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Comparison of traffic-related pollution level using street dust and passive dust samplers

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Abstract

The magnetic susceptibility and concentrations of traffic-related heavy metalswere used to compare the pollution level estimated for street dust (SD) and passive dust samplers (PDS) collected from 24 sampling sites in Warsaw (Poland). It was shownthat the disadvantages of SD disturb the assessment of the real traffic-related pollution level. The application of SD is limited because of unknown accumulation time, difficulties in the estimation of background values of heavy metals, and the strong influence of geological backgrounds and weather conditions. As an alternative to SD, we propose PDS as a more universal study material, which effectively reflects the pollution level and has well-defined initial concentrations of heavy metals obtainedbefore the exposition on pollution.

Keywords: Passive dust sampler, Heavy metals, Street dust, Magnetic susceptibility, Environmental magnetism

1. Introduction

Traffic-related pollution associated with heavy metals (HM) is generated from fuel combustion and abrasion and corrosion of engine, vehicle body, tires, brake linings, and asphalt (Schauer et al., 2006).

The concentrations of HM in SDare of high concern because of their toxic and nondegradable properties. Cadmium, Cr, and Pb have cumulative effects, causing growth retardation and low birth mass in children, kidney disease, cancer, and many other negative health problems of the circulatory and respiratory systems (Zeng et al., 2016).

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The properties of SD are often used in environmental studies to estimate the level of pollution. However, the amount and type of deposited SD are influenced by factors related to different geological backgrounds, weather conditions, and unknown accumulation time. Street dust consists of two types of materials: natural (e.g., soils and weathered rocks) and anthropogenic (e.g., mainly traffic-related particles). The geological backgroundsof different areas significantly contribute to the magnetic properties of SD (Jordanova et al., 2014); therefore, application of SD to investigate the urban pollution requires considering the properties of lithogenic materials. The strong influence of geological background causes difficulties in the estimation of magnetic properties and HM concentrations of SD. In addition, it is still difficult to compare the pollution level of SD obtained from sites with different geology.

The second group of disturbing factors arethe weather conditions and street cleaning done by the city services. For example, rainfall and wind can wash and erode the particulates awayfrom road surface. Amato et al. (2010) revealed that cleaning the street efficiently removes 26% (<100 um particles in diameter)–64% (>125 um particles) of accumulated dust, thus significantly affecting the amount of dustand the distribution of the grain size. As a consequence, it is difficult to estimate the accumulation time of the collected sample. Therefore, one seeks for other appropriate collectors that inherit the advantages and avoid the disadvantages of SD.

For public health and environment protection, it is important to find the "clear/blank" matrix, theinitial features of which have a negligible influence on the assessment of the pollution level. For this reason, we appliedthe new tool–"passive dust sampler" (PDS) which effectively accumulates pollution and is devoid of the limitations of SD. The PDS is constructed using a 20-cm length and 10-cm diameter drainage pipe with geotextiles on the bottom of the pipe. The container is filled with a well-tested mixture highlycapable ofaccumulating pollutants. The method of PDS construction and the type of filling are the result of our previous study (Dytłow & Górka-Kostrubiec 2018). The background values of HM (BG PDS) concentrations and magnetic parameters of the PDS were measured before exposure to pollution. The PDS has many technical advantages such as compactness, mobility, user friendly, easy implementation evenin hazardous environments, andless-complicated design which make it very convenient to use, thanks to the well-tested preparation protocols.

The objective of this study is to comparethe pollution level estimates of both SD and PDS collected from the same sampling sites, there by revealing the impact of SD over the assessment of real traffic-related pollution level. As an alternative of SD, we propose a more universal material–PDS. To achieve this goal, we applied the combination of magnetic measurements and inductive plasma–coupled mass spectrometry (ICP-MS). The approach is highly effectiveas anthropogenic magnetic particles (AMP) present in pollution coexist with HM. Hence, concentration-dependent magnetic parameters (i.e., magnetic susceptibility (χ)) are effectively used as a proxy of HM pollution level.

2. Material and methods

This research was conducted in 24 locationsin Warsaw (Poland), which differed in traffic intensityrepresenting areas from limited traffic to multilanecrossroads. In addition, the sampling sites differ in traffic density, speed of vehicle, presence of traffic lights, and number of lanes. The locations for the collection of 248 SD samples from Warsaw were chosen using a spatial distribution map of magnetic susceptibility (χ_{SD}) (Dytłow et al., 2018). The PDS and SD sampling sites were the same locations selected using a hand-held global positioning system. Street dust were collected from about 1 m^2 area of road surfaces using clean plastic brush and dustpan during the continuously sunny days of June–July 2013. Samples were air-dried naturally at room temperature and then screened through a 1-mm mesh to remove refuse and mall stones. The PDS were filledup with coarse sand and peat in 1:1 proportion and then installed on roadsides at flat areas where the material was heavily compacted and covered with low grass. They were placed at the ground level at a maximum distance of 1 m from the green belt along the road. After 12 months of exposure to traffic pollution (May 2013–May 2014), the samplers were removed and transported to the laboratory. Each filling of drainage pipe was divided into 20 layers of 1 cm thickness, which resulted in 20 subsamples of 78.5 cm^3 volume.

The low-field mass-magnetic susceptibility (χ) of both the SD and PSD samples were measured at a magnetic field of 976 Hz using the Multi-Function Kappabridge MFK1-FA (AGICO, Czech Republic). Each sample was measured three times and the average value of χ was calculated. The χ of PDS (χ_{PDS}) was calculated as a sum of χ of 20 subsamples.

The concentrations of elements such as Mn, Fe, Cd, Pb, Zn, Co, Cr, Ni, and Al were determined using ICP-MS method. Samples (0.15–0.20 g) were prepared according to the procedure described in Szczepaniak-Wnuk & Górka-Kostrubiec (2016).

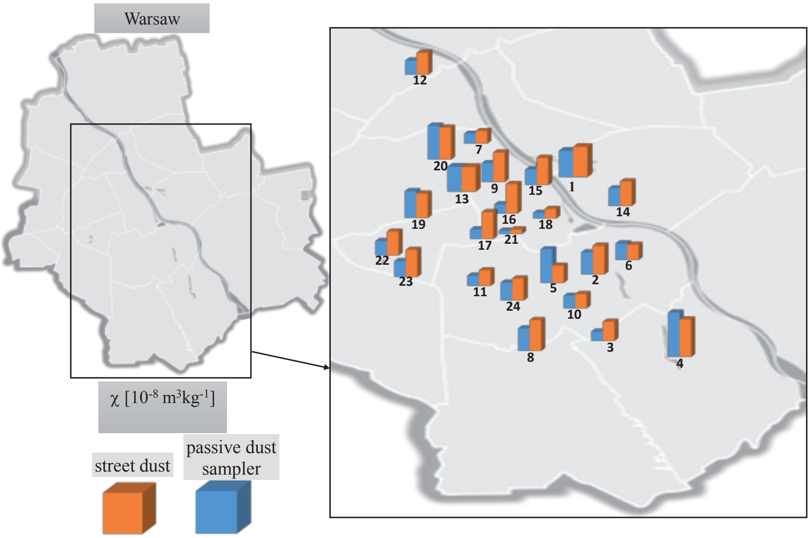
3.Results and discussion

*3.1. Magnetic susceptibility of passive sampler*s (χ_{PDS}) *and street dust* (χ_{SD})

The spatial distribution of χ_{PDS} and χ_{SD} (Fig. 1) of thesampling sites in Warsaw showed that χ_{PDS}, similar to χ_{SD}, varied widely ranging from ~$36 \cdot 10^{-8}$ m^3/kg to ~$406 \cdot 10^{-8}$ m^3/kg and ~$49 \cdot 10^{-8}$ m^3/kg to ~$520 \cdot 10^{-8}$ m^3/kg, respectively. Although the χ_{SD} and χ_{PDS} values of individual sampling sites significantly differ, they follow the same trend in case of traffic intensity. The values of χ_{SD} and χ_{PDS} were higher mainly at the crossroads of multilane roads with high-intensity traffic. For example, χ_{PDS2} ~$400 \cdot 10^{-8}$ m3/kg and χ_{SD2} ~$520 \cdot 10^{-8}$ m^3/kg were obtained from one of the biggest and busiest crossroads in the city center with almost 70,000 cars and trams crossing through per day. In places of traffic restricted to privileged vehicles and public transport, relatively low values of χ_{PDS18} ~$61 \cdot 10^{-8}$ m^3/kg and χ_{SD18} ~$104 \cdot 10^{-8}$ m^3/kg were obtained. The lowest values of χ_{PDS21} ~$49 \cdot 10^{-8}$ m^3/kg and χ_{SD21} ~$36 \cdot 10^{-8}$ m^3/kg were observed in one of the biggest park in the center of Warsaw. Although the park is surrounded by streets with heavy traffic, it is separated from the roads by tree lines. Thus, it proves that green walls and effectively reduce traffic-related pollution (Abhijith et al., 2017).

A general trend between traffic intensity and χ values cannot be observed in all sampling sites because of several local factors, e.g., different concepts of space management (density, height of buildings, distance of buildings from road edge) and surface runoff (often rainfall, cleaning streets) that disturb the spread of SD particles. For example, the high value of χ_{PDS5} ~$366 \cdot 10^{-8}$ m^3/kg (Fig. 2) obtained from the sampler installed at a multilane crossroad (sampling site number 5) reflects the impact of high traffic intensity with ~73,000 cars crossing per day. However, the relatively low value of χ_{SD5} ~$187 \cdot 10^{-8}$ m^3/kg obtained from another crossroad suggests the influence of several factors on the distribution and amount of SD particles. The crossroad is characterized as unusual by the Warsaw land developmentdue to the absence of buildings and the presence of ample open area providing good ventilation and, thus, facilitating the particles being blown away and lowering the χ than that of PDS. However, this effect was not observed for PDS5, which is able to accumulate and preserve the pollution particles by transporting them inside the sampler. All these observations proved that the properties of SD could rather be used for preliminary tests or as a supporting measurement than for detailed studies.

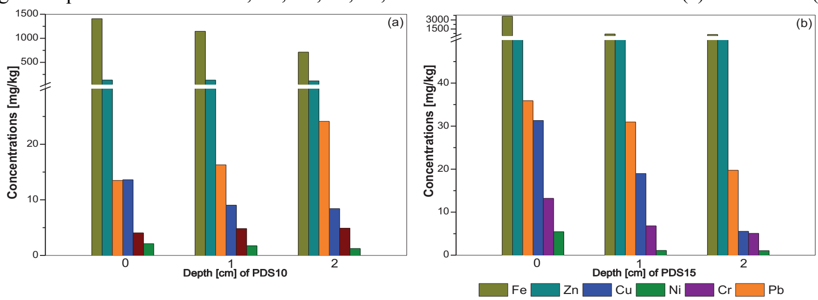
Fig.1. Spatial distribution of mass magnetic susceptibility (χ) of PDS and SD in Warsaw (Poland)



3.2 Concentrations of heavy metals

Figure 2 presents the depth distribution of Fe, Zn, Cu, Ni, Cr, and Pb concentrations obtained from the surface layer (0–3 cm) of PDS10 and PDS15. The concentrations of all the HMs decreased with depth following the trend observed for depth changes of χ. The changes in the percentage of HM concentrations with respect to the maximum values obtained from the 0–1 cm layer were compared to demonstrate the ability of PDS to accumulate HMs. The results showed that the Fe concentration of PDS10 and PDS15 decreased about 50% and 85%, respectively. Similarly, the concentration of Cu decreased by about 38% for PDS10 and 82% for PDS 15. Strong accumulations of these elements in the surface layers of PDS confirm the ability of PDS to accumulate, transport, and then preserve pollution.

Fig. 2. Depth distribution of Fe, Zn, Cu, Ni, Cr, and Pb concentrations for PDS10 (a) and PDS15 (b)



In environmental studies, Tomlinson Pollution Load Index (PLI) (Tomlinson et al., 1980) is commonly used in the estimation of the HM contribution to the total/overall pollution load.

The PLI is defined as the geometric mean of contamination factors CFn, obtained the following equation:

$$PLI=\sqrt[n]{\mathrm{CF}_1 \cdot \mathrm{CF}_2 \cdot \ldots \cdot \mathrm{CF}_n} \quad (1),$$

Where CF_n is calculated as a concentration of individual HM in reference to their BG values. The PLI classifies the HM pollution level as following: PLI <1 means unpolluted, 1≤ PLI ≤2 unpolluted to moderately polluted, 2≤ PLI ≤3 moderately to highly polluted, 3≤ PLI ≤4 highly to very highly polluted, and PLI >5 very highly polluted (Islam Ahmed & Habibullah-Al-Mamun, 2015).

According to the PLI index, calculation of contamination factors, CFn, requires the precisely designated/established BG concentrations of HMs. Table 1 lists the BG values of sampled HM from both SD (BG SD) and PDS (BG PDS). For SD, we used the minimal value obtained from a set of 248 samples collected in Warsawas part of another study (Dytłow et al., 2019). We state that the comparison of HM concentrations with relation to the geological backgrounds of the investigated area such as BG SD is not a best assumption because significant amount of SD is obtained from the greenbelt along street or spilled on the road during winter.

Table 1 The comparison of BGof HM - Ni, Zn, Fe, and Cu for SD (BG SD) and PDS (PDS BG)

	Ni [mg/kg]	Zn [mg/kg]	Fe [mg/kg]	Cu [mg/kg]
PDS BG	0.5	10.1	200.3	1.0
SD BG	3.9	27.4	3886.3	12.4

Figure 3 presents the PLI calculated for traffic-related HM pollution of SD and PDS collected from five sites. In all the locations, PLI for PDS is higher differing from ≈5% for location 10 to ~500% for location 15. This difference influences the proper assessment of real pollution level. For example, sampling site 22 is classified as "moderately to highly polluted" on the basis of PLI SD and "very highly polluted" on the basis of PLI PDS. It suggests that relatively high concentrations of BG SD increases the concentrations of HM and decreases PLI. This way, we obtain an artificial pollution level which does not reflect the real one.

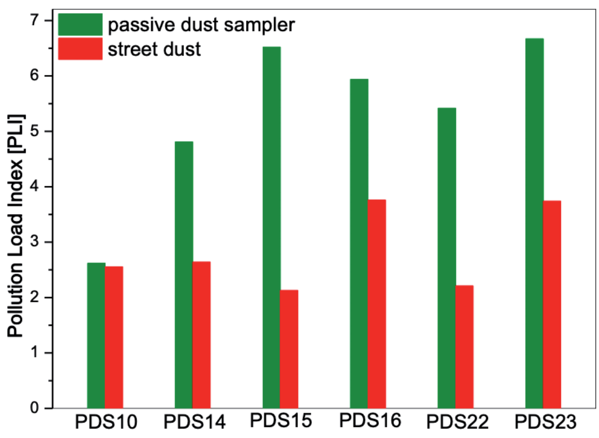


Fig. 3. Comparison of Pollution Load Index (PLI) for SD and PDSof six sites: 10, 14, 15, 16,22, 23

4. Conclusions

The present study confirmed that the application of PDS combines both the advantages (i.e., low cost) and the disadvantages of SD. The PDSs fully reflect the traffic-related pollution level and HM concentrations providing detailed results obtained for a specified exposition time. The BG values of HM are obtained at the initial accumulation of pollution; therefore, the use of commonly applied pollution indicators is reliable.

The application of SD to estimate HM pollution levels is limited by factors significantly influenced by the preciseness and the quality of studies. These disadvantages are due to different geological backgrounds, weather conditions, cleaning of the streets, and unknown accumulation time. For this reason, it is advised to use SD mainly in preliminary and field-screening studies due to its good availability in urban areas and no problematic collection methods.

The study provided important knowledge about the influence of SD on the magnetic properties and the concentrations of HMs which help in proper selection of study materials for environmental studies.

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