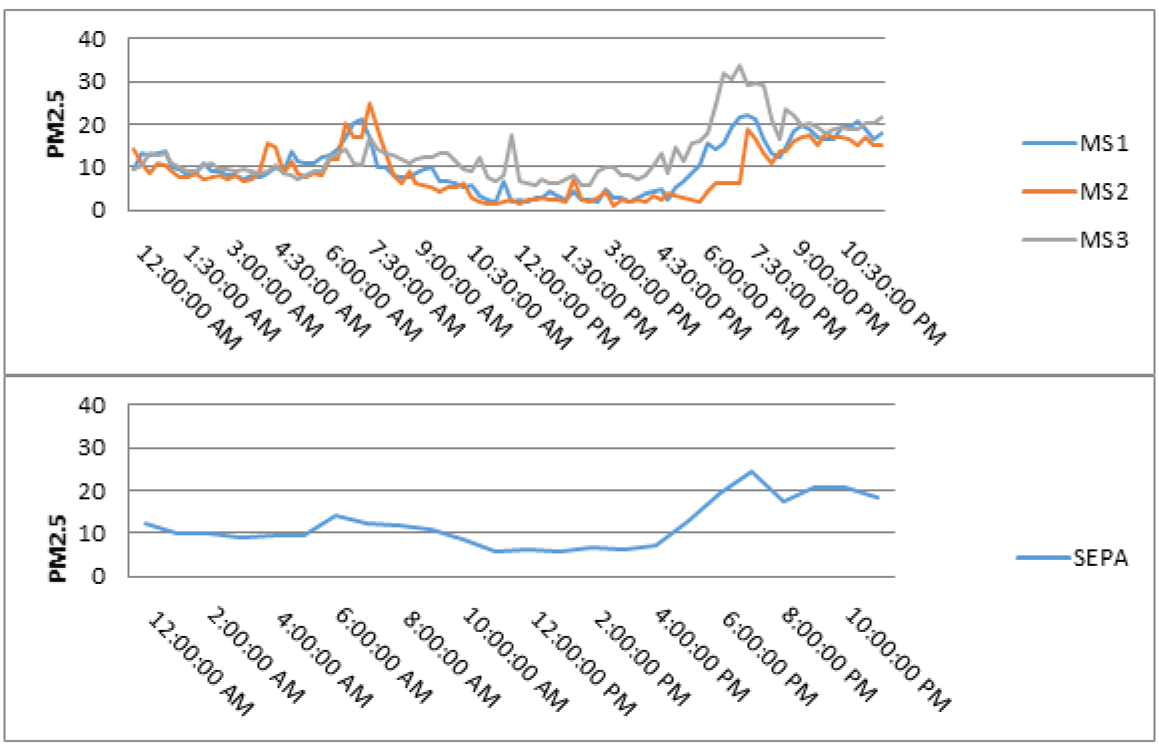


e) Daily variation of PM2.5 on 12 March 2020 at MS1, MS2 and MS3 and SEPA

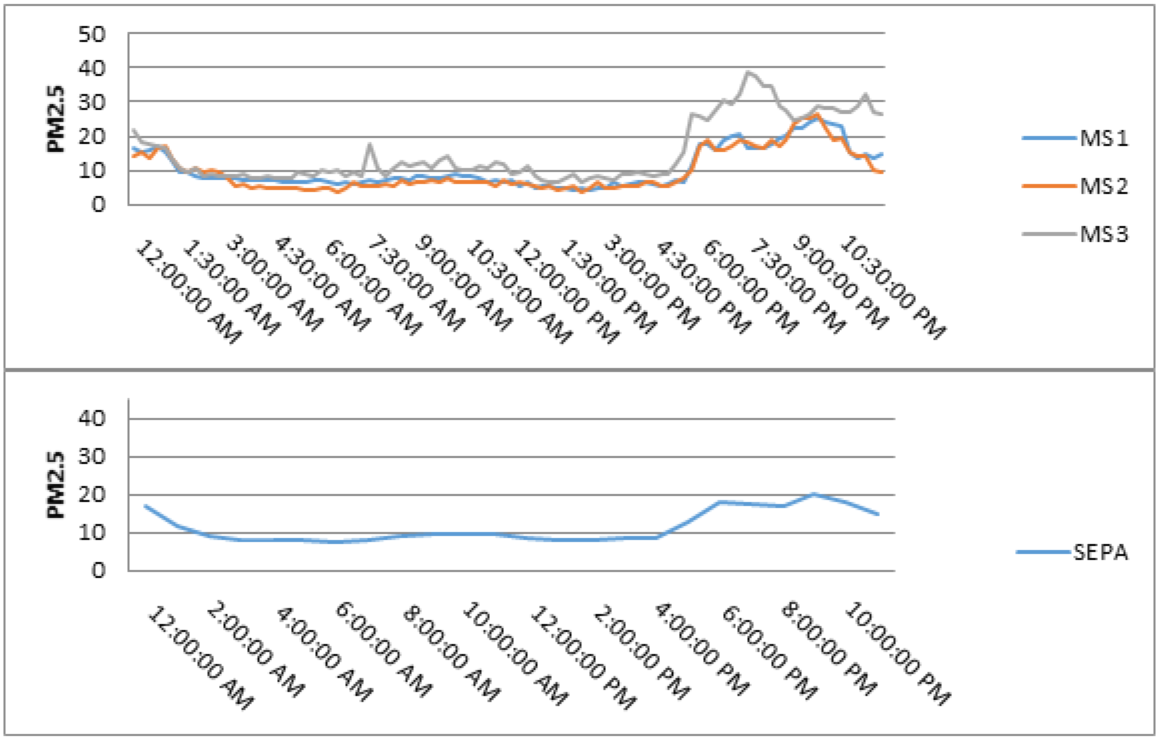


f) Daily variation of PM2.5 on 13 March 2020 at MS1, MS2 and MS3 and SEPA

26

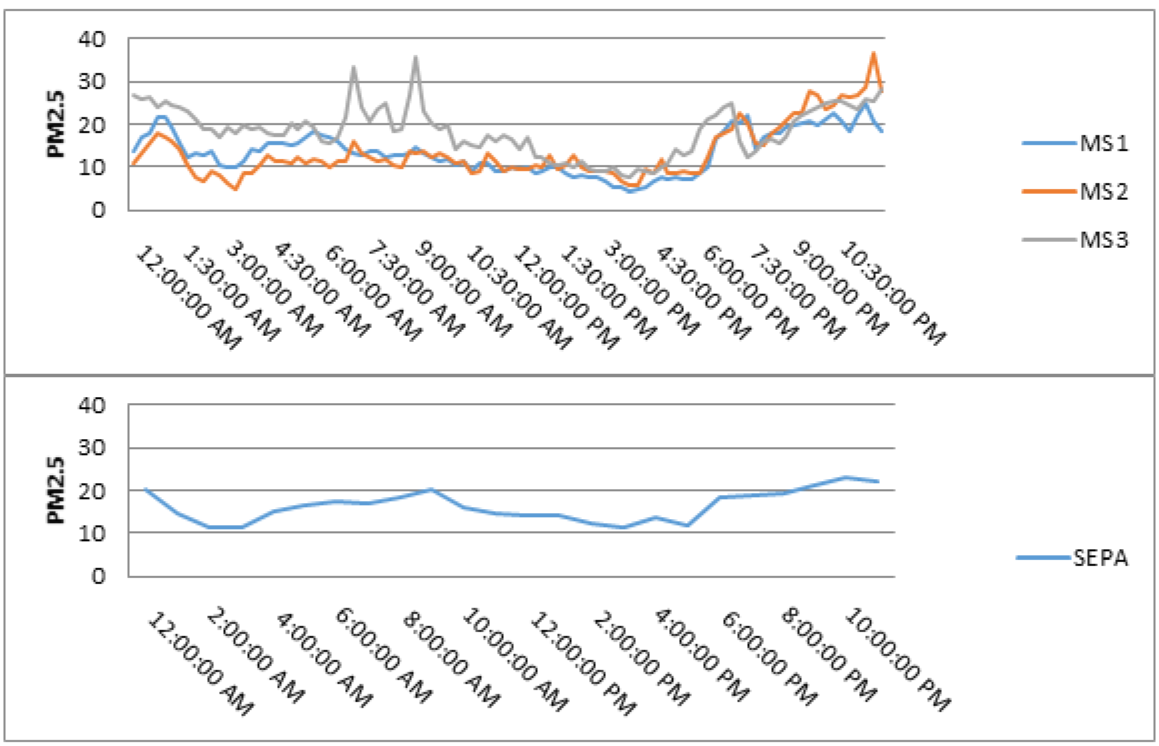


g) Daily variation of PM2.5 on 14 March 2020 at MS1, MS2 and MS3 and SEPA

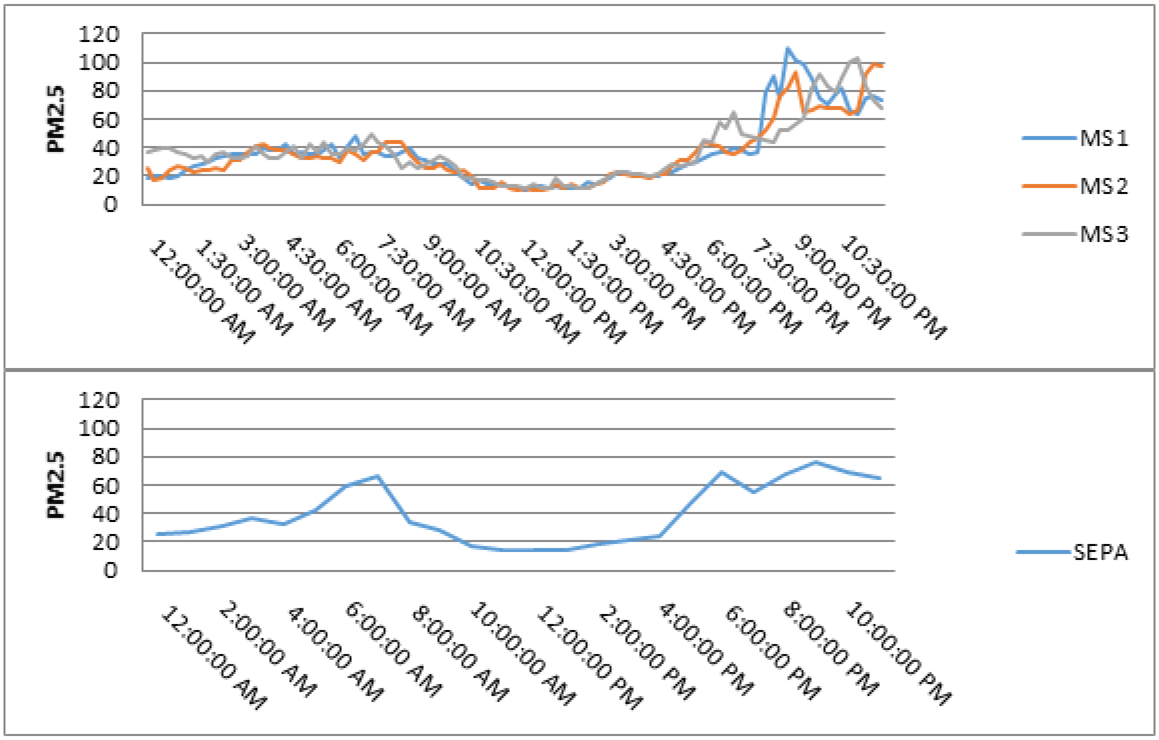


h) Daily variation of PM2.5 on 15 March 2020 at MS1, MS2 and MS3 and SEPA

27

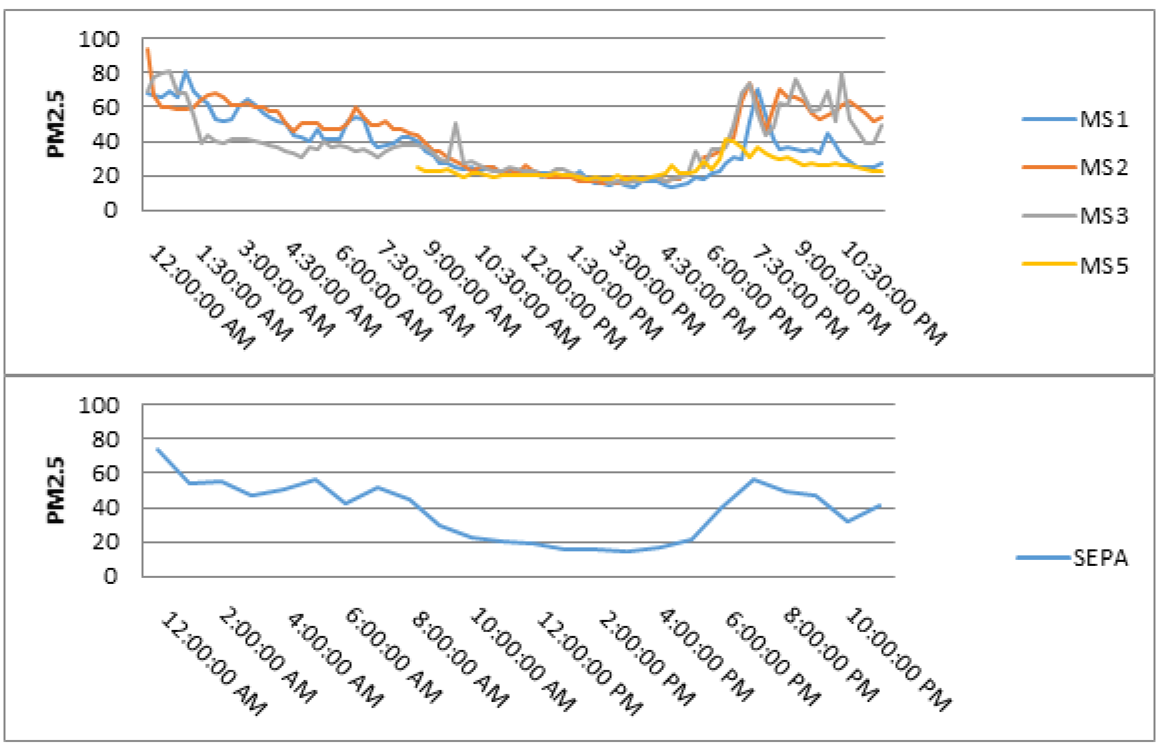


i) Daily variation of PM2.5 on 16 March 2020 at MS1, MS2 and MS3 and SEPA

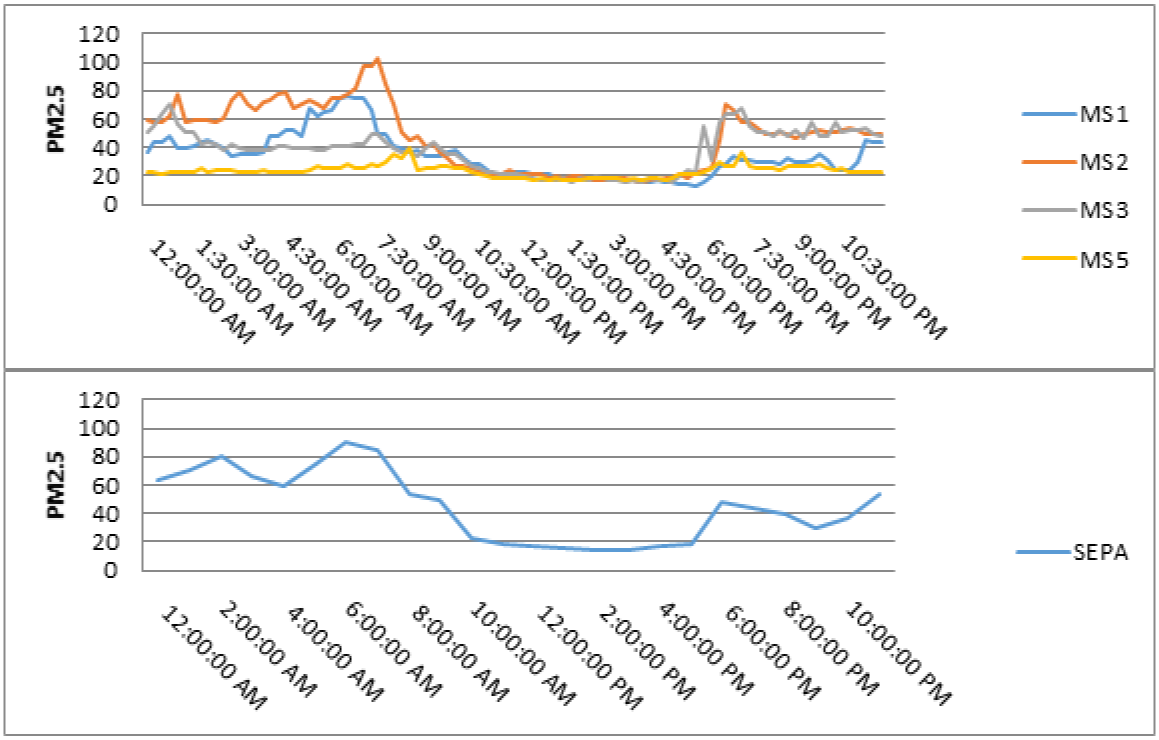


j) Daily variation of PM2.5 on 17 March 2020 at MS1, MS2 and MS3 and SEPA

28

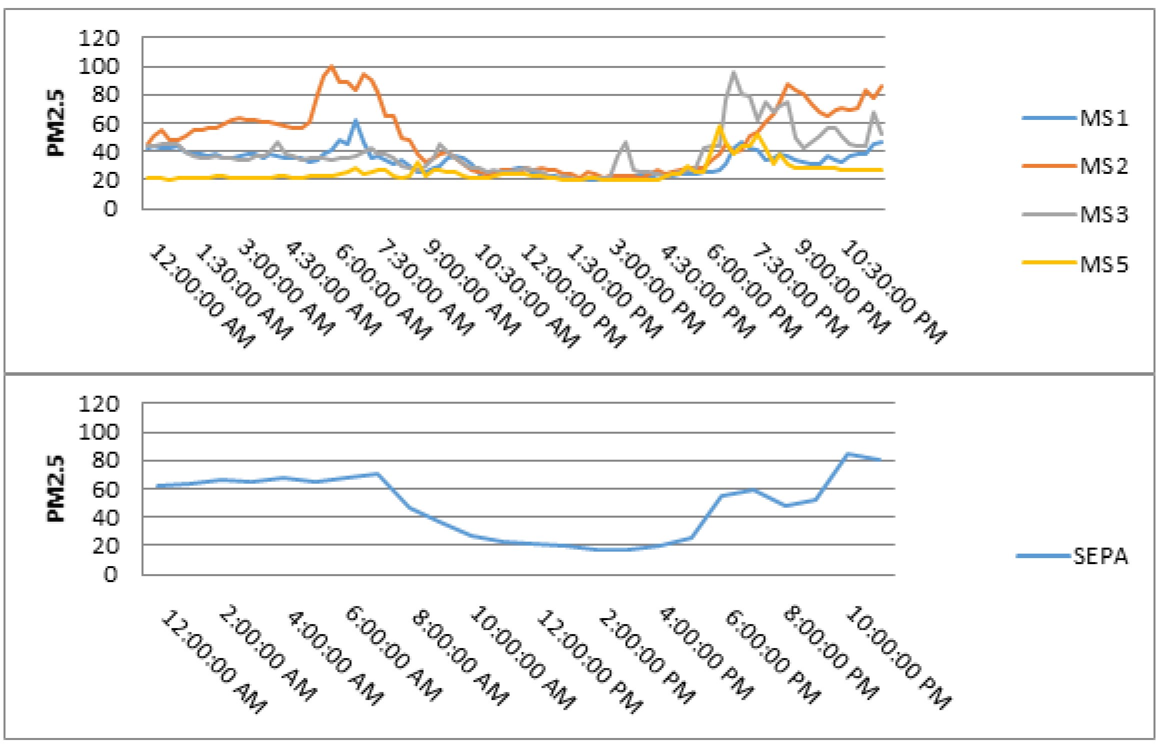


k) Daily variation of PM2.5 on 18 March 2020 at MS1, MS2 and MS3 and SEPA

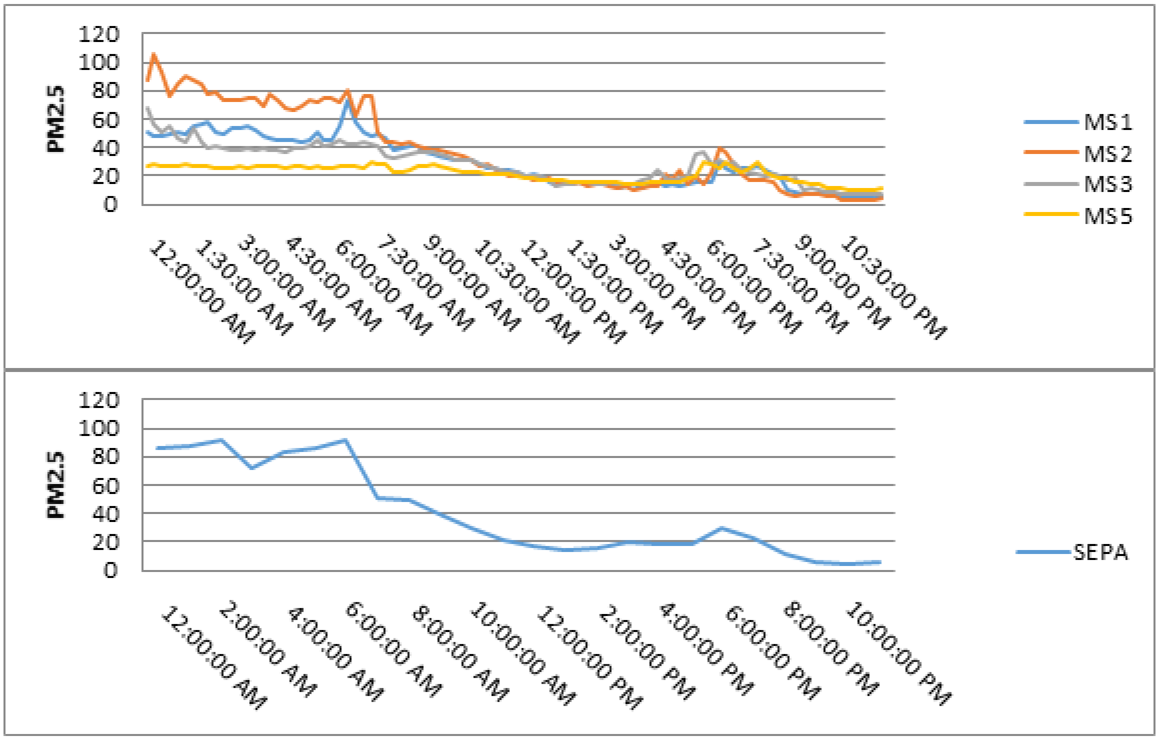


l) Daily variation of PM2.5 on 19 March 2020 at MS1, MS2 and MS3 and SEPA

29

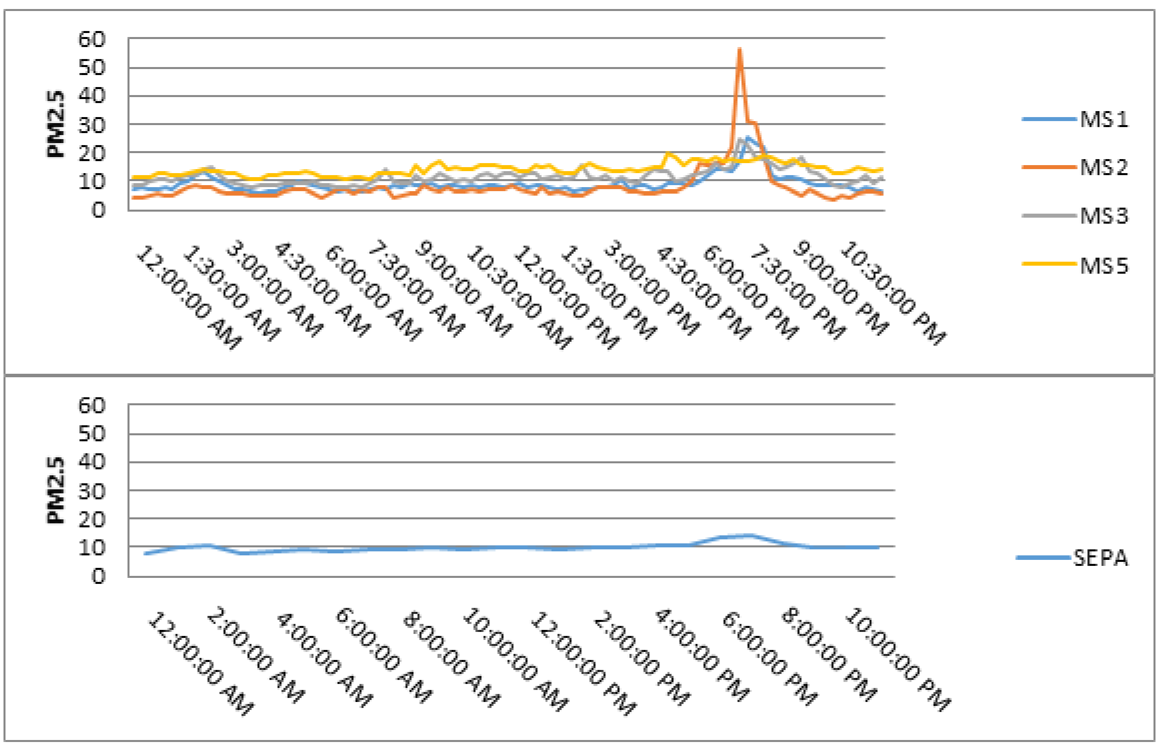


m) Daily variation of PM2.5 on 20 March 2020 at MS1, MS2 and MS3 and SEPA

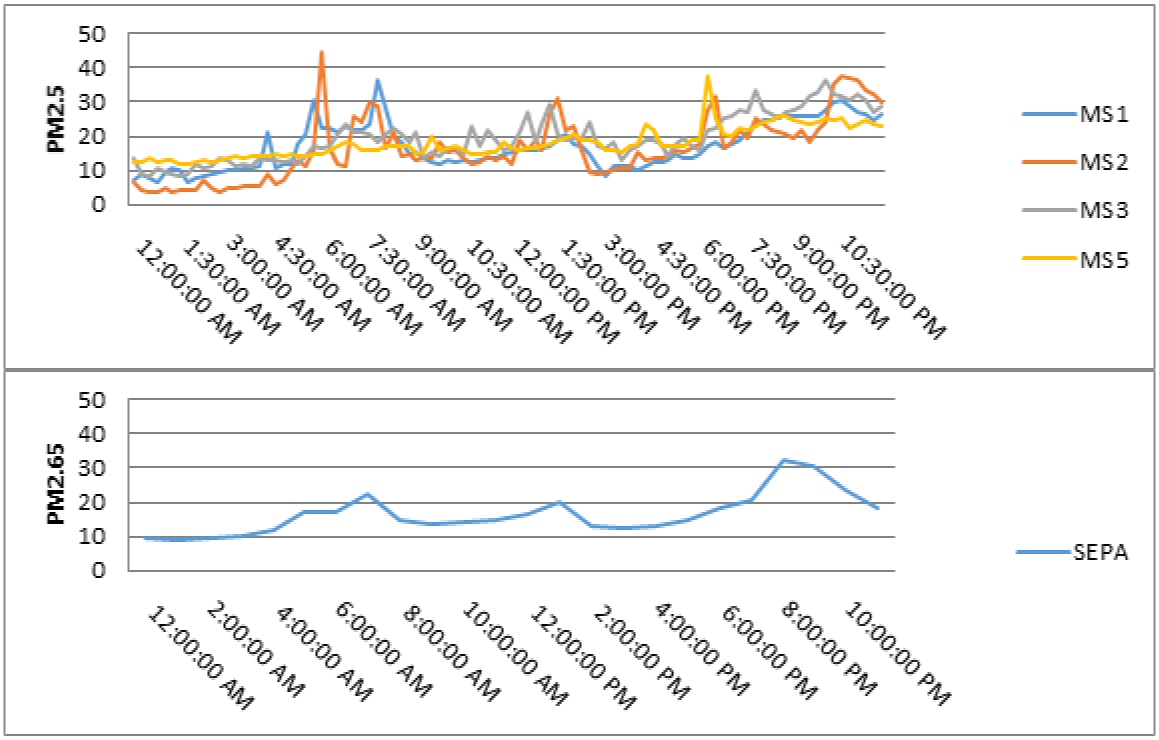


n) Daily variation of PM2.5 on 21 March 2020 at MS1, MS2 and MS3 and SEPA

30



o) Daily variation of PM2.5 on 22 March 2020 at MS1, MS2 and MS3 and SEPA



p) Daily variation of PM2.5 on 23 March 2020 at MS1, MS2 and MS3 and SEPA

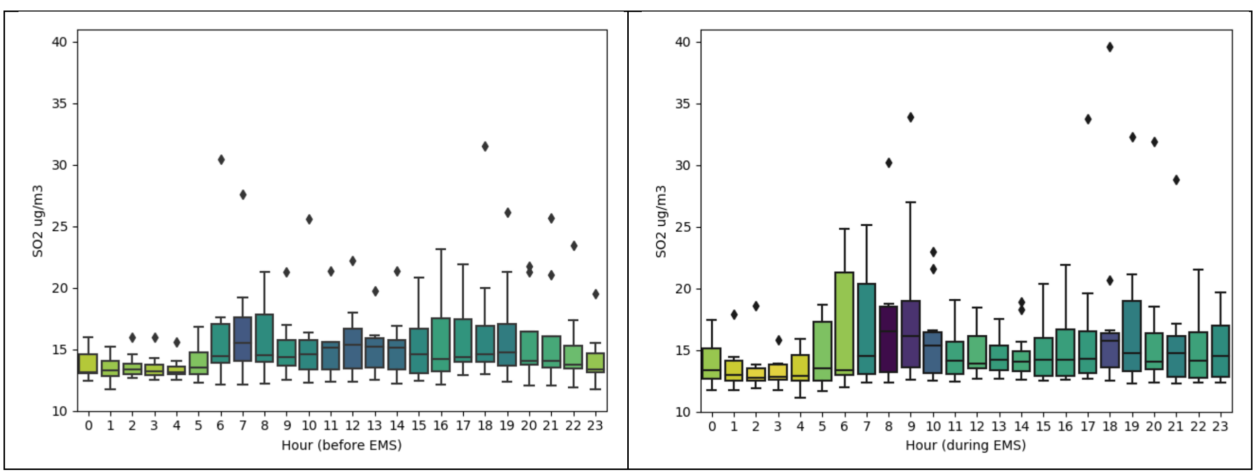
31 **Figure 13.** Daily variation of PM2.5 at MS1, MS2 and MS3 and SEPA stations during the campaign in the period from a) 8 March 2020 to p) 23 March 2020. All results and data originating from low-cost sensors, which are calibrated using deployment location calibration

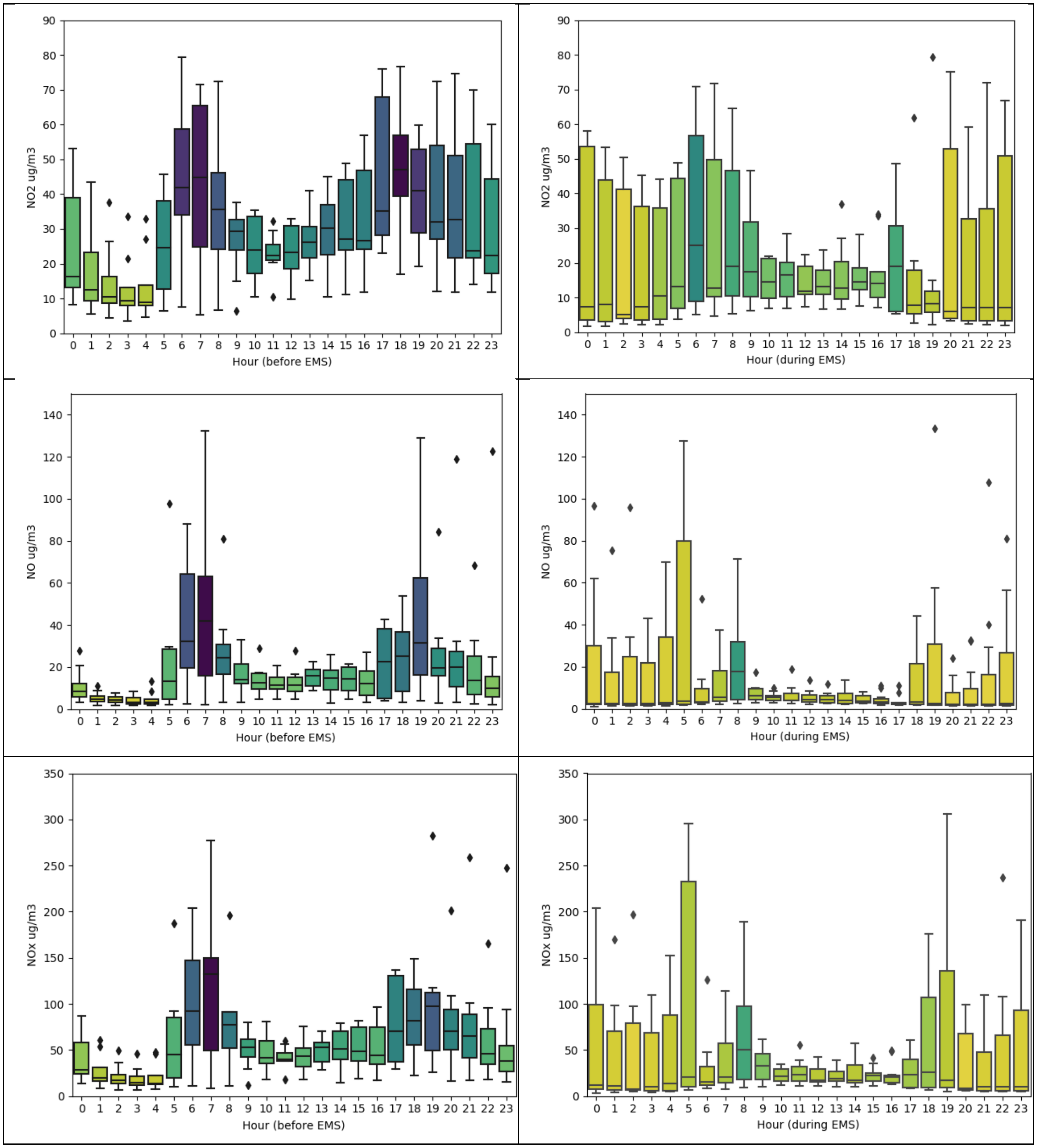
In the period before and during the state of emergency, a good agreement was found between the measured PM2.5 data at each site and data recorded by the equivalent instrument reference station (SEPA). As shown in Figure 13, the daily variations of $PM_{2.5}$ at all sites followed the SEPA station's data, with certain exceptions. Certain variations observed at each measuring site, especially early in the morning or late evening, are probably due to local traffic density and meteorological condition changes. Also, the changes in daily variations from the values measured at the SEPA station were influenced by the distance of the measuring site and the characteristics of each site.

9. Changes in diurnal variation of main gaseous pollutants at NN1 and NN2 before and after measures of the state emergency

In Figure 14. the diurnal variation of the main gaseous pollutants at Rumenačka SEPA, NN1 before and after measures of the state emergency are shown:

- Daily profiles of SO_2, the main pollutant, depicted in the form of a box plot, show that, on average, there was no significant change a week before and 10 days during the emergency state. For most hours of day, SO_2 concentration was below 20 μg/m^3, with occasional "outliers" in the range from 35-40 μg/m^3 in the morning and afternoon pollution peaks
- Daily profiles for NO, NO_2 and NO_x show a clear change in daily patterns. Since boxplot colour corresponds to the value of median, it is evident that during most hours of the day the median of these main pollutants was reduced during the first 10 days of the emergency state. NOx boxplots show clear morning and afternoon pollution peaks, both before and during the emergency state, but the median of these peaks is reduced during the emergency state (median around 80-95 μg/m^3 before emergency state from 18h-19h, and an evident reduction to the median of about 15-25 μg/m^3 during the emergency state). Also, during the most active hours of the day (period from 9h to 17h) a significant drop in the level of air pollution can be observed, indicated by lower median and smaller interquartile range (median around 50 μg/m^3 before emergency state during this time of day, and about 25 μg/m^3 during emergency state in this time of day).
- Observing CO daily profiles following conclusions can be reached. During the active hours of the day, in the period from 9h to 17h level of air pollution stayed similar in, going around 0.8 mg/m^3 with a relatively narrow interquartile range. During morning hours, the situation is similar, with a slight increase during the emergency state, median still being in the range from 0.8 to 1 mg/m^3 but with larger interquartile ranges during the emergency state. On the other hand, from 18h to 23h, there is a slight reduction in CO level during the emergency state. Since there are no significant changes in the daily profiles before and during the emergency state for CO levels, it can be argued that pollutants with domestic heating source profiles mostly exhibited constant levels.




NO2 ug/m3
Hour (before EMS)
NO2 ug/m3
Hour (during EMS)
NO ug/m3
Hour (before EMS)
NO ug/m3
Hour (during EMS)
NOx ug/m3
Hour (before EMS)
NOx ug/m3
Hour (during EMS)

33

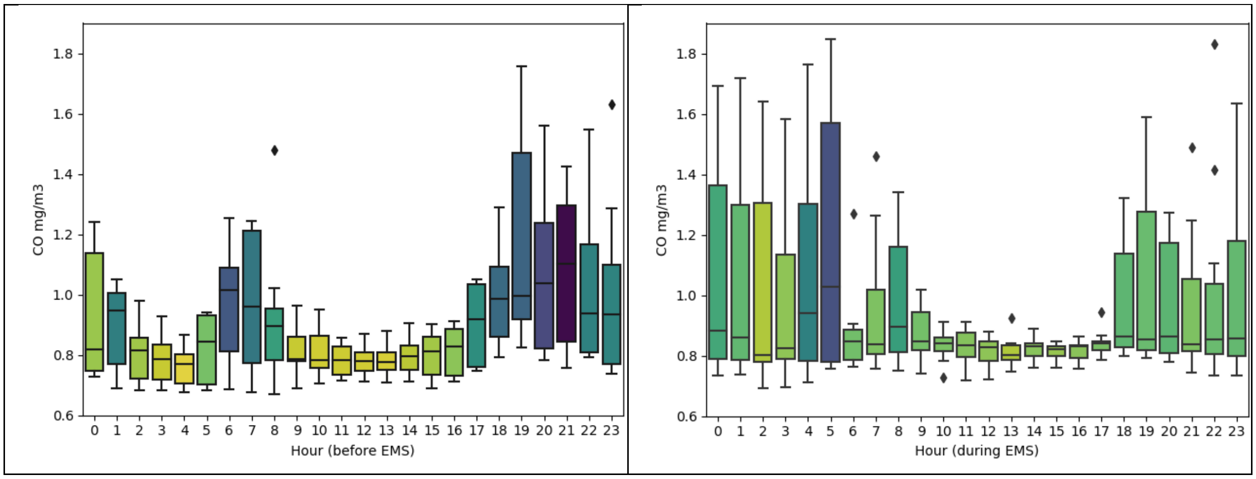
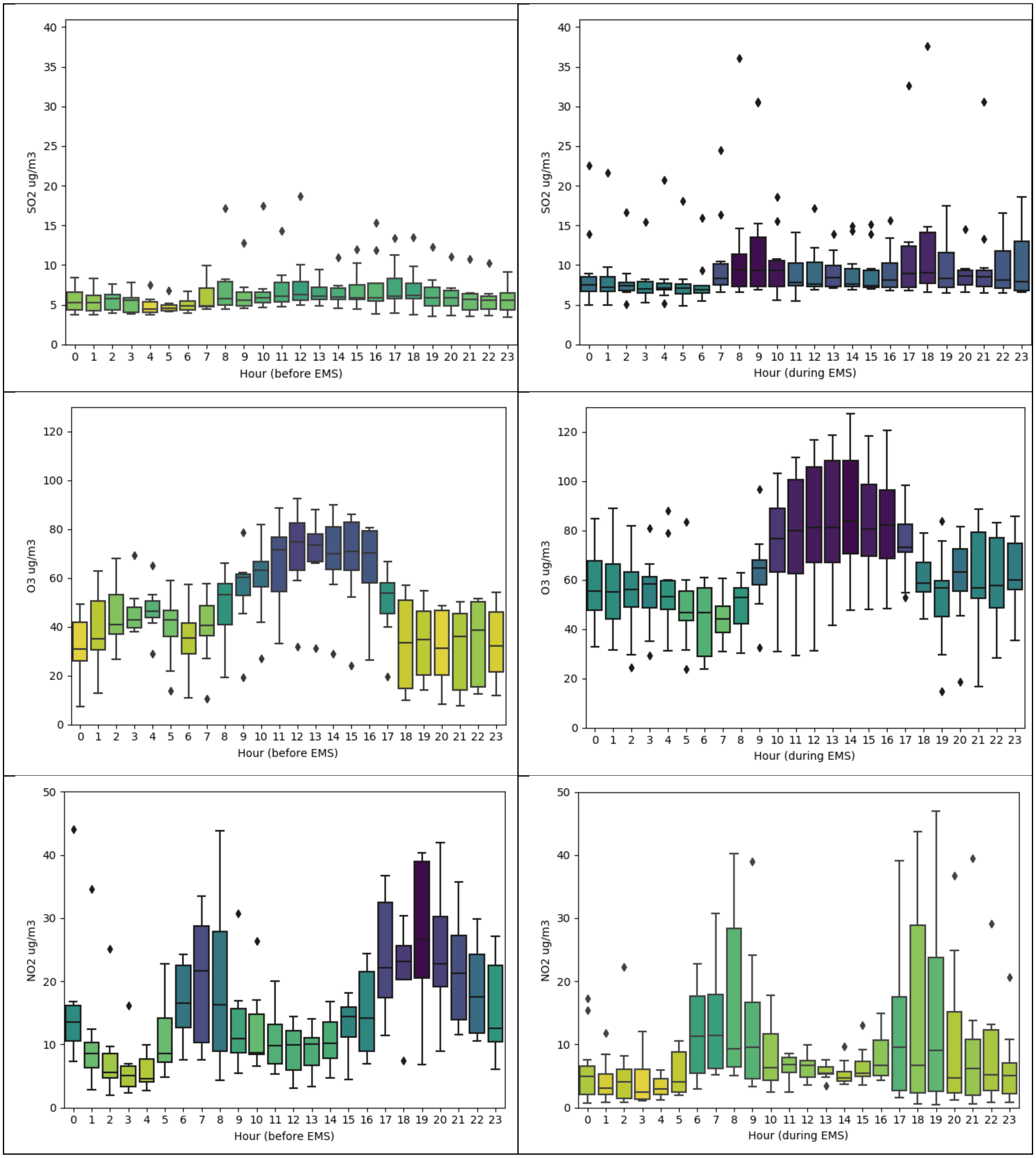


Figure14. Rumenačka SEPA, NN1 station, hourly box plots before (2020-03-08 until 2020-03-15) and during emergency state (2020-03-16 until 2020-03-26)

In Figure 15. diurnal variation of the main gaseous pollutants at Liman SEPA, NN2 automatic monitoring station before and after measures of the state emergency are shown:

- Daily profiles of SO_2, the main pollutant, depicted in the form of a box plot, show that, on average, there is a slight change a week before and 10 days during the emergency state. In the week before, for most hours of day, SO_2 concentration was approximately 5 μg/m^3, while in the first 10 days of the emergency state, the median is a bit higher between 7-8 μg/m^3 from midnight till morning hours and about 10 μg/m^3 later during the working hours and evening.
- Daily profiles for O_3 , the main pollutant, follow diurnal cycle with maximal levels from 10h to 16h with the median about 70 μg/m^3 in the week before and 80 μg/m^3 in the first 10 days of the emergency state. During mooring and evening hours, median values are also for 10 μg/m^3 lower in the week before (about 50 μg/m^3) than in the first 10 days of the emergency state (60 about μg/m^3). Interquartile ranges are larger during the emergency state in period of day with maximal levels of O_3.
- Daily profiles for NO, NO_2 and NO_x at Liman NN2 site, although lower in general, show a clear change in daily patterns similar to Rumenačka NN1 site. NOx boxplots show clear morning and afternoon pollution peaks, both before and during the emergency state, but the median of these peaks is reduced during the emergency state (median around 30-35 μg/m^3 before emergency state from 18h-19h, and an evident reduction of the median of about 15 μg/m^3 during the emergency state). Also, during the most active hours of the day (period from 9h to 17h) significant drop in the level of air pollution can be observed, indicated by a lower median (median around 15-30 μg/m^3 before the emergency state during this time of day, and about 10-15 μg/m^3 during emergency state in this time of day).
- Observing CO daily profiles at Liman, NN2 site, the following conclusions can be reached. During the active hours of the day, from 9h to 17h level of CO stayed similar, going between 0.4 and 0.5 mg/m^3, with a narrower interquartile range were during the emergency state. During morning hours, the level of median is similar, but with larger interquartile ranges before the emergency state. Similar as at the Rumenačka site, from 18h to 23h there is a slight reduction in CO level during the emergency state. Daily profiles before and during the emergency state for CO levels are connected with domestic heating sources that stay the same and traffic, leading to a slight reduction.


SO2 ug/m3
Hour (before EMS)
SO2 ug/m3
Hour (during EMS)
O3 ug/m3
Hour (before EMS)
O3 ug/m3
Hour (during EMS)
NO2 ug/m3
Hour (before EMS)
NO2 ug/m3
Hour (during EMS)

35

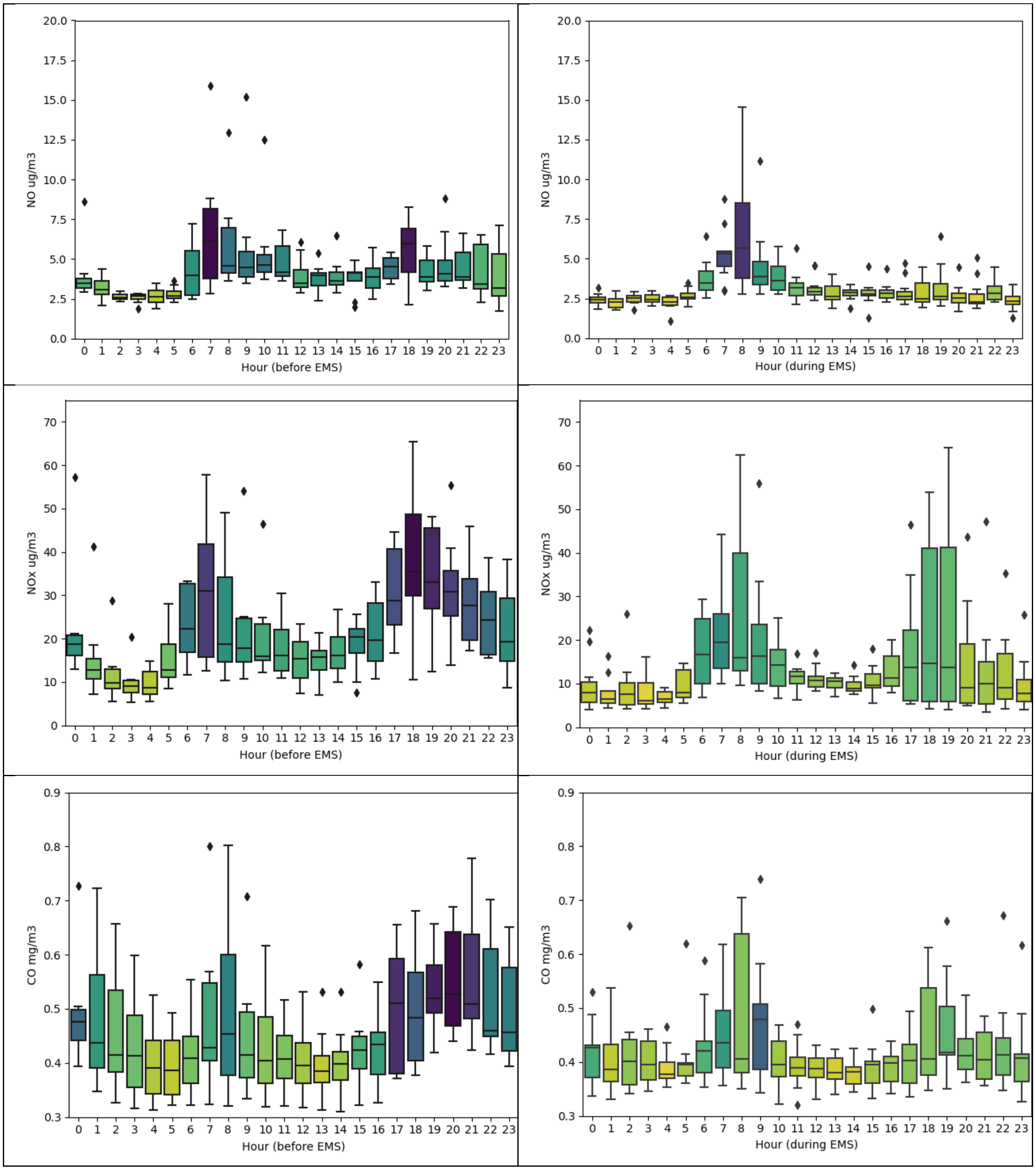
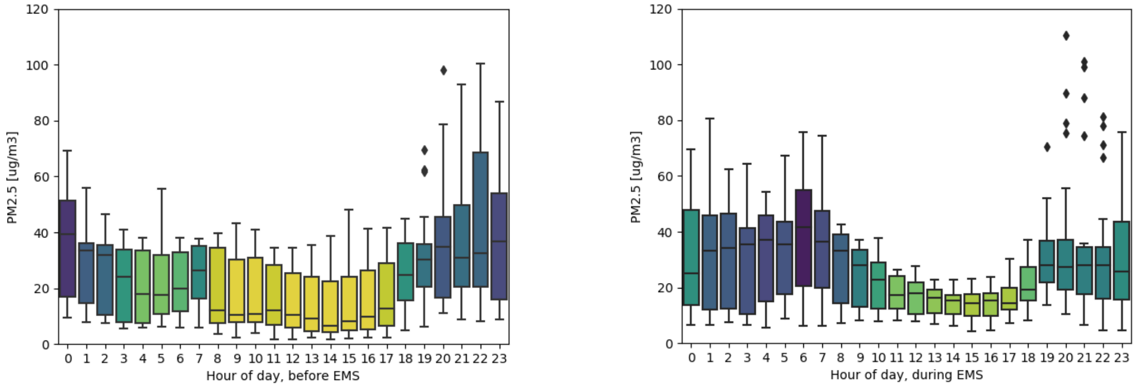
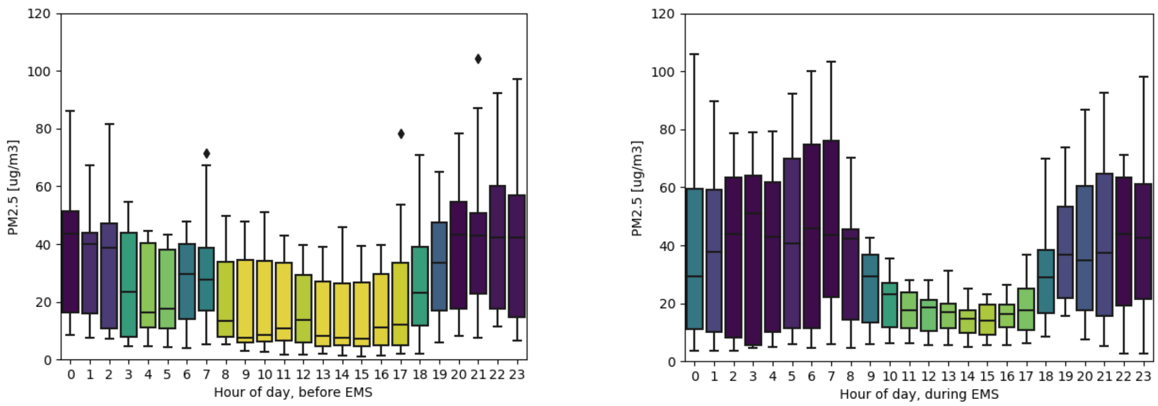


Figure15. Liman SEPA, NN2, station, hourly box plots before (2020-03-08 until 2020-03-15) and during emergency state (2020-03-16 until 2020-03-26)

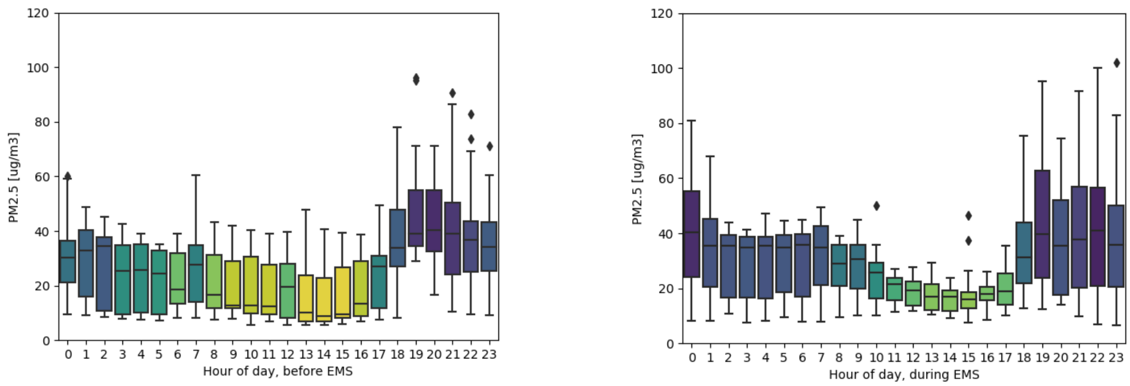
10. Changes in diurnal variation of PM2.5 at sampling site MS1, MS2, MS3, MS5 and NN1 before and after measures of the state emergency



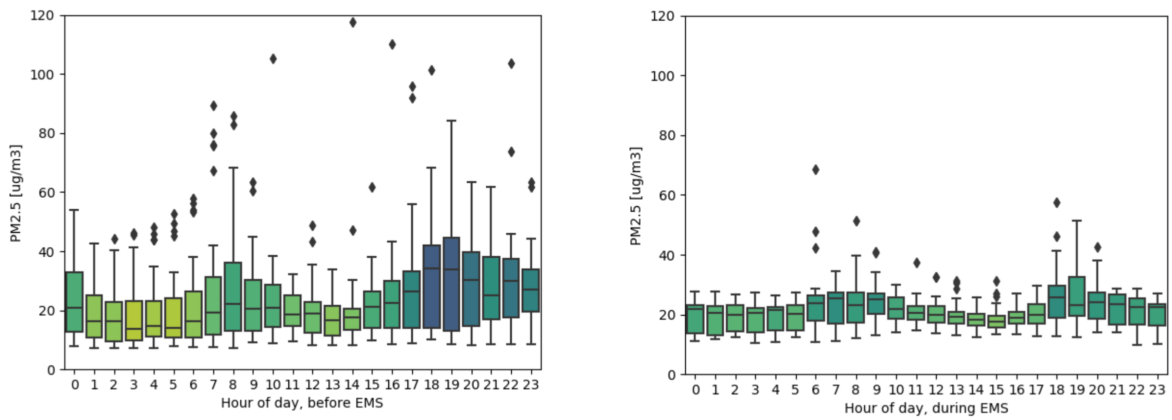
a) Daily profile of PM2.5 measured with low-cost sensor in the last week of BEMS and at the beginning of EMS at sampling site MS1



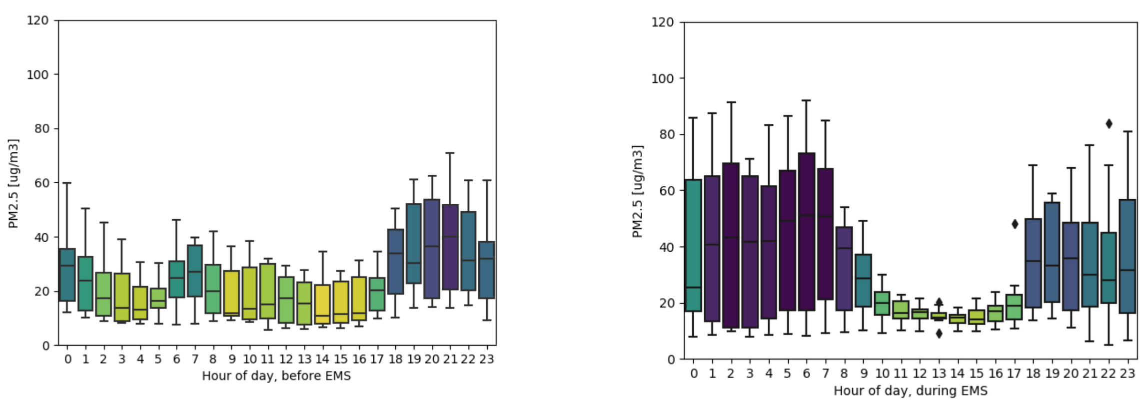
b) Daily profile of PM2.5 measured with low-cost sensor in the last week of BEMS and at the beginning of EMS at sampling site MS2



c) Daily profile of PM2.5 measured with low-cost sensor in the last week of BEMS and at the beginning of EMS at sampling site MS3



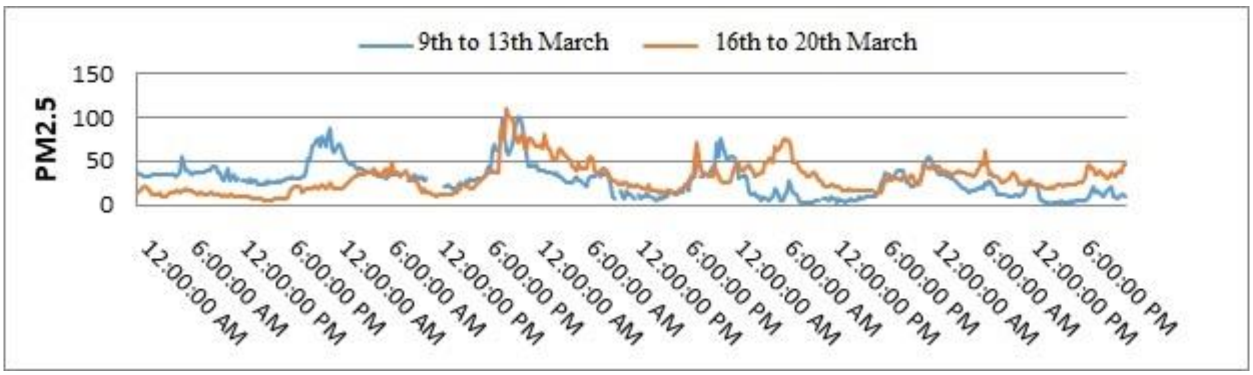
d) Daily profile of PM2.5 measured with low-cost sensor before EMS in February and at the beginning of EMS at the sampling site MS5



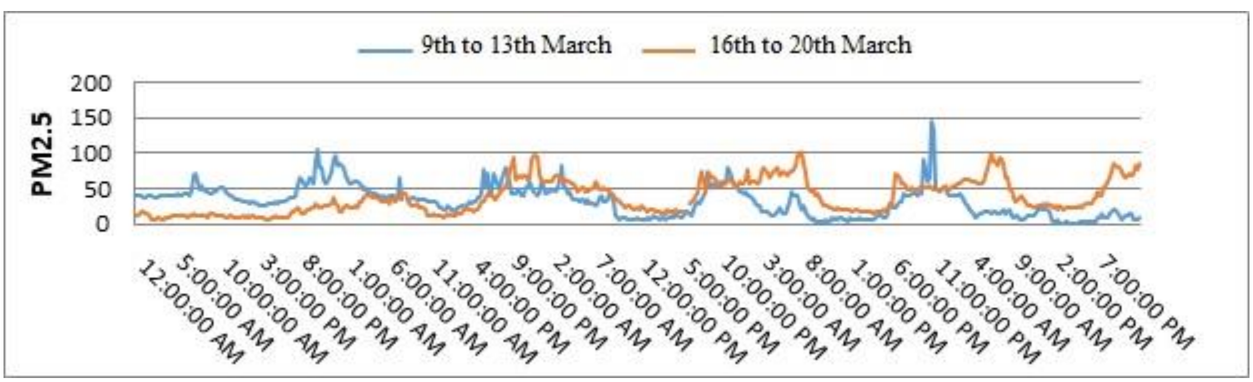
e) Daily profile of PM2.5 measured with equivalent instrument in last week of BEMS and at the beginning of EMS at sampling site NN1

Figure 16. Daily profile of PM2.5 measured before measures of the state of emergency and during measures of the state of emergency at a) MS1 b) MS2 c) MS3 d) MS5 e) NN1

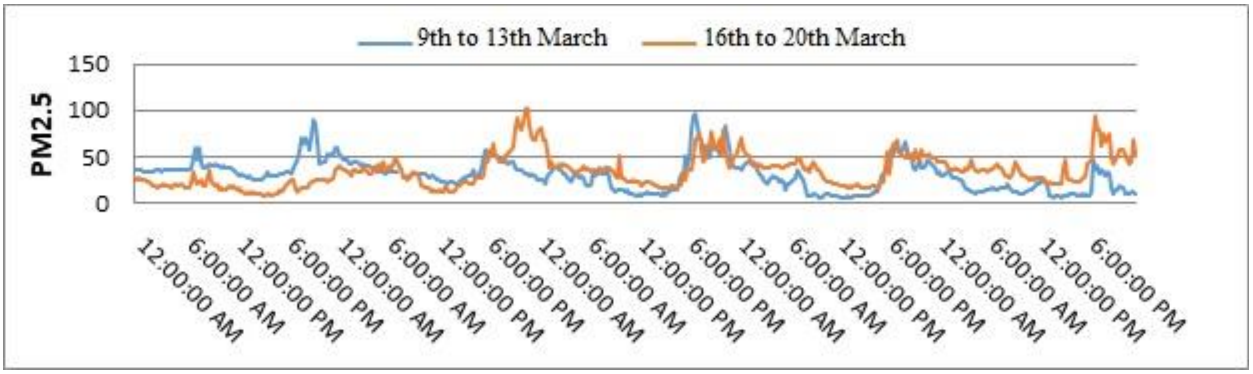
The reduced movement of vehicles, as well as reduced industrial and construction activities during lock down in Novi Sad, leading to the reduction of the exhaust and non-exhaust emissions, were a probable cause for a reduction and a more uniform profile of the $PM_{2.5}$ levels during working hours (8 AP -5 PM). According to recently published studies similar findings were identified in several cities in various part of the world (Singh et al, 2020). In the first month of lock down, period 15.03-15.04.2020., the official heating session was still ongoing. For the most part mean daily temperatures in the week before and in the first weeks of lock down, during which the sampling campaign was conducted, were below 10 °C. Residential heating sources caused higher concentration in the morning and during the night at almost all sampling sites that may be clearly recognised from box-plot that represent 1h-variation in the week before the EMS and period at the EMS beginning.



a) Workdays at **MS1** before EMS (from 9 to 13 March) and during EMS (from16 to 23 March)

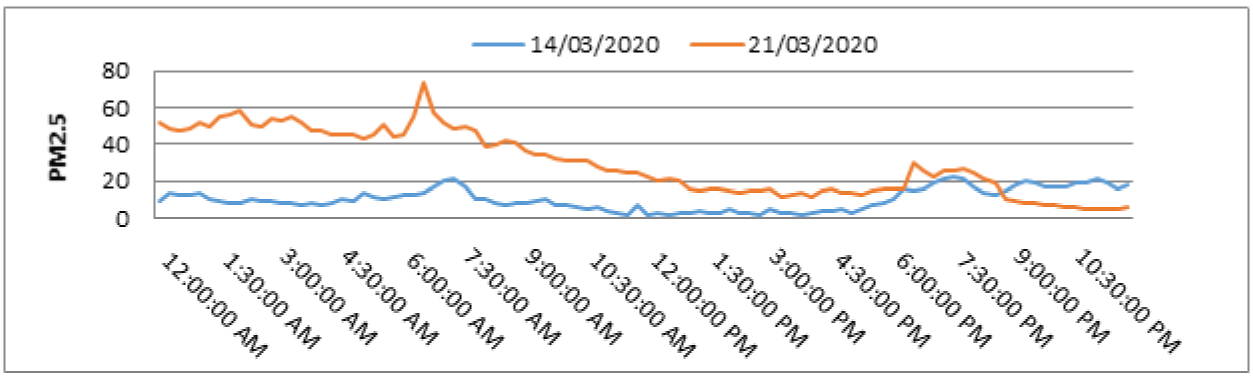


b) Workdays at **MS2** before EMS (from 9 to 13 March) and during EMS (from16 to 23 March)



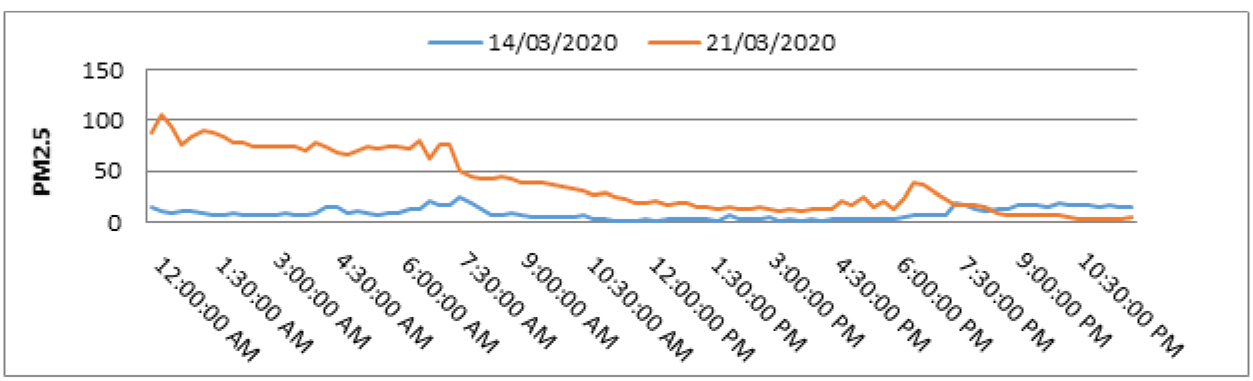
c) Workdays at **MS3** before EMS (from 9 to 13 March) and during EMS (from16 to 23 March)

Figure 17. Workdays before EMS (from 9 to 13 March) and during EMS (from16 to 23 March) at a) MS1 b) MS2 and c) MS3

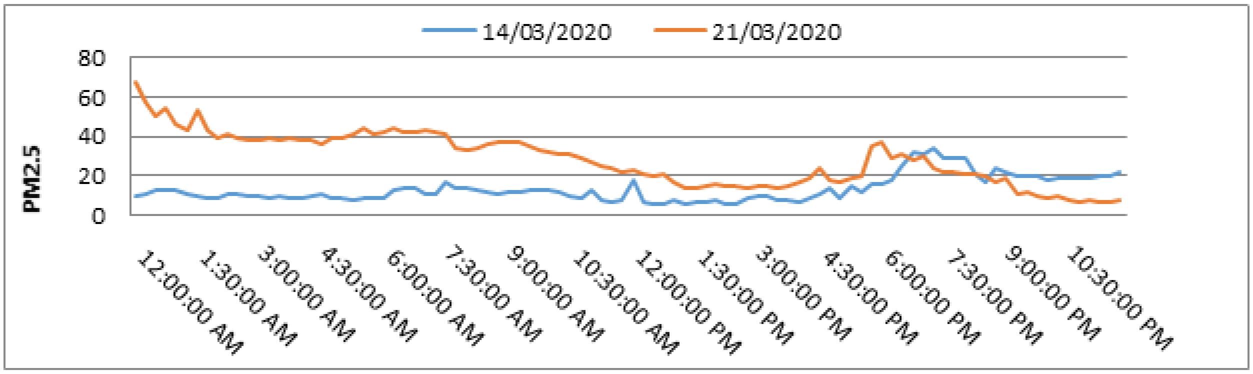


40

a) Saturday before EMS (14 March) and after EMS (21 March) at **MS1**

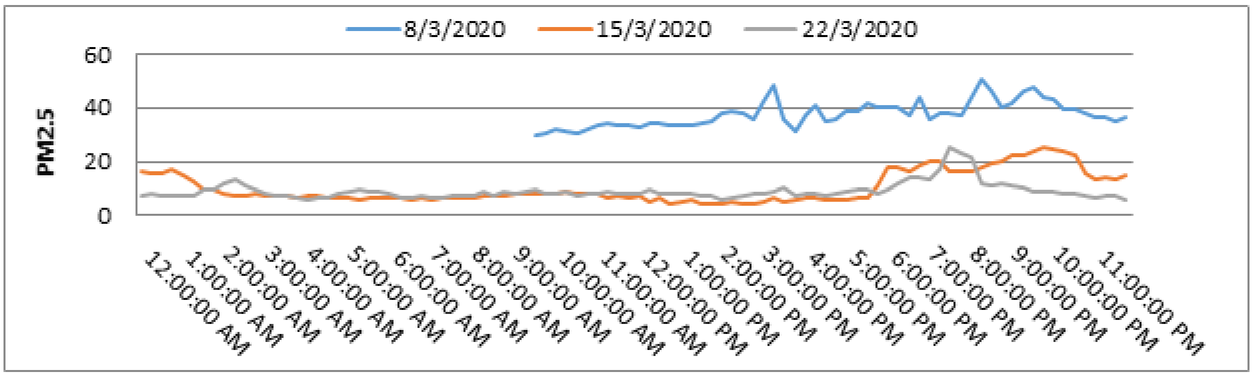


b) Saturday before EMS (14 March) and after EMS (21 March) at **MS2**



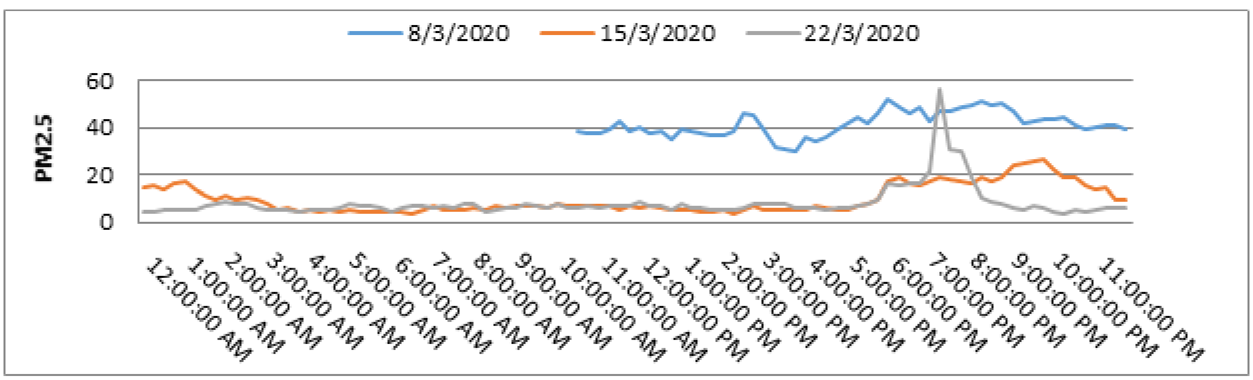
c) Saturday before EMS (14 March) and after EMS (21 March) at **MS3**

Figure 18. Weekend day (Saturday) before EMS (from 9 to 13 March) and during EMS (from16 to 23 March) at a) MS1 b) MS2 and c) MS3

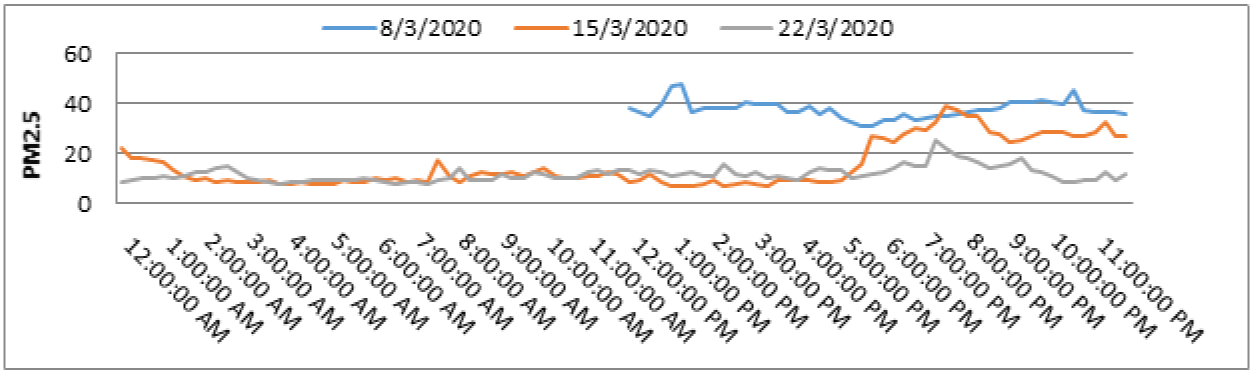


41

a) Sunday before EMS (8 March) and after EMS (15 and 22 March) at **MS1**



b) Sunday before EMS (8 March) and after EMS (15 and 22 March) at **MS2**



c) Sunday before EMS (8 March) and after EMS (15 and 22 March) at **MS3**

Figure 19. Weekend day (Sunday) before EMS (from 9 to 13 March) and during EMS (from16 to 23 March) at a) MS1 b) MS2 and c) MS3

10. Conclusions

In this report, we have presented a part of a more extensive research study targeting particulate matter pollution in the city of Novi Sad that was conducted during February and March of 2020. On March 15th, 2020, when COVID-19 lockdown started and emergency state measures were declared, a sampling campaign of collecting data with gravimetric pumps and IOT low-cost sensors has been already in progress. New circumstances were promptly integrated into the campaign's planning, as they opened possibilities to examine the influence of broader societal changes on air pollution. Additional campaign efforts, which now also included examining of COVID-19 lockdown influence were carried out and data were collected both before and at the beginning of COVID-19 lockdown in Novi Sad.

In parallel we presented data about main air pollutants, particulate matter and gaseous such as SO2, NO2, NO, NOX, CO and O3, collected at monitoring sites that belong to national s regional and local network, in total seven sites in the wider area of Novi Sad.

Looking at descriptive aggregate statistical data, we have not identified a significant reduction in PM2.5 concentration levels at a daily level. The measuring campaign and data collection were finished at the last sampling site (MS5) on March 26th. Up until that point, no significant non-local sources were influential. On March 27th and 28th, when the concentrations of PM2.5 and PM10 were extremely high in the whole of Serbia and surrounding countries, Aralkum desert was pointed out as the external source of high increase in PM. This source of dust was confirmed via back trajectory tracing to Aralkum Desert. Trends and levels of fine and coarse particulate matter in Novi Sad and other cities in Serbia before and after lockdown were under multiple factors similar like it was observed is cities in region e.g. Budapest and Sofia (Copernicus Europe`s eyes on Earth, 2020.).

In the city of Novi Sad, air pollution mainly comes from traffic and residential heating, where citizens of Novi Sad use a variety of fuels for heating of individual houses: gas, biomass, and fossil fuels. More detailed analysis showed that morning peak and higher concentration during the night period remained present in the daily profiles even after the COVOD-19 lockdown, and in that period, there were also no significant changes in the daily profile at all sampling sites. Morning peak and higher concentrations during the night and variability characteristics for that period stayed the same at all four sampling sites and part of the daily profile for that period was similar before and after emergency state measures were declared. For the period corresponding to working hours, between 8 AM and 5 PM, when people are the most active and traffic is usually the most frequent, PM concentrations and their variability were lower during COVID -19 lockdown than during the week before COVID-19 lockdown. This can probably be attributed to the fact that many citizens stayed at home, leading to reduced traffic and associated emissions.

11. References

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