Atmospheric particulate matter pollution over residential urban areas during COVID-19 quarantine

R Ilieva¹, B Angelova¹, M Iliev¹, D Stoyanov², V Groudeva¹, Z Cherkezova-Zheleva¹ and I Nedkov²

¹ - Sofia University “St. Kliment Ohridski”, Faculty of Biology, Bulgaria
² - Bulgarian Academy of Science, Institute of Electronics, Bulgaria

E-mail: nedkovivan@yahoo.co.uk

Abstract. This study of particulate matter (PM) pollution was conducted in May and June 2020 during the COVID-19 lockdown in residential areas of the Bulgarian capital Sofia. Its methodology was based on lidar monitoring of the ground layer of the atmosphere and focused on the sampling procedure. The sampling was performed with portable instruments in situ in the areas with air pollution fixed on the city’s map during the lidar monitoring. The collected PM was examined by a set of physical methods (XRD, SEM, EDAX) and PCR tests for viral contamination. A wide range of data on the nature of PM were obtained. Data on the number of COVID-19 positive individuals in the town for the period was also summarized.

Key words: particulate matter (PM), bioaerosol, lidar monitoring, COVID19 lockdown period.

1. Introduction

The subject of this study is the particulate matter (PM) carried by the atmospheric bioaerosol. The term PM is collective expression for particles and usually describes the solid-state part of water droplets [1, 2]. In assessing the PM pollution, it is widely accepted to work with the mass concentration of PM 2.5 µm and PM 10 µm. In nature, PM have different origin, their size varies widely and their morphology creates the conditions for them to be carriers of various inorganic and bioorganic pollutants. Moreover, their water envelope in the atmospheric aerosol can become a breeding ground for bacteria, fungi and viruses, so that they can present danger to human health. On 11 March 2020, the World Health Organization (WHO) declared the coronavirus pandemic. The new virus Sars-Cov-2 (COVID-19) is poorly studied and spreads very rapidly among the human population. It is mainly transmitted by inhalation of aerosol droplets. The conventional view [3] of viral spread uses the term “short-range transmission” and assumes that droplets ejected by the infected subject are heavy and spread over short distances. However, when this process takes place outdoors, the droplets become part of the aerosol environment and could undergo a different way of spreading. The diameter of these diverse particles is normally very small, they sediment slowly and are easily conveyed by air currents in the so-called “long distance transmission” [2]. This was confirmed by a study in 2010, when Chen and al. [4] reported that the avian flu virus was found in large concentrations in the air after dust storms. European authors reported recently on observing a relationship between the spread of the Sars-Cov-2 virus and air pollution [5]. The present work offers an extended study of the atmospheric bioaerosol during a COVID 19 lockdown over densely populated urban areas of the capital of Bulgaria, the city of Sofia, and provides extensive information on the type of PM (size and morphology) and their inorganic and organic content, including bacteria and fungi.
2. Methods and devices

The lidar mapping was performed by a lidar system installed in the Lidar Station of the Institute of Electronics, Bulgarian Academy of Sciences (IE-BAS). The laser emitter (wavelength of 510.6 nm) is a pulsed CuBr vapor laser with a repetition rate of 10 kHz at a 15-ns pulse duration. The PM sampling was implemented using an Andersen Cascade Impactor. Nutrient agar with cycloheximide was used for bacteria and YGC agar for fungal enumeration. The positive hole method was used for total colony count expressed as CFU/m³. The control of the particles by size and mass concentration in this experiment was expanded through the systematic use of a Microcontroller SDS 011 – PM2.5 and PM10 during the lidar experiments and in the daily experimental practice. Additionally, the PM was collected on # 3µm filters during the lidar monitoring. The collected PM was studied by SEM, EDAX, Mössbauer spectroscopy and PCR tests for viral contamination.

3. Results and discussion

This study was conducted in May and June 2020, when a COVID-19 lockdown was strictly observed. The subject of the study were the residential areas (Mladost and lower part of Lozenets districts - see Fig.1a) of Sofia. The formal control of PM urban air pollution is focused mainly on the content of PM2.5 and PM10. Three stationary licensed stations of the Executive Agency (EA) at the Ministry of Environment and Water are located in the areas studied and provide daily online information on the PM concentration.

![Map of the city Sofia showing the fixed licensed stations and outlining the area under study](image1)

![Data on the variation of the mass concentration of PM during the month of May in an area 7 km away from the Lidar Station](image2)

Figure 1. a) Map of the city Sofia showing the fixed licensed stations and outlining the area under study; b) Data on the variation of the mass concentration of PM during the month of May in an area 7 km away from the Lidar Station

The designated area was subject to lidar monitoring. The characteristics of the lidar scan adopted in this case are discussed in detail in our chapter of the book [6]. Below we will briefly describe the basic expressions and the lidar data processing. The two major lidar parameters, the extinction coefficient $\alpha(r)$ and the backscatter coefficient $\beta(r)$, are calibrated in terms of the aerosol mass concentration following the well-known method in [7] and making use of the mass concentration $M_a$ data obtained by the sampling device. For the lidar ratio $LiR = \alpha(r)/\beta(r)$ we adopted the typical value of $LiR=50$ [7]. The parameters $\beta(r)$ and $\alpha(r)$ were calculated using the lidar equation under the assumption of a horizontally-homogeneous atmosphere:

$$P(r) = P_0 \frac{c \tau}{2} C \frac{\beta(r)}{r^2} \exp \left[-2 \int_0^r \alpha(r) dr\right]$$

(1)
where $P(r)$ is the power of the detected laser radiation backscattered from the atmosphere from a distance $r = \frac{ct}{2}$ after a period of time $t$ following the moment of laser pulse emission, and $\tau$ is the pulse duration. The calibration dependencies were constructed of $\alpha(r)$ and $\beta(r)$ on the mass concentration in $[mg/m^3]$. In both cases, the linear fit ($y = A + Bx$) shows acceptable values of the standard deviation (less than 4%) and the correlation coefficient (over 0.92). The plots can be used directly for calibrating the lidar maps. More detailed information about the lidar monitoring during the spring period of 2020 can be found in our work [8]. Fig. 1b illustrates a typical example of the remote sensing capabilities. The dependence of the PM concentration calculated on the basis of the extinction in the aerosol of the surface atmosphere at a height of up to 30 m is presented for a distance of 7 km from the Lidar Station, with the whole scanned city area being about 24.4 km². The mass concentration varies in a small range from 0.01 to about 0.03 mg/m³. The maximums of PM pollution in the urban atmosphere are within the permissible norms for the whole period of studies.

The quality of the lidar sensing deteriorates in rainy weather and strong solar radiation and does not allow direct differential analysis in terms of particle size. During the experiment, this reduced the number of lidar experiments and necessitated the development of the current methodology, which expends the possibilities for objective daily assessment. An important element of the methodology is sampling. For this purpose, in areas with increased air pollution fixed on the city plan by the lidar monitoring, in situ sampling was performed using the following portable instruments: 1. Absorber with filters that collect PM ≥ 1 µm in size. For this purpose, a portable device with 4 filter sockets is used. The device reads the water content and the solid part of the aerosol; 2. Cascade Impactor, which separates the PM by size and allows one to study their microbial content; 3. Electronic sensors, which are calibrated with respect to data of the licensed stations [8] and give information about the mass concentration of PM2.5 and PM10.

After sampling, the material collected from devices 1 and 2 was examined by a set of physical methods (XRD, SEM, EDAX, MöS) and PCR viral contamination tests. This enabled us to obtain a wide range of data on the PM crystallo-chemical composition and morphology, on the nature of the surface and on their microbiota and elemental composition. The studies showed a wide variety of particles, which strongly depended on the seasonal characteristics, such as flowering and humidity. A common feature is that mostly aggregates of particles are observed, where in a peculiar way they combine inorganic and bioorganic material. Fig. 2 summarizes the weekly data for May (Fig. 2a) and June (Fig. 2b) from the measurements of PM2.5, PM10, bacterial contamination and the presence of fungi. Tables 1 and 2 show the meteorological data for the months considered. The X-ray diffractograms recorded show that the examined PM are amorphous – no crystalline phases were detected. The MöS analyses of the PM show the presence of iron ions in the second valence of oxidation, mostly in the atmosphere of Lozenets district, while equal amounts of divalent and trivalent iron were registered in the samples from Mladost district. More information was presented in our work [8]. Quantitative analyses were performed to determine the total number of cultured microorganisms as follows: aerobic heterotrophic bacteria (NA medium) and fungi (YGC medium). The samples were collected by means of the six-stage Cascade Impactor and performed in triplicate for each sample.
Table 1. Meteorological data for May 2020

| Meteo Data | 1st week | 2nd week | 3rd week | 4th week |
|------------|----------|----------|----------|----------|
| $T$ (°C)   | 12 ± 2   | 19 ± 3   | 27.3 ± 1.8 | 18 ± 3.1 |
| RH (%)     | 46.9 ± 3 | 45.3 ± 12 | 41.5 ± 3.2 | 64.5 ± 3.5 |
| Wind (m/s) | 5.65 ± 0.65 | 1.9 ± 0.7 | 1.7 ± 0.2 | 3.5 ± 5 |

Table 2. Meteorological data for June 2020

| Meteo Data | 1st week | 2nd week | 3rd week | 4th week |
|------------|----------|----------|----------|----------|
| $T$ (°C)   | 24.5 ± 1.5 | 20.25 ± 3.75 | 24 ± 4 | 21.6 ± 4.5 |
| RH (%)     | 44.5 ± 14.5 | 65.7 ± 15.2 | 61.7 ± 13 | 70.8 ± 17 |
| Wind (m/s) | 1.8 ± 2 | 3.57 ± 4.2 | 4.6 ± 4 | 1.7 ± 1 |

Figure 2. Monthly variation in the mass concentration of PM2.5, PM10, bacteria and fungi contents a) in May and Table 1 and b) in June and Table 2 with weekly meteorological-data.

The results of the analysis show a significantly higher number of bacteria and fungi in both time intervals of the study. When comparing the data from this analysis over time: May, 2020 and June, 2020, a significant increase in the number of the two studied groups is reported. As already mentioned,
the first interval tested in May is characterized by extremely low anthropogenic pressure due to the lockdown sanitary-epidemiological restrictions for the period (Fig. 2a). Typical for the period shapes of PM are presented in the insets. The figures show that the pollution with PM is within the standard permissible limits, while in the first two weeks of June an increase of PM2.5 and PM10 is seen. The bacterial contamination in the two months is within 200 CFU/m³, the content of fungi in the air increases sharply in June up to 1600 CFU/m³.

An attempt was made to compare these data with the official data of national institutions monitoring the epidemic. Based on these data, Fig.3 shows the number of people infected with COVID-19 in the city of Sofia. The analyses of the data on PM and microbial contamination in the context of COVID-19 lockdown at first glance shows an increase in the infected individuals occurring 3-4 days after the observed increase in PM2.5, PM10 and fungi in the area. Nevertheless, we do not undertake to make a definitive relationship assessment, unlike our colleagues in works [4, 5]. The main problem comes from the fact that in a large city like Sofia with more than 1.3 million inhabitants it is incorrect to draw conclusions on the number of infected in the whole city using data pertaining to areas with a population of 160 thousand. In addition, during the experiment, the air pollution was below the generally accepted norms and should not have posed a danger.

![Graph showing daily change in the number of COVID-19 positive persons during the period discussed (May-June 2020)](image)

**Figure 3.** Daily change in the number of COVID-19 positive persons during the period discussed (May-June 2020)

### 4. Conclusions

Combining lidar monitoring with *in situ* sampling and examination of the solid part of the PM is the main goal of this work. During the experiment, the air pollution did not exceed the generally accepted permissible limits. The strong dependence of the microbial pollution on the seasonal features is impressive. The increase in temperature and humidity in June greatly increases the presence of fungi in the air. The area studied is residential with many parks with tall trees than emit pollen during the period, while last year’s rotting organic matter on the ground causes an increase in the fungi content. The search for correlation between air pollution and viral epidemics is not the main task of this work; however, in June an increase of the COVID-19 positive cases was registered 4-5 days after an increase of PM2.5 and PM10. These results give us grounds to continue these studies, as they open prospects for obtaining in-depth results on the relationship between the PM content and the COVID-19 epidemic, thus creating preconditions for rapid prevention.

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