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MONITORING OF VEHICLES DERIVED PARTICULATES USING MAGNETIC PROPERTIES OF LEAVES

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Abstract. Biomonitoring of vehicle-derived particulates is conducted by taking magnetic measurements of roadside tree leaves. Remanent magnetization ($IRM_{300\,mT}$) of more than 400 *Dalbergia sissoo* leaves was determined and $IRM_{300\,mT}$ normalized for the leaf area. The normalized 2-D magnetization as shown by results is dominantly controlled by the tree's distance to the road. The spatial and temporal variations of vehicle-derived particulates were mapped using magnetic analysis. 2D-magnetizations values were higher for leaves collected adjacent to major road sections than for those from village road suggesting vehicle emissions, rather than resuspended road dust, as the major cause of magnetic particles of roadside tree leaves. Vehicles derived particulates are responsible for tree leaf magnetism, and the leaf magnetizations values fall significantly from high values proximal to the roadside to lower values at the distal side. This suggests the ability of trees to reduce particulates concentrations in the atmosphere. The rainfall produces a net decrease in the leaf magnetic dust loadings.

Keywords: background magnetization, $IRM_{300\,mT}$, vehicular pollution, spherules

1. Introduction

A strong positive correlation have been demonstrated between fine-grained ($<10\ \mu$m) particulate matter and the risk of respiratory and circulatory morbidity and mortality. Magnetic minerals derived from vehicular combustion and street-trams are mainly maghemite and metallic iron grain having size range of 0.1–0.7 μm (Muxworthy *et al.*, 2002). This grain size is particularly dangerous to humans because of its ability to be inhaled into the lungs. Moreover, in aerosols, magnetite is associated to other heavy metals like zinc, cadmium and chrome (Georgeaud *et al.*, 1997) and to mutagenic organic compounds (Morris *et al.*, 1995) which are dangerous to human health (Shu *et al.*, 2001). In atmosphere, magnetic minerals are derived from combustion processes, such as industrial, domestic and vehicle emissions (Hunt *et al.*, 1994; Flanders, 1994) or from abrasion products from asphalt and from vehicles brake systems (Hoffmann *et al.*, 1999). The magnetic fine particles mostly consist of spherules and grains of irregular shapes that contains variable amounts and grain size of magnetite and hematite, which depends upon the fuel type and the temperature of combustion (Matzka *et al.*, 1999). Magnetic properties of soils (Hoffmann *et al.*, 1999; Hay *et al.*, 1997; Hanesch *et al.*, 2001;

Leocoanet *et al.*, 2001; Xie *et al.*, 2001) filters (Muxworthy *et al.*, 2002; Xie *et al.*, 2001) and leaves (Georgeaud *et al.*, 1997; Matzka *et al.*, 1999) have been used for identifying spreading of pollution derived from vehicular or industrial emissions.

Iron often occurs as an impurity in fossil fuels during industrial, domestic or vehicle combustion, carbon and organic material are lost by oxidation whilst the iron forms a non-volatile residue, often comprising glassy spherules (due to melting). These spherules are magnetic, with magnetizations easily measurable. It has been shown that combustion processes simultaneously release hazardous substances and magnetic particles into the atmosphere. In addition to these combustion-related particles, vehicles, via exhaust emissions and abrasion/corrosion of engine and/or vehicle body material (Olson *et al.*, 1975), can generate non-spherical magnetite particles.

Leaves with large surface areas per unit of weight and favorable surface properties having waxy coating and long lifespan, like conifer needles or evergreen tree leaves, are considered to be good accumulators of particulate matter from the atmosphere (Alfani *et al.*, 2000; Freer-Smith *et al.*, 1997). Rainwater containing particles collected from the atmosphere, could either contribute to dust accumulation on leaf surfaces or, by detaching previously collected particles, cause its reduction. Magnetic Biomonitoring of pollutants by measurements of roadside tree leaves is potentially efficient: samples are abundant and hundreds of samples can be collected and analyzed in days. The method is simple, rapid, inexpensive and nondestructive.

2. Sampling Methods

The city of Varanasi (82°15′E to 83°30′E and 24°35′N to 25°300′N, India), and its surrounding area, is characterized by little industry but, due to more than 1 million inhabitants, a substantial volume of traffic exists. The whole sampling protocol was divided in two parts.

(1) The leaf samples were collected from six different sites which are major roads (national highways) having high traffic density, village road nearby to major road and parks in the city. *Dalbergia sissoo* is abundant in both urban and rural environment (e.g. gardens, parks, roadsides) and hence selected for sampling. Leaves were collected from one species of tree to avoid the possibility of species-dependent differences in dust absorbency. Each sample consisted of six leaves, taken from the outer canopy at a height of 3–4 m, packed into 10 cc plastic sample pots. To ensure leaves of similar age, only the oldest leaves of the newest twig growth were collected. To determine the reliability of the method, two samples were taken for every sampling position and their mean value and deviation calculated. Consequently, the calculated magnetizations for each sample point are based on the measurement of 12 leaves.

(2) A separate determination of four individual tree leaves was conducted, which are at different distances from a major road (National highway) i.e. at 2, 5, 8 and 13 m. These trees are between the major road (National highway) and a minor village road running parallel and separated by approximately 15 m. Sampling was carried out for five days.

3. Measurements

The samples were magnetized with a pulsed magnetic field of 300 mT by a Molspin pulse magnetizer (10–300 mT). The isothermal remanent magnetization ($IRM_{300\,mT}$) was then measured with a CCL cryogenic magnetometer having the sensitivity of 10^{-10} Am^2 (the weakest leaf samples had magnetizations of $\sim 10^{-8}$ Am^2). Area of individual leaf was calculated by digitizing their computer-scanned images. The 2D-magnetization was calculated as the magnetic moment per leaf area, in units of Amperes ($A = Am^2/m^2$). A small number of leaves, representative of different sampling locations, was cleaned with water, detergent and ultrasonics, after measurement of 2-D magnetization to determine their ‘background’ magnetization. Magnetic susceptibility depends on the whole composition of the dust deposited on the leaves and is however dominated by ferrimagnetic minerals

TABLE I

$IRM_{300\,mT}$ values of sampled *Delbergia sisso* leaves for different locations versus ‘background’ $IRM_{300\,mT}$ of the subsequently cleaned leaves. Leaf samples from *Delbergia sisso* trees proximal to major roads show much higher 2D-magnetizations than those from the rural roads and urban parks. Cleaning with detergent and subsequent ultrasonic cleaning removes between 60.26 % and 84.99 % of the magnetization.

Sampling location	2-D magnetization (10^{-6} A)	2-D magnetization after cleaning of the leaf (10^{-6} A)	% magnetization removed by cleaning
1. Remote rural road (near Amara village)	13.13	1.97	84.99
2. Company garden (Maidagin)	11.33	2.37	79.08
3. Beniya park (Beniyabag)	6.77	2.69	60.26
4. Proximal to street (National Highway near Daphi)	57.38	13.51	76.45
5. Median of a National highway (near Mohansarai)	75.23	17.53	76.70
6. Distal to street (National Highway near Rohaniya)	35.79	6.57	81.64

that have much higher susceptibility values than other common paramagnetic and diamagnetic minerals like clay or quartz. To characterize the grain size Alternating Field (AF) demagnetization measurements were made with the help of LDA-3AF demag having the sensitivity of 1 to 300 mT.

4. Results and Discussion

The 2-D magnetizations of leaves from trees at different sites and their background values are shown in Table I. The magnetizations values are minimal for park trees, higher for rural roadside trees and highest for trees most proximal to major roads. This magnetic pattern matches that reported by Impens *et al.*, 1979 for total dust interception by roadside trees. Maximum 2D-magnetizations were encountered for a sample taken between traffic lanes of major road. For the distal, least magnetic samples, ∼60% of the measured signal is derived from adhering dust particles; for the proximal, most magnetic samples, ∼85% is removed upon cleaning of the leaf (Table I). The residual magnetization may be due to imperfect cleaning of the leaf, incorporation of some dust particles, or a non-airborne, biogenic magnetic contribution.

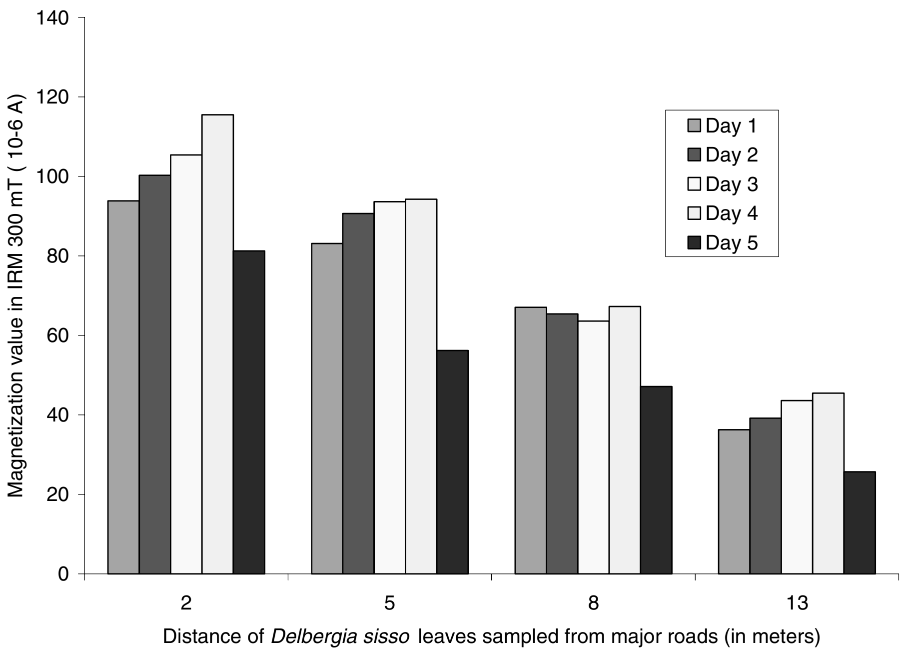

Figure 1. Variation of 2D-magnetization of *Delbergia sisso* leaf with distance from road and number of days after which sampling was done. Sampling days are as indicated by the different colors in the index box. The lower 2D-magnetization on day 5 as compared to day 4 is because of rainfall, which was between sampling day 4 and 5.

A separate determination of four individual tree leaves collected from between major city road (national highway) and a minor village road running almost parallel to major road and having a gap of about 15 m. Leaves were collected from four individual *Dalbergia sissoo* trees (at four distances i.e. 2, 5, 8 and 13 m) between the highway and village road (Figure 1). Sampling was carried out on day 1 (13 January 2005), days 2, 3, 4 and 5. All four days i.e. day 1 to day 4 show the same magnetization pattern, with higher values displayed by leaves from the tree adjacent to the major road. Maximum $IRM_{300\,mT}$ values range from 93 to 115×10^{-6} A, significantly higher than at the level section of this road. As the vehicles normally travel faster on the village road because of less traffic, they would probably raise more road dust. Conversely, vehicles of national highway require more energy because the transportation is mainly due to heavy-duty diesel vehicles, thus raising fuel consumption and exhaust emissions. The magnetization maximum next to the major road suggests that many of the magnetic particles are derived from combustion and exhaust-related sources. The different sampling days not only show the reproducibility of this magnetization pattern, but also changes with time and weather. In the four sunny days from day 1 to day 4, the magnetization increased. After sampling on day 4, there were heavy rainfalls in Varanasi. Re-sampling on

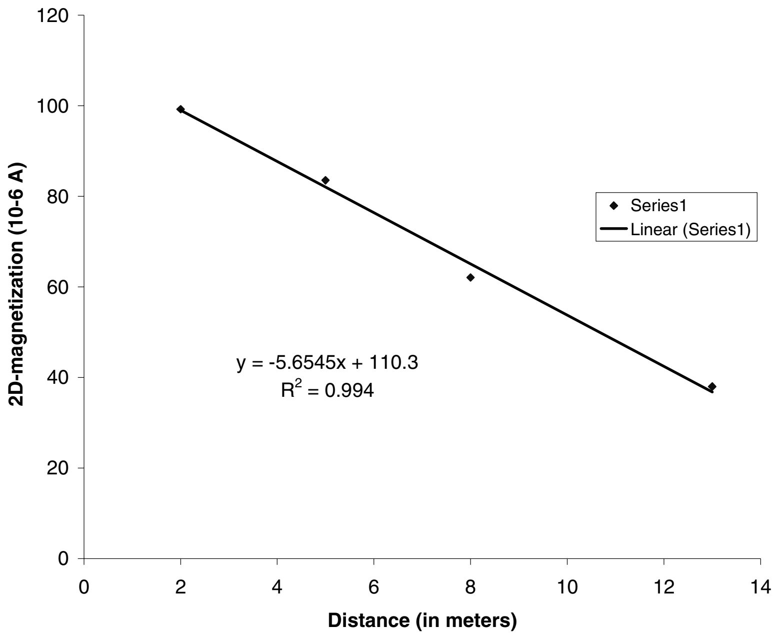

Figure 2. Correlation between the 2D magnetization of *Delbergia sisso* leaf and distance from the major road. The 2D magnetization decreases as the distance of *Delbergia sisso* tree increases from the road suggesting that vehicular derived particulate matter is cause of magnetic properties of tree leaves.

day 5 showed a decrease in the magnetization, identifying the net removal of particles from leaf surfaces by rainwater. A strong negative correlation exists between $IRM_{300\,mT}$ (10^{-6} A) value of particulates collected from *Delbergia sisso* tree and distance from the road (Figure 2) indicating that magnetic properties of tree leaves is due to vehicular derived particulate matter.

Alternating Field (AF) demagnetization experiments displayed similar magnetic stability. Their coercivity of remanence (the magnetic field required to demagnetize the IRM is >40 mT, indicating magnetic particles with a grain size from 0.03 to 3 μm (Heider *et al.*, 1996).

5. Conclusions

1. The magnetization of *Delbergia sisso* leaf samples collected from urban and rural area is controlled by their proximity to major roads and may be an easily measurable proxy for vehicle derived particulates.
2. Highest leaf magnetizations were found adjacent to the major road of a National Highway, indicating a combustion- and/or exhaust-related source of the magnetic particles.
3. Demagnetization analysis indicates that the grain size of the particles is of the order of 0.3–3 μm, a size of potential hazard to human health due to its capacity to be respired deeply into the lungs.
4. For leaves from individual trees, magnetization values fall from higher values on the road-proximal side to lower values on the distal side, indicating the ability of trees to reduce particulate concentrations at respirable height within the atmosphere.
5. Rainfall produces a net decrease in the concentrations of magnetic particles on leaf surfaces.

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