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The characteristics of the air pollution of a transition economy city: the example of Belgrade

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Abstract: The results of sulphur dioxide (SO_2), nitrogen dioxide (NO_2) and black smoke (BS) levels in the Belgrade metropolitan area, the only pollutants measured at almost all 20 monitoring stations set up in the area, were critically analysed, the most reliable ones select and the pollution characteristics were defined in these terms. Belgrade was found to have pollution typical for a city in economical transition – still high SO_2 and BS levels, with seasonal variation, while moderate NO_2 levels. This is discussed in terms of sources, as well as spatial and temporal distribution.

Keywords: urban air pollution, air quality, monitoring, Belgrade.

INTRODUCTION

Urban air pollution and its impact on urban air quality is a world–wide problem. It manifests itself differently in different regions depending on the economical, political, and technological developments, on the climate and topography and on the nature of the available energy sources. Although the air quality in European cities has generally improved in recent decades, air pollution is still considered a top priority environmental problem with both urban and large scale impacts. Air pollution in a developing urban area initially increases, passes through a maximum and then decreases when pollution abatement becomes effective.[1] Cities in the industrialized western world are in some respects at the last stage of this development. In transition economies, many cities are in the stabilization stage. In developing countries, the pollution levels are still rising.

In order to provide a database for determining the air quality in major metropolitan areas, to observe pollution trends in urban and non-urban areas and to assess the compliance or progress made towards meeting air quality standards, it is necessary to have a reliable air pollution monitoring network. The current urban Belgrade air monitoring features 20 monitoring stations belonging to two networks.

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The objective of the present study was to analyse and characterise the air quality in the Belgrade metropolitan area in terms of the three most commonly monitored parameters, SO_2, NO_2, and BS, based on measurements from the official monitoring networks.

AIR POLLUTION MONITORING IN BELGRADE

Geography and climate

Belgrade (population about 1.6 million) is situated at the crossing of the communication paths between eastern and western Europe, on the Balkan Peninsula. It has grown around the banks of two rivers (Fig. 1), the Sava and the Danube, at their confluence, and has an average elevation of 116.75 m, with the characteristics of a hilly city. The Belgrade metropolitan area combines two different natural settings: the Pannonian Plain to the north and the hilly Šumadija to the south.

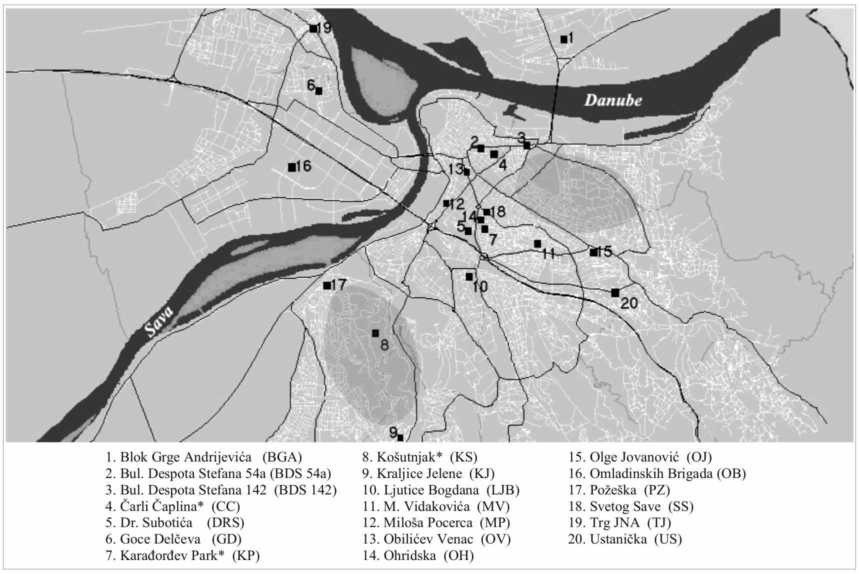

Fig. 1. Belgrade metropolitan area with the locations of the air-monitoring stations of IPH (unmarked) and HSRS (marked with *). Gray ellipses represent the major elevations of the terrain.

The climate is moderate continental, with four seasons; the average annual air temperature is 11.9 °C, January is the coldest month (average 0.4 °C) and July the hottest (average 21.7 °C); an annual average of 139 days with precipitation (annual average 667.9 mm).

As in many big cities, the Belgrade climate is characterised by the "heat island" phenomenon, where the central part of the city shows higher average temperatures (up to 3 °C) than its surroundings. During the winter months, lakes of cool air form in the lower parts of the city during nights, causing the phenomenon known as temperature inversion.[2]

Belgrade monitoring network

The monitoring of air pollution levels in Belgrade was established by the National Health Service in 1953 and was conducted by the Institute of Public Health (IPH). At this moment, there are 20 monitoring stations, combined between IPH (17 stations) and the Hydrometeorology Service of the Republic of Serbia (HSRS–3 stations), measuring various air pollutants. They are presented in Fig. 1. Of these stations, 14 are semi-automatic and 6 are automatic, with on-line monitoring since 2003 (BDS 54a, OH, OB, KP, CC, and KS in Fig. 1).

The monitoring stations are set up in five distinctive areas: central area with heavily saturated day traffic, mixed residential and industrial areas, primarily residential areas, prevailingly industrial areas, landscape area with no traffic (urban background). The stations monitor various pollutants, but almost all of them monitor SO_2, NO_2, and BS.

EXPERIMENTAL

The semi-automatic stations collect samples as 24-hour averages and the pollutant concentrations are determined in the laboratory (SO_2 by the tetrachloromercurate (TCM) method ISO 4221, NO_2 by the triethanolamine (TEA) method ISO 6768 and BS by reflectometry of the collecting filter). The automatic monitors collect SO_2 and NO_2 samples continuously, analyse by ultraviolet (UV) fluorescence ISO 1996 and chemiluminescence ISO 1985, respectively, and generate values as 3 min or 30 min averages.

RESULTS AND DISCUSSION

Outline of the data

The observations are based on the daily averages of the concentrations of SO_2, NO_2, and BS in the period 2003–2005, inclusive. They were analysed in terms of temporal and spatial variations, which reveal characteristics and sources of the pollution.

Prior to detailed analyses, the whole body of available data of the 1999 – 2005 period was scrutinised for consistency and reliability. This revealed that most of the SO_2 data from the semi-automatic stations were not sufficiently reliable in the low concentration range, when the values fell below the detection limit of the employed TCM method. Also, in many cases, the semi-automatic stations gave generally lower values than the more reliable automatic stations. This is consistent with comparisons at Schauinsland, Germany.[3] The stability of unprotected TCM samples is affected by temperature and light. This suggests that the data quality could be inconsistent across the sites. National comparisons in Germany showed that the TCM method gave slightly lower results than the impregnated filter method, even during winter. A national comparison in Turkey, February–November (1997), indicated that the low SO_2 results obtained by TCM may be caused by interference from ozone or some other oxidant.[4] In addition, some semi-automatic SO_2 data do not even follow the real seasonal annual variation, or are a possible victim of the arrangement of street canyon building.[5,6] For these reasons, all further considerations involving SO_2 are based primarily on SO_2 data from the automatic stations. Excluded are the stations: BGA, BDS 142, KJ, LJB, OJ, SS, and US.

The data for NO_2 and BS show more overall consistency and no significant differences exist between the automatic and semi-automatic data.

Seasonal and spatial variations

The SO_2 data show very regular variability, with high concentrations in winter (October–March), the cold season, and a gradual decrease to minimum values in summer. Black smoke shows similar, albeit less expressed, seasonal changes. NO_2 does not show significant seasonal variations.

Since spatial variation of pollutants is expected over the whole area,[7,8] the spatial distribution of the pollutants across a Belgrade street map was plotted using Golden Software Surfer (Version 6), a contouring and surface mapping software. The input data were the geographic coordinates of the stations and the average concentrations of the chosen pollutants at those locations during summer (June–August) and winter (October–March) in the period 2003–2005. Only the stations with reliable data in that period were included into the consideration, as discussed. This Surfer software creates contour maps which identify different ranges of data by automatically assigning a different colour to each data range. The most relevant features in the plots are the indications of maxima or minima defined by the iso-concentration curves.

Average SO_2 concentrations for summer and winter periods during 2003–2005 for the chosen stations are given in Table I. The summer data from stations OB, DRS, TJ, GD, and MV were not reliable enough to be taken into account, due to the reasons already discussed.

TABLE I. Average summer and winter SO_2 concentrations during 2003 – 2005 at the chosen monitoring stations

Station	BDS 54a	CC	KP	KS	OH	OB	DRS	TJ	GD	MV
Summer	17	30	35	25	49	*	*	*	*	*
Winter	73	83	149	45	141	33	101	28	19	50

The plots of SO_2 (Fig. 2) indicate that the maximum in winter months is concentrated around the area with several poorly filtered large heating systems near the centre of the city. In summer, the maximum is shifted more to the Industrial area near the Danube riverbank.

The data show that the SO_2 values exceed the limit value only during the winter season, almost exclusively in the central city zones.

The average NO_2 summer and winter concentrations for 2003–2005 were calculated from 14 monitoring stations (Table II).

The plots of NO_2 (Fig. 3) feature open iso-concentration curves in some parts, which may be an artefact due to lack of data in those parts, but the winter superposition (Fig. 3a) indicates the contribution of the district heating plants located more prevalently in the western parts of the city. This contribution is absent in summer (Fig. 3b), and the summer plot basically indicates the traffic density distribution.

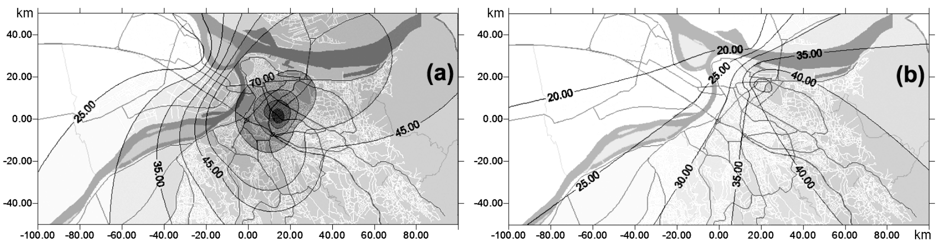

Fig. 2. Spatial distribution of SO_2 in (a) winter and (b) summer. Based on the measurements from the OB, KS, BDS 54a, CC, OH and KP stations (for the summer period) plus the DRS, TJ, GD and MV (for winter) stations, the iso-concentration lines are indicated in μg m^{-3}.

TABLE II. Average summer and winter NO_2 concentrations during 2003 – 2005 at the chosen monitoring stations

Station	BGA	BDS 54a	BDS 142	CC	KP	KS	MV	MP	OV	OH	OB	PZ	SS	TJ
Summer	11	34	29	24	22	21	30	42	31	38	16	24	22	35
Winter	13	48	33	21	34	18	26	35	31	74	35	26	24	34

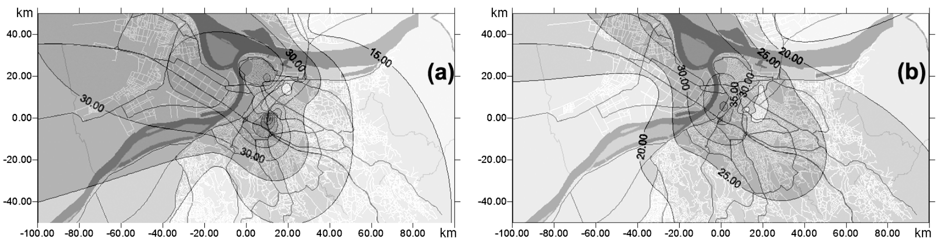

Fig. 3. Spatial distribution of NO_2 in (a) winter and (b) summer. Based on the measurements of the BGA, BDS142, MV, MP, OV, PZ, SS, TJ, OB, KS, BDS54a, CC, OH and KP stations, the iso-concentration lines are indicated in μg m^{-3}.

The NO_2 limits are rarely exceeded (1 % to 9 %, in Fig. 4). More do so during the heating season for stations near the district heating plants (OH, BDS 54a, KP, OV, OB), or in the non-heating season, the stations where traffic is the predominant source of NO_2 (MP, MV).

Both the winter and the summer plots of BS (Fig. 5a and 5b, respectively) show a clear "island" of "clean" air around the monitoring station KS, which is expected, as it is situated at an elevated urban background point. Generally, high BS concentrations seem to be confined to the lower parts of the city, where particulate matter naturally accumulates. That indicates natural and traffic sources of this pollution. High summer BS concentrations to the north from the main city area also indicate a strong natural source of this parameter – natural dust, which is quite present in the north, towards the Pannonian Plain. In winter, there is an "island" of high BS pollution around the city centre, where most of the individual and poorly filtered heating sources are situated (Fig. 5a). In this period, district heating plants in the western parts of the area apparently add to the seasonal contribution as well.[9]

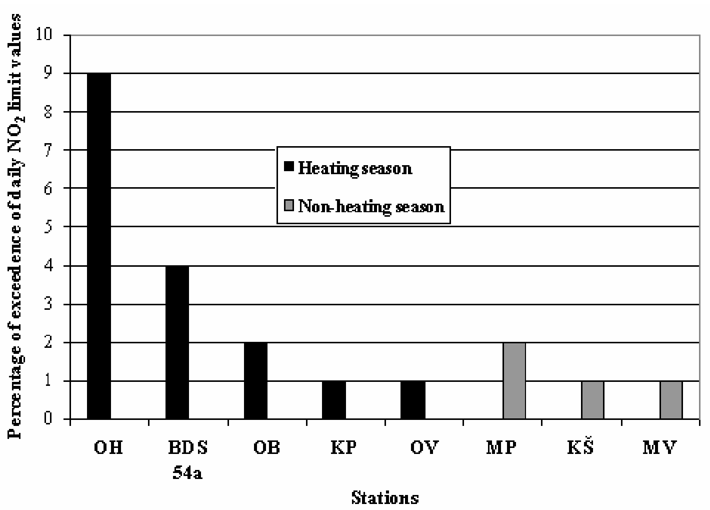

Fig. 4. Exceedence of daily the NO_2 limit values (85 μg m^{-3}) in 2005 during the heating and non-heating season.

The most extensive set of data was available for BS, which was measured at 17 locations in Belgrade (Table III).

This is in agreement with data on BS exceedences which show that in the heating season they occur in the central, northern, and western parts roughly twice as much as they do in the non-heating season. Heating is obviously still a major BS source in winter.

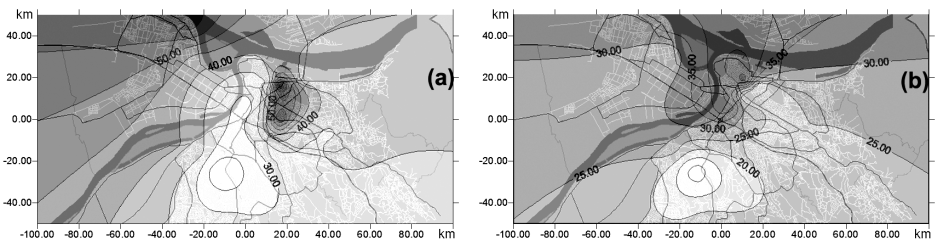

Fig. 5. Spatial distribution of BS in (a) winter and (b) summer. Based on the measurements of the BDS 142, DRS, GD, KJ, LJB, MV, MP, OV, OJ, PZ, SS, TJ, US, KS, BDS 54a, CC and KP stations, the iso-concentration lines are indicated in μg m^{-3}.

The situation is somewhat different at station BDS 54a, where the BS exceedence percentage is not significantly different in the two seasons and is even higher during the non-heating season. This is an indication that at this particular spot, the dominant source of BS is traffic, which adds to the complexity of the BS sources. In order to shed more light onto the nature of the BS measurements, some available PM_{10} (particles below diameter 10 μm) data were examined.

TABLE III. Average summer and winter BS concentrations during 2003 – 2005 at the chosen monitoring stations

Station	BDS 54a	BDS 142	CC	DRS	GD	KP	KS	KJ	LJB	MV	MP	OV	OJ	PZ	SS	TJ	US
Summer	53	28	22	27	25	30	6	23	*	23	45	20	25	27	*	38	23
Winter	39	38	76	42	44	67	20	32	33	38	30	37	34	39	42	63	37

Unlike BS values, those of PM_{10} show a great difference between the seasons, such that heating adds a significant contribution to the overall concentration of PM_{10} particles. Some studies have shown that mineral based particles (diameter around 50 μm) originate from either combustion processes (*e.g.* lead compounds from gasoline engines) or from brake and clutch lining wear.[10] These larger particles than 10 μm can appear in the material measured as BS, but not in the filtered PM_{10} material. PM_{10} particles mostly originate from various stationary combustion processes, transport, wind erosion, and resuspended road dust.[11] The results in Fig. 6 show that at this location the dominant source of PM_{10} in winter is stationary combustion (heating). This means that PM_{10} is here a better indicator of combustion processes than BS itself, which actually reflects traffic activity better.

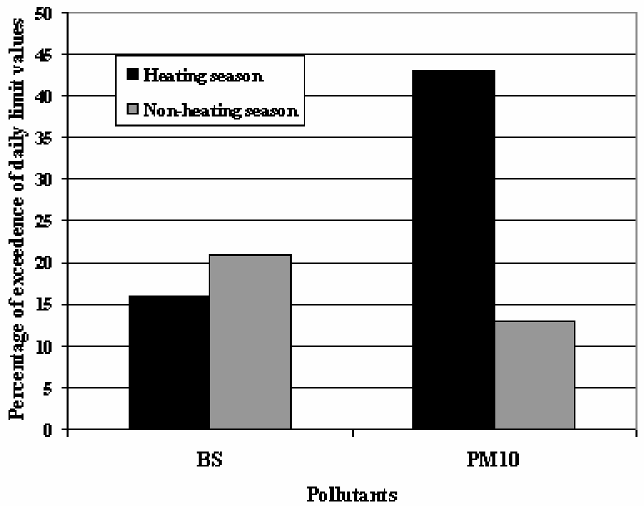

Fig. 6. Exceedence of the daily limit values for BS and PM_{10} in 2005 during the heating and non-heating season at the BDS 54a station.

Comparisons with other European cities

In comparison to some other European cities, the Belgrade situation is apparently the worst in terms of SO_2 and BS levels, and moderate in terms of NO_2 levels (Fig. 7).[12] Since SO_2 and BS are pollution parameters associated with outdated technologies, the situation reflects the lagging behind of technical developments of heating, industrial, and traffic practices in Belgrade. On the other hand, moderate NO_2 levels indicate that traffic is apparently still not as dense as in the more developed cities.

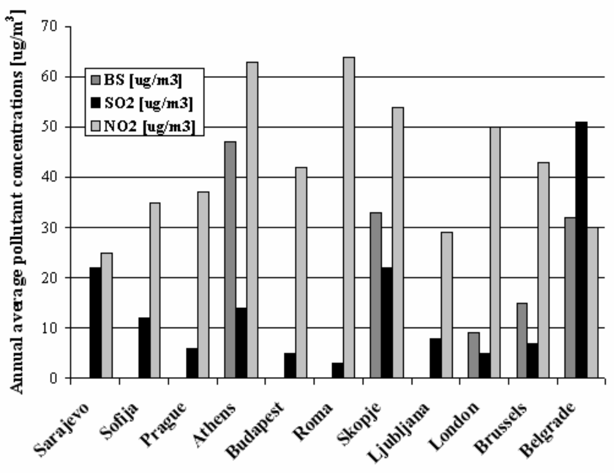

Fig. 7. Average annual BS, SO_2 and NO_2 concentrations in some European cities in 2004.

During the 1990s, the industrial "hot spots" shifted from western Europe to the central and eastern Europe (CEE), where heavy industry, use of low-quality fuels and outdated production technologies resulted in high emission levels. As a consequence, the emissions of NO_x and SO_2 per unit gross domestic product (GDP) in the CEE were more than 4 times higher, and emissions of particles and volatile organic compounds (VOC) considerably higher.[13] A transition period characterized the second part of the 90s in the CEE countries, when a series of management procedures were introduced, such as closing inefficient industries and power plants, fuel switching from brown coal to natural gas, and the introduction of flue gas desulphurization. The result was significant air-quality improvements.[14]

The ratio of the concentrations NO_x/SO_2 is apparently an indicator of the structure of pollution.[15] Nitrogen oxides are mainly produced by mobile sources, the role of which increases with the development of the economy. Simultaneously, the employment of sulphur-rich fuels typically decreases with modernisation of the technologies. Consequently, the value of this index significantly increases in urban areas with economic development. Cities in western Europe have a dominant traffic contribution to air pollution, and the resulting index has high values (Amsterdam, London, Helsinki, Milan, in Fig. 8). Cities of eastern and south-eastern Europe, which in the 1990s underwent rapid economic developments, show intermediate values of this index (Vilnius, Tallinn, Budapest, Prague, Warszawa, Ljubljana, Nicosia), whereas most of the Balkan cities (Skopje, Sofia, Sarajevo, Belgrade) show values below 5, typical of transition economy cities.

In most respects, air pollution in Belgrade has the characteristics of most East European cities in the past decade, of countries in transition in which economic conditions have a strong effect on the atmospheric environment (the quality of the car fleet and the types of environmental protection related to installations at stationary sources, as well as the type of home heating).[16]

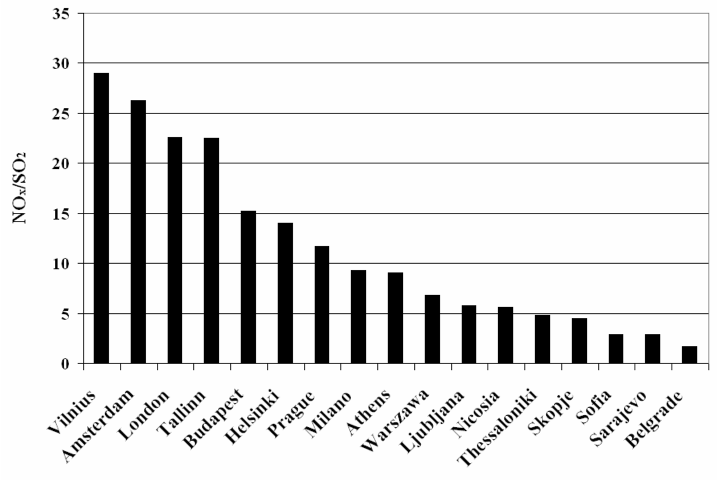

Fig. 8. Average annual concentration ratio of NO_x/SO_2 in some European cities in 2004.

CONCLUSIONS

Analysis of the data from twenty monitoring stations in the Belgrade metropolitan area showed that the TCM method used for SO_2 detection in the semi-automatic stations is quite unreliable, especially in the low concentration range. It follows that only the automatic stations can be trusted in this respect. This leaves only three reliable stations in the Institute of Public Health network, clearly indicating the need for modernisation of the equipment. Fortunately, the Hydrometeorology Service contributes to the available data with its additional three automatic stations.

The most significant characteristics of air-pollution in Belgrade are: high SO_2 and elevated BS pollution in the cold season, mainly caused by domestic heating; NO_2 pollution which follows the temporal and spatial variations of traffic emissions, with some seasonal contributions from heating; and indications of significant traffic and natural contributions to BS generally. It should be interesting to follow these indications by more detailed research which would answer important questions about the origin, and more importantly, characteristics and health impact capacity of the particulate matter in Belgrade generally, with possible mapping of the natural/anthropogenic influences across the whole area. Monitoring of the classical "Black Smoke" parameter obviously cannot answer these questions alone and has to be appended by monitoring parameters such as PM_{10}, $PM_{2.5}$, and PM_1, together with chemical analyses.

Since mapping requires inclusion of as many measuring points as possible, in the present study it was confined only to the pollutants monitored by all the available stations of the existing networks. Also, the obtained average concentration ratio of NO_x/SO_2 below the value of 5 clearly classifies Belgrade as a transition economy city.

Substitution individual heating with coal and heavy oil by gas district heating would help enable considerable decreases in the SO_2 and BS levels. Better traffic organisation should contribute to a lowering or containment of NO_2 levels, which are not so critical in comparison with other European cities.

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ИЗВОД

КАРАКТЕРИСТИКЕ АЕРОЗАГАЂЕЊА ГРАДОВА ЗЕМАЉА У ЕКОНОМСКОЈ ТРАНЗИЦИЈИ: ПРИМЕР БЕОГРАДА

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У раду су критички анализирана мерења нивоа SO_2, NO_2 и чађи на територији града Београда. Концентрације ових загађивача се мере на већини од 20 мерних станица мониторинг мреже постављене на широј територији града, од којих су одабране само оне најпоузданије и на основу тих мерења дефинисане су основне карактеристике аерозагађења у Београду. Нађено је да Београд карактерише аерозагађење типично за градове земаља са економијом у транзицији – високи нивои SO_2 и чађи који показују знатне сезонске варијације и умерено високи нивои NO_2. Разматрани су извори, просторна и временска расподела ових аерополутаната.

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