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# An economic passive sampling method to detect particulate pollutants using magnetic measurements

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ABSTRACT

Identifying particulate matter (PM) emitted from industrial processes into the atmosphere is an important issue in environmental research. This paper presents a passive sampling method using simple artificial samplers that maintains the advantage of bio-monitoring, but overcomes some of its disadvantages. The samplers were tested in a heavily polluted area (Linfen, China) and compared to results from leaf samples. Spatial variations of magnetic susceptibility from artificial passive samplers and leaf samples show very similar patterns. Scanning electron microscopy suggests that the collected PM are mostly in the range of 2–25 μm; frequent occurrence of spherical shape indicates industrial combustion dominates PM emission. Magnetic properties around power plants show different features than other plants. This sampling method provides a suitable and economic tool for semi-quantifying temporal and spatial distribution of air quality; they can be installed in a regular grid and calibrate the weight of PM.


## 1. Introduction

According to the World Health Organization (WHO), up to ~4.6 million people die each year from causes directly attributable to air pollution (Science Daily, 2014). Air pollutants are a complex mixture of gases, liquids and particulate matter (PM) (Altwicker et al., 1997), of which PM is thought to have the most damaging effects on health (Wayback Machine, 2010) such as heart disease and lung cancer, even at low concentrations (World Health Organization, 2005). Therefore, it is necessary to quantify PM concentrations and trace emission sources.

Principally, PM is a complex mixture of small particles and liquid droplets. The components consist of organic chemicals (such as PAHs), metals (normally including Fe, Pb, Zn, Cu, Cr, Ni, and Cd), acids (such as nitrates and sulfates), and natural dust. Strong magnetic particles (iron oxides and sulfides) are also found in PM. They are not hazardous to human health in itself, but are often related to other hazardous substances formed during combustion (Hansard et al., 2012), such as heavy metals and carcinogens (*acrylamide and benzo[a]pyrene*). For fly ash, a close relationship of magnetic concentration and heavy metals has been demonstrated in numerous studies and well explained as a consequence of common sources (as coal-burning industries) and similar transport paths into the environment (Gautam et al., 2005). The ubiquity of magnetic particulates, together with sensitive and inexpensive magnetic analysis can provide a robust means of detecting and semi-quantifying air pollutants. Magnetic measurements can be even performed in situ (Petrovský et al., 2004) and samples can be collected from widely dispersed natural materials, including soils (Petrovský et al., 2004; Blaha et al., 2008a), lake and river sediments (Boar and Harper, 2002) and biomass such as tree leaves (Hu et al., 2008; Hofman et al., 2013), tree bark (Kletetschka et al., 2003), moss and lichens (Salo et al., 2012, Salo and Mäkinen, 2014).

Because the analysis of magnetic PM on leaves is a fast and economic approach, bio-monitoring was widely applied for high spatial resolution studies of current air pollution assessment (McIntosh et al., 2007; Kardel et al., 2012). However, one has to be aware that the amount and type of magnetic PM deposited on biomass are also influenced by other processes. For example, rainfall and wind can wash and erode the particulates away (Sadeghian, 2012) and the capacity for collecting PM depends on tree species (Beckett et al., 2000; Gautam et al., 2005). Therefore, one seeks for other appropriate PM collectors that inherit advantages and avoid disadvantages of bio-monitoring methods. In this study, we present a simple artificial passive sampling system that

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simulates the bio-monitoring method but is better controlled.

Since 1980s, the concept of passive sampling was introduced in atmospheric environmental monitoring, and a number of devices and techniques have been developed. The used samplers have a badge and a diffusion tube-filter absorbent with an adsorbent surface. Although these artificial devices (filters) are quite accurate in one sampling point, they are complex and not that cheap for installing a large network. This limits the possibility to cover a large-scale region with a high spatial resolution. We designed a simple artificial passive sampler as an alternative tool to assess PM concentrations for air monitoring. The main goals are improving the reliability of bio-monitoring methods and the applicability of artificial filters (simplicity, cost-effectiveness, more representative).

## 2. Material and methods

### 2.1. Study area

The scene of this study, Linfen basin, is situated in the southwest of Shanxi Province (central China) (Fig. 1b). The Lüliang and Zhongtiao Mountains border the basin in the west and east, and a large urban area and numerous industrial sites stand in the basin center. Loess is the parent material of soils. Linfen has a semi-arid to semi-humid continental climate. About thirty years ago, with the dramatic increase in energy demand due to China's rapid industrialization and urbanization, Linfen city (in the heart of China's coal belt) emerged a severe environmental destruction owing to overexploitation and lack of regulation. The primary source of air pollution source are atmospheric emissions from energy combustion (such as coal, oil, natural gas) in various factories. In 2006, Linfen has been listed as one of the world's ten most polluted cities by the Blacksmith Institute (2006).

### 2.2. Design and installation of passive samplers

Artificial passive samplers were installed on trees in November 2012 at 84 sites, avoiding direct traffic emission by keeping a larger distance (>20 m) to the nearest road (Hoffmann et al., 1999). In order to check for consistency of results, and taking into account that samplers may be destroyed, we installed two samplers (Fig. 2b) at each site. We chose one year as the monitoring period to obtain an overview of spatial pollution variation integrated on one complete annual cycle. After one year of exposure, we successfully recovered samplers from 48 sites (at least one of the duplicates). At the other 36 sites, both samplers were destroyed by people, animals or otherwise. The distribution of sites is displayed in Fig. 1a. Note that some sites are close together and cannot be clearly distinguished in the map. Details on the positions are given in Table S1 and Figure S1.

The design of the passive samplers accounts for simplicity, low cost, efficiency of dust collection and reducing the risk of vandalism (Fig. 2b–d). It consists of a carrier, sorbent, membrane and semi-open cover. As a carrier, we chose a green diamagnetic container (8 cm diameter) that does not attract attention of people preventing from damages. The bottom of the container is leaking to avoid waterlogging. As a sorbent we used natural wool ($3 \pm 0.05$ g mass, $\chi \approx -3.924 \times 10^{-9}$ $m^3/kg$) filled in the interior of the plastic container. This kind of sorbent was chosen because of its low cost, easy access, high adsorption efficiency and no environmental contamination (Mahdavian, 2012). Filter paper (Ø ≈ 3 μm, $\chi \approx -4.55 \times 10^{-9}$ $m^3/kg$) is placed at the bottom of the container acting as a membrane to avoid PM being washed away. A polyethylene mesh (Ø ≈ 0.850 mm) is used as a semi-open cover to prevent loss of sorbent and insects or bird feces falling inside.

### 2.3. Leaf sampling

We collected the leaf samples (i.e., needles) from 2 to 3 m high evergreen *Juniperus Chinensis* trees. One sample generally consisted of leaves that were collected all around a tree at a height of ~1.5 m above ground. Only new twigs (3–8 months after sprouting) from the outer crown were taken (Hu et al., 2008). In order to avoid intra-contamination between samples from different trees, we used new disposable gloves for each collection. The leaf samples were placed into zipper mouth sealable plastic bags. In the laboratory the leaf samples (in the plastic bags, but with open mouths) were put into

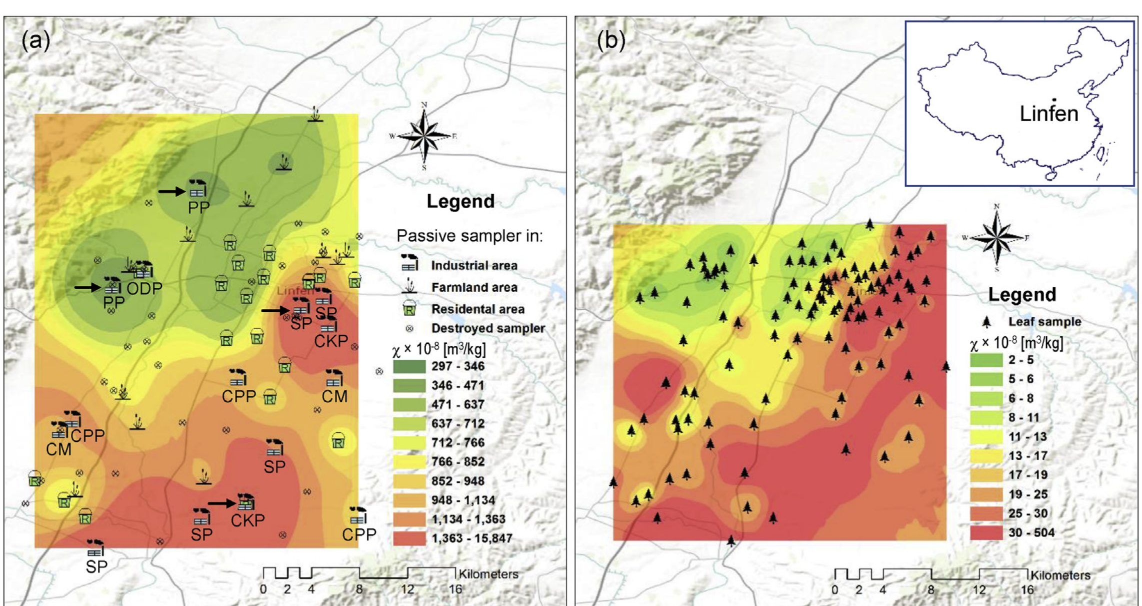


**Fig. 1.** Contour maps of mass-specific magnetic susceptibility (χ) values for artificial passive samplers (a) and leaf samples (b) at Linfen area. PP: power plant; SP: steel plant; CM: coal processing plant; CPP: coal preparation plant; CKP: coking plant; ODP: ore dressing plant; CEP: cement plant.