Source Apportionment of Atmospheric Bulk Deposition in the Belgrade Urban Area Using Positive Matrix Factorization

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Abstract. The primary objective of the present study was to assess anthropogenic impacts of heavy metals to the environment by determination of total atmospheric deposition of heavy metals. Atmospheric depositions (wet + dry) were collected monthly, from June 2002 to December 2006, at three urban locations in Belgrade, using bulk deposition samplers. Concentrations of Fe, Al, Pb, Zn, Cu, Ni, Mn, Cr, V, As and Cd were analyzed using atomic absorption spectrometry. Based upon these results, the study attempted to examine elemental associations in atmospheric deposition and to elucidate the potential sources of heavy metal contaminants in the region by the use of multivariate receptor model Positive Matrix Factorization (PMF).

1. Introduction

Clean air is considered to be a basic requirement for human health and well being. Various chemicals are emitted into the air from both, natural and anthropogenic sources. In spite of the introduction of cleaner technologies in industry, energy production and transport, air pollution remains a major health risk and tighter emission controls are being enforced by many governments. The studies of the transport and mobilization of trace metals up to now have attracted attention of many researchers [1,2,3]. Trace metals are persistent and widely dispersed in the environment and interacting with different natural components result in toxic effects on the biosphere.

The urban atmosphere is subjected to large inputs of anthropogenic contaminants produced by both stationary (power plants, industries and residential heating) and diffuse sources (road traffic) [4,5]. According to their different physical and chemical properties (vapor pressure, Henry’s law constant), the size and composition of the source particles, these pollutants are partitioned between particulate and vapor phases and are subsequently transported to the Earth’s surface through dry and wet deposition [6].

Most trace elements in terrestrial ecosystems originate from atmospheric wet and dry deposition, which are recognized as important processes determining pollutant dynamics in the atmosphere. The magnitude of atmospheric deposition and the ratio of wet to dry deposition is controlled among others by emission sources, distance to emission sources and the sampling site [7] and meteorological conditions, e.g. prevailing wind directions, and type, frequency and amount of precipitation. Because either mode, wet or dry, may contribute equally to or predominate in total deposition, it appears
essential to include both wet and dry deposition to estimate loading from atmospheric deposition. From a biogeochemical perspective, the characterization of total atmospheric deposition is relevant in order to identify the variability and sources of the atmospheric pollutants [8]. Direct collection of atmospheric deposition using bulk sampling devices offers a practical approach to monitor atmospheric heavy metal deposition providing valuable information on the influences of atmospheric inputs of heavy metals on the surface environment [9,10]. During the past decades, wet and dry deposition of metals has been widely studied [10,11,12,13,14] and some authors have studied “bulk” (dry + wet) deposition [15,16,17,18].

Identification of air pollution source characteristics is an important step in the development of air quality strategies. Receptor modeling, using measurements of pollutant concentrations at one or more sample sites, is often a reliable way to provide information regarding source regions of pollution. Positive Matrix Factorization (PMF) modeling as source identification tool for atmospheric pollutants was already successfully tested in air quality studies. The objective of this study was to examine the use of PMF on elemental bulk atmospheric depositions data set for source apportionment purpose. Bulk atmospheric monthly deposits were sampled at three sites within the Belgrade urban area from June 2002 to December 2006 and analyzed for major (Fe and Al) and minor elements (Pb, Zn, Cu, Ni, Mn, Cr, V, As and Cd) using atomic absorption spectrometry. Seasonal trends were analyzed together with the spatial distribution and an assessment of the level of the trace element pollution was carried on.

2. Methodology

2.1. Studied sites and sample collection

The present study was performed in Belgrade (latitude N 44°49′14″, longitude E 20°27′44″), the capital of Serbia, situated at average height above sea level of 116.75 m, and on the junction of two rivers - Sava and Danube. It has a population of about 2 million in an area of about 3,222 km². The climate of Belgrade is moderate continental with fairly cold winters and warm summers. Mean annual air temperature is 11.7°C, mean annual rainfall of 669.51 m² and mean atmospheric pressure of 1,001 millibars. The prevailing wind is N-NW, but a characteristic wind “Košava” (SE-ESE) blows with an annual frequency of 26% and an average speed of 4 m s⁻¹. In the winter, severe air pollution in the form of aerosol smog occurs frequently in the urban area of Belgrade, particularly during meteorologically calm (wind speed < 2 m s⁻¹) and stable conditions. Heavy automobile traffic is characteristic for Belgrade urban area. The average age of passenger cars is more than 15 years, which means that leaded gasoline (0.4 g l⁻¹ Pb) is still widely used. There are 18 large heating plants with a total capacity of 2018 MW, run on natural gas or crude oil and 59 smaller plants run only on crude oil (approximately 193 MW). Fuel used for domestic heating consists mainly of coal or crude oil.

The total atmospheric deposition (TD) collection was performed using an open polyethylene cylinder (29 cm inner diameter and 40 cm height) fitted on a stand at about 2 m above the ground. The devices collected both dry deposition and precipitation continuously for one month periods from June 2002 to December 2006 at three sites in the urban part of Belgrade: a) on the roof of the Rector’s Office building of Belgrade University in Student Square (RB), at a height of about 20 m, near a small city-park; b) Botanic Garden (BG), about 50 m far from heavy-traffic streets and c) the platform above the entrance steps to the Faculty of Veterinary Medicine (FVM) at a height of about 4 m from the ground, 5 m away from a street with heavy traffic and close to the big junction with the main state highway. The collection bottles were filled before each sampling period with 20 ml of 10% acidified (HNO₃ 65% (Suprapure, Merck) ultra pure water. Precautions were taken to avoid contamination of samples in both the field and laboratory. Details on studies sites and sampling procedures are given elsewhere [19,20].
2.2. Analytical procedures

Total atmospheric deposition samples were evaporated to dryness, digested with 50 ml 0.1 N HNO₃ on ultrasonic bath, the digested solution was filtered using 0.45 μm porosity Sartorius membranes and analyzed using a flame and graphite furnace atomic absorption spectrometer. Laboratory blanks were analyzed in the same manner as field samples and the heavy metal concentration values were below the detection limit values for all analyzed metals.

The elemental composition (Al, V, Cr, Mn, Fe, Ni, Cu, Zn, As, Cd, and Pb) of total atmospheric deposition, was measured by the atomic absorption spectroscopy method (AAS). Depending on concentration levels, samples were analyzed for a set of elements by flame (FAAS) (Perkin Elmer AA 200) and graphite furnace atomic absorption spectrometry (GFAAS) using the transversely-heated graphite atomizer (THGA; Perkin Elmer AA 600) with Zeeman-effect background correction. The THGA provided a uniform temperature distribution over the entire tube length, rapid heating and an integrated L’vov platform, which gave an improved signal/interference ratio and high analytical sensitivity. Analyte injection (20 µl) and the atomization were done in five steps controlled by the appropriate software and auto-sampler.

For calibration, standard solutions containing all metals of interest were prepared using Merck certified atomic absorption stock standard solutions containing 1000 mg l⁻¹ metal in 0.5 N HNO₃ and Milli-Q quality deionized water, with no matrix modifier addition. Detection limits for the trace elements were found to be: 0.04 ng ml⁻¹ for Cd, 0.1 ng ml⁻¹ for Cr, 0.2 ng ml⁻¹ for Cu, 0.5 ng ml⁻¹ for Pb, 2 ng ml⁻¹ for Zn, 0.4 ng ml⁻¹ for Ni, 0.2 ng ml⁻¹ for Mn, 5 ng ml⁻¹ for V, 0.5 ng ml⁻¹ for Fe, 2 ng ml⁻¹ for Al, and 0.5 ng ml⁻¹ for As. Standard practices for the handling of trace metal samples were implemented. For quality assurance, NIST 2783 standard reference material was used. Altogether 140 samples were analyzed.

Data treatment included the calculation of Al, V, Cr, Mn, Fe, Ni, Cu, Zn, As, Cd, and Pb monthly deposition fluxes.

2.3. Source apportionment using PMF

Positive Matrix Factorization (PMF) has been shown to be a powerful receptor modeling tool and has been commonly applied to particulate matter data [21,22,23] and recently to VOC data [24,25,26]. To ensure that receptor modeling tools are available for use in the development and implementation of air quality standards, the United States Environmental Protection Agency’s Office of Research and Development has developed a version of PMF with the name of EPA PMF1.1 that is freely available [27].

PMF solves the general receptor modeling equation using a constrained, weighted, least-squares approach [28,29,30]. The general model assumes there are p sources, source types or source regions (termed factors) impacting a receptor, and linear combinations of the impacts from the p factors give rise to the observed concentrations of the various species.

The model can be written as

\[ x_{ij} = \sum_{k=1}^{p} g_{ik} f_{kj} + e_{ij} \]  

(1)

where \( x_{ij} \) is the concentration at the receptor for the \( j^{th} \) species on the \( i^{th} \) sample, \( g_{ik} \) is the contribution of the \( k^{th} \) factor to the receptor on the \( i^{th} \) sample, \( f_{kj} \) is the fraction of \( k \) factor that is species \( j \) or chemical composition profile of factor \( k \), and \( e_{ij} \) is the residual for the \( j^{th} \) species on the \( i^{th} \) sample. The objective of PMF is to minimize the sum of the squares of the residuals weighted inversely with error estimates of the data points. Furthermore, PMF constrains all of the elements of G and F to be non-negative. The task of PMF analysis can thus be described as to minimize Q, which is defined as
where $s_{ij}$ is uncertainty of the $j^{th}$ species measured in $i^{th}$ sample.

In this study the robust mode has been used for analyzing element concentrations in bulk atmospheric deposition data set. The robust mode was selected to handle outlier values (that is any data that significantly deviates from the distribution of the other data in the data matrix) meaning that outliers are not allowed to overly influence the fitting of the contributions and profiles. This can be achieved by a technique of iterative reweighing of the individual data values, thus, the least-squares formulation becomes to

$$Q = \sum_{i=1}^{n} \sum_{j=1}^{p} \left( \frac{x_{ij} - \sum_{k=1}^{p} g_{ik} f_{kj}}{s_{ij}} \right)^2$$

(2)

where

$$Q = \sum_{i=1}^{n} \sum_{j=1}^{p} \left( \frac{e_{ij}}{h_{ij} s_{ij}} \right)^2$$

(3)

$$h_{ij} = \begin{cases} 1 & \text{if } \left| \frac{e_{ij}}{s_{ij}} \right| \leq \alpha, \\ \left| \frac{e_{ij}}{s_{ij}} \right| / \alpha & \text{otherwise}, \end{cases}$$

The parameter $\alpha$ is called the outlier threshold distance and the value $\alpha = 4$ was used in this analysis. One of the most important advantages of PMF is the ability to handle missing and below detection limit data by adjusting the corresponding error estimates. In this analysis missing values were replaced with the geometrical mean of the measured concentrations for each chemical species, and large error estimates were used for them.

3. Results and discussion

3.1. Elemental atmospheric total deposition rates

A total of 140 atmospheric deposits were collected monthly from June 2002 to December 2006 in three sites in the urban area of Belgrade, RB, BG and FVM, and trace and other metal (Al, V, Cr, Mn, Fe, Ni, Cu, Zn, As, Cd, and Pb) monthly fluxes were calculated. For ease of comparison, seasonal and annual atmospheric heavy metal deposition rates were calculated based on the produced data. To calculate the daily atmospheric depositions of heavy metals per unit area ($\mu g m^{-2} day^{-1}$) in each season, total mass of trace metal was divided by the number of sampling days, exposed to the ambient environment and cross sectional sampling area of the container.

Summary statistics of the average daily elemental atmospheric depositions in the Belgrade urban area, for all sampling sites, for the period of 2002 to 2006 is presented in Table 1.

Table 1. Descriptive statistics of average daily elemental atmospheric depositions ($\mu g m^{-2} day^{-1}$) for all sampling sites from June 2002 to December 2006

| Elements | Fe  | Cd  | Pb  | Cu  | Ni  | Zn  | Cr  | Mn  | Al  | V   | As  |
|----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| N         | 140 | 140 | 140 | 140 | 140 | 140 | 140 | 140 | 140 | 140 | 93  |
| Average  | 1627.3 | 0.6 | 59.4 | 94.5 | 31.0 | 113.5 | 4.5 | 71.8 | 901.1 | 54.1 | 9.7 |
| S.D.     | 1245.7 | 0.5 | 39.1 | 82.9 | 73.8 | 91.4 | 5.2 | 55.0 | 600.4 | 65.4 | 22.5 |
| Max      | 6113.6 | 3.6 | 229.8 | 423.0 | 598.2 | 615.4 | 30.0 | 351.2 | 3722.9 | 340.7 | 154.8 |
| Min      | 42.8 | < d.l | 2.4 | 10.9 | 0.7 | 16.1 | < d.l | 3.4 | 42.5 | 0.4 | 0.2 |
| 98th Percentile | 5322.3 | 1.8 | 148.4 | 316.4 | 186.2 | 347.8 | 19.0 | 228.7 | 2270.6 | 272.0 | 81.9 |

N – Number of samples; S. D. – Standard arithmetic deviation; d.l. – Detection limit
The most abundant trace metal in bulk depositions was Zn, followed in order of abundance by V, Mn, Ni, Cu, Pb, As, Cr and Cd. This order is similar to those already obtained for bulk deposition (wet and dry) in some other studies [9,10,15]. A large variation in the monthly deposition rates of all the elements was observed, which explains the high standard deviations from the mean deposition rates. This is ascribed mainly to weather conditions that strongly affect the dispersion and deposition of air pollution, as well as to the variation of emission sources over the seasons.

3.2. Spatial variations
Measured bulk atmospheric deposition rates, TD (μg m⁻² day⁻¹) of analyzed elements at three sampling sites are presented in Table 2. In general, deposition of some heavy metals showed large variations between different sampling locations and this variation may be ascribed to variations in traffic density, presence of industries and different land use properties. As expected, the TD values were highest at FVM site for almost all metals except Cu. High deposition of Cu in samples at Rector’ Office building (RB) comparing to other locations could point to the presence of point sources, which are clearly site specific (foundry nearby) and could be related to roof covering nearby as well. High total deposition values (μg m⁻² day⁻¹) of Pb, Ni, V and Zn in samples at FVM have been expected due to its traffic oriented point.

The spatial distribution of Al and Fe shows that the concentrations of Fe are highest at FVM site. Values of the Fe/Al ratio range from 1.41 to 1.62, from 1.33 to 1.69 and from 1.91 to 2.28 at RB, BB and FVM, respectively. Fe/Al ratios in the Earth’s crust are variable, depending on chemical enrichments and different ratios for the upper continental crust are reported such as 0.40 [31] and 0.85 [32]. The Fe/Al ratios measured at RB, BB and FVM are higher than Fe/Al ratios of pure crustal sources, indicating that both elements contained in the acid-soluble fraction of particles coming from atmospheric deposition have an anthropogenic source. At the BB site, the influence of crustal particles containing Al and Fe is enhanced as the ratios obtained at this location are closer to the Earth’s crustal ratio.

Table 2. Measured bulk atmospheric deposition rates, TD (μg m⁻² day⁻¹) of analyzed elements at sampling sites for the period June 2002 to December 2006

| Elements | Rector’s Office building | Botanic Garden | Faculty of Veterinary Medicine |
|----------|--------------------------|----------------|--------------------------------|
| Fe       | 776.2                    | 1451.3         | 1292.1                         |
| Cd       | 0.4                      | 2.5            | 0.4                            |
| Pb       | 39.3                     | 87.5           | 48.5                           |
| Cu       | 166.5                    | 423.0          | 43.2                           |
| Ni       | 11.0                     | 49.2           | 15.7                           |
| Zn       | 60.8                     | 119.9          | 122.9                          |
| Cr       | 1.5                      | 6.4            | 4.3                            |
| Mn       | 31.1                     | 56.7           | 72.1                           |
| Al       | 494.7                    | 1410.5         | 869.1                          |
| V        | 25.7                     | 107.2          | 30.7                           |
| As       | 3.7                      | 75.2           | 4.4                            |

d.l. – Detection limit
3.3. Seasonal variation

Seasonal variations of elemental atmospheric bulk depositions have been analysed. In general, a seasonal variation is likely associated with the nature of the sites and seasonal trend is difficult to recognise because of the number of variables that influence removal from the atmosphere during each sampling period (e.g., the number and intensity of rainfall events, hours of dry weather, wind direction, and other meteorological parameters such as mixing depths). The analysis of seasonal variation of elemental TD in Belgrade atmosphere has shown the pronounced seasonal dependence for V, Ni (Fig.1) and As, less pronounced but significant for Fe, while seasonal variations of the other elements were not evident. The higher depositions of V, Ni and As in winter periods are related to the combustion of fossil fuels (fuel oil, coal) as the urban site of Belgrade is highly influenced by domestic heating and automobile traffic.

![Figure 1. Seasonal variation in total atmospheric depositions of V and Ni in Belgrade urban area at Rector’s Office building (RB), Botanic Garden (BG) and Faculty of Veterinary Medicine (FVM) for the period 2002 - 2006](image)

Annual atmospheric deposition of heavy metals (Cd, Cu, Ni, Pb and Zn) in units of mg m\(^{-2}\) yr\(^{-1}\) in this study is compared with the data from other studies (Table 3).

| Location                  | Period     | Cd   | Cu    | Ni    | Pb    | Zn    | References                  |
|---------------------------|------------|------|-------|-------|-------|------|----------------------------|
| Belgrade                  | 2002-2006  | 0.20 | 34.99 | 11.30 | 21.69 | 41.42| This study                  |
| Paris                     | 2001–2002  | 0.24 | 6.0   | 0.62  | 4.2   | 30   | Motelay-Massei et al. (2005) |
| Pearl River Delta, China  | 2001–2002  | 18.6 |       | 12.7  | 104   |     | Wong et al. (2003)          |
| Massachusetts Bay         | 1992–1993  | 0.27 | 2.50  | 1.50  | 1.80  | 7.80 | Golomb et al. (1997)        |
| Lake Superior             | 1993–1994  | 0.46 | 3.10  | 0.80  | 1.50  | 8.80 | Sweet et al. (1998)         |
| Lake Michigan             | 1993–1994  | 0.45 | 1.90  | 0.61  | 1.60  | 6.00 | Sweet et al. (1998)         |
| Fiorland, New Zealand     | 1993–1995  | 0.004| 0.023 | 0.035 | 0.025 |      | Halstead et al. (2000)      |
| North Sea                 | 1993–1994  | 1.24 |       | 3.52  | 6.50  |      | Injuk et al. (1998)         |
| Irish Sea                 | 1993–1994  | 2.60 |       | 1.62  |       |      | Williams et al. (1998)      |
| Mediterranean Coast       | 1988–1993  | 0.31 | 2.60  | 0.57  | 3.80  |      | Guieu et al. (1997)         |
| Ligurian Sea              | 1997–1998  | 0.06 | 1.28  | 1.10  | 1.20  | 41.2 | Sandroni and Migon (2002)   |
Annual bulk deposition fluxes of Cu, Ni, and Pb exceeded the corresponding reported data from other sites. The largest contributor to the copper loading might be the specific local source in the vicinity of Rector’s Office building, building siding and brake emissions from automobiles. Confirmation of the presence of nickel in elevated concentrations, in a great number of soil samples in Belgrade [40], at certain locations, points to its geographical origin followed by the emission of heavy fuel combustion. High Pb values are the consequence of the still wide use of leaded gasoline.

3.4. PMF modeling

A critical step in PMF analysis is determination of the number of factors. To determine the number of sources, it is reasonable to test different numbers of sources and use the one that both adequately fits the data and provides the most physically meaningful results.

The PMF analysis of the TD data set resulted in five factors for Rectorat’s Office building and Botanic Garden sites and six for Faculty of Veterinary Medicine site and they have been identified as possible sources at each site. Figs. 2, 3 and 4 present the identified source profiles and time series plots of estimated monthly contributions for bulk atmospheric depositions at Rector’s Office building, Botanic Garden and Faculty of Veterinary Medicine, respectively.

![Figure 2. Source profiles and time series plot of source contributions resolved from the Rector’s Office building](image)
Among the resolved factors, five factors are common to RB and BB sites. They are traffic, soil, coal combustion, oil combustion, and industry.

Traffic factor at RB site has significant loadings of Pb, Cd, Mn, Fe, Zn, and Cu. Lead, Zn, and Cu are indicator elements of traffic emission; Cu, Fe and Zn are present in resuspended brake wear particles; tires are the major Zn source from road traffic; the high Mn concentrations, specially at FVM are related to motor vehicles that burn gasoline with the Mn additive. Fe and Mn are crustal elements, which may have been present in dust resuspended by traffic; Fe is related to heavy-duty diesel emissions. This factor related to traffic has median contribution of 27%, 21% and 26% for RB, BG and FVM sites respectively.

The soil factor (crustal) includes high loadings of the typical crustal elements such as Fe, Al, and Mn. This factor could represent local soil strongly contaminated with Zn, Cr and Pb. This factor does not show a regular season pattern, but it has a few high values at apparently random times. Soil component is fairly consistent among the RB and BB sites. This soil factor contributes with 14% and 21% of the total data set for RB and BG respectively.

The oil combustion source shows the high loadings of Ni and V, which are the fingerprint elements for fuel oil burning. This source most probably reflects urban region where residual oils are common.
fuels for utility and industrial sources. This factor associated to heavy oil burning has median contribution of 24%, 25% and 14% for RB, BG and FVM respectively.

The factor having high loadings of Cr and weak loadings of V, Ni and Fe can be attributed to coal combustion followed by emission from ferrous factory or other metal industry. Time series plot of this factor have the same pattern for RB and BB sites showing the significant increase in 2006 year. The time series for FVM indicate the stronger influence of coal combustion from residential heating units in surroundings compared to the contribution from industry, as the seasonal variation trend of the factor was observed.

The factor identified as industry source includes Zn, Cd, Mn, Al, Cu, and Fe, the elements associated with industrial emissions. Zink Fe, and Mn are elements characteristic of iron manufacturing; Cu and Zn may be attributed to non ferrous metallurgy; Zn comes from many pollution sources, including incinerators and smelters.
The third factor resolved from the TD data at Faculty of Veterinary Medicine is attributed as traffic exhaust source mostly loaded with Pb, V and Cd. The factor most loaded with V, Zn, and in smaller amounts with Fe, Cd and Al was resolved at Faculty of Veterinary Medicine site and was difficult to identify. As given combination of elements might have the origin from different sources, this factor apparently is a mixed pollution signal and we named it as a general pollution factor. Median factor contributions at sampling sites, discussed previously in text, are presented in Fig.5.

![Figure 5. Median PMF factor contributions at: a) RB, b) BG, c) FVM](image)

![Figure 6. Observed versus predicted atmospheric depositions of Zn and Ni a) RB, b) BG, c) FVM](image)
A comparison of the predicted bulk atmospheric depositions of Zn and Ni from all sources with atmospheric depositions for Zn and Ni measured at RB, BG, and FVM is shown in Fig. 6. The squared correlation coefficients higher than 0.90 (except for Zn at RB) indicates that the resolved sources effectively account for most of the variation in the atmospheric deposition.

4. Conclusion
Elemental bulk atmospheric deposition data obtained at three sampling sites in the Belgrade urban area in the period from June 2002 to December 2006 were subjected to multivariate receptor model Positive Matrix Factorization (PMF). PMF was used as a means of source identification and apportionment and suggested possible anthropogenic sources which explain different metal deposition patterns. The PMF method uses the estimates of the error in the data to provide optimal point-by-point weighting and permits efficient treatment of missing and below detection limit values. It also imposes the non-negativity constraint on the factors.

Five factors have been resolved at Rector’s Office building (RB) and Botanic Garden (BG) sites and six factors at Faculty of Veterinary Medicine site (FVM). Among the sources resolved at the three sites, four were common: traffic, oil combustion, coal combustion and industry. Soil factor represented by typical crustal elements as Fe, Al and Mn, followed by small amounts of Zn, Cr and Pb, was present only at RB and BG sites while at FVM pollution origin from mixed sources was identified as a general pollution factor with contribution of 15%. Traffic factor at RB and BG have almost same chemical composition, Cu, Cd, Pb, Zn and Mn, while their contribution was much smaller compared to FVM site, traffic oriented site with two resolved factors related to vehicle emission with total contribution of 38%. Oil combustion source characterized by Ni and V as typical markers, exhibit not only similar chemical compositions, but also similar seasonal variations at RB and BG. Coal combustion factor with high loading of Cr and weak loadings of V, Ni and Fe have the same pattern at RB and BG sites while the contribution from residential heating units was more pronounced as the seasonal variation trend of this factor was observed at FVM. The factor identified as industry source includes Zn, Cd, Mn, Al, Cu, and Fe. Zink, Fe, and Mn are elements characteristic of iron manufacturing; Cu and Zn may be attributed to non ferrous metallurgy; Zn comes from many pollution sources, including incinerators and smelters.

PMF modelling applied to element total atmospheric deposition data from Belgrade urban area indicated that the atmospheric deposition is mostly under the influence of anthropogenic activities.

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