Particulate matter bio-monitoring through magnetic properties of an Indo-Burma hotspot region

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ABSTRACT

Present study aimed to investigate the bio-monitoring study of particulate matter (PM) pollutants of 12 roadside plant species, in Aizawl, Mizoram, India (an Indo-Burma hot spot region). While, the second part was ascribed to the bio-magnetic monitoring studies. Pertaining to first part of study, highest dust deposition was noted for Ramrikawn (RKN-Med) site on Ficus bengalensis (1.2 mg cm\(^{-2}\)) and lowest in Bauhinia variegata (0.8 mg cm\(^{-2}\)). Further, increased concentration of heavy metals (Fe, Cu and Zn) was recorded at RKN-Med site. Roadside plant leaves of \(F.\) bengalensis recorded maximum accumulation of Fe (26.1 mg kg\(^{-1}\)) and Cu (19.5 mg kg\(^{-1}\)) while Cassia auriculata (12.1 mg kg\(^{-1}\)) showed lowest accumulation of Fe. \(B.\) variegata (1.88 mg kg\(^{-1}\)) recorded lowest accumulation of Cu. Zn was recorded maximum (48.2 mg kg\(^{-1}\)) in Mangifera indica while \(B.\) variegata showed lowest accumulation of 11.3 mg kg\(^{-1}\) Cu at Ramrikawn site. In relation to second part of the study, \(M.\) indica, \(Ficus\) benghalensis, \(Psidium\) guajava and \(Artocarpus\) heterophyllus were found to be efficient in bio-magnetic monitoring because all the magnetic properties (magnetic susceptibility, anhysteretic remanent magnetisation and isothermal remanent magnetisation) were high and significantly correlated with ambient PM (\(R^2 = 0.424\) to \(R^2 = 0.998\)) thus may act as proxy for ambient PM.

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1. Introduction

Air pollution originating from rapid industrialisation, urbanisation, population growth and economic development has perturbed the pristine environment of urban ecosystems. Unfortunately, urban ecosystems of ecologically sensitive regions like Indo-Burma hot spot are under severe air pollution stress.[1,2]

Air pollutants comprised of both particulate matter (PM) and gaseous pollutants may cause adverse health effects in human, affect plant life and impact the global environment by changing the atmosphere of the earth.[3–5] Air pollution emanating from PM is particularly deleterious as they lead to various cardio-pulmonary diseases through oxidative stress.[5,6] Many studies highlighted the importance of PM with an aerodynamic diameter of less than 10 µm (PM\(_{10}\)), which, due to their small size, can penetrate deep into the human lung and cause cardio vascular diseases.[4–8] These fine and ultrafine particulates
have higher burdens of toxicity as they become coated with heavy metals and chemicals, which, when inhaled, can become absorbed into the body and may target specific organs. [5,6,9–11]

Heavy metals are classified among the most deleterious groups of anthropogenic environmental pollutants due to their toxicity and persistence in the environment. [86,87] Presence of heavy metals in the roadside and PM in the ambient air is serious and has adverse human health effect. Presence of heavy metals above their threshold level also could be potentially harmful on local vegetation and environment. Elevated levels of heavy metals may cause oxidative stress either by inducing the generation of reactive oxygen species (ROS) within sub cellular compartments or by decreasing enzymatic and non-enzymatic antioxidants due to an affinity with sulphur-containing group (–SH). [86,87] Disturbance in heavy metals concentration can cause significant modification of biochemical processes in plants leading to loss of production, [86,87] lower yield and quality of agricultural crops. Loss of hazel nut production due to high zinc concentration was shown in the leaves of Corylus avellane. [86,87] Excessive copper may destroy sub cellular structure of plants. [86,87] High concentration of sulphur become toxic to plant as it produces various biochemical changes in plants such as destruction of the chlorophyll and cells causing reduction in the thickness of the annual rings of the trees. [86,87] Photosynthetic efficiency of most of the plants is affected by heavy metals. [86,87 Supp. Ref.] Metals have multifaceted impact on photosynthesis. [86,87]

Instead of existing plethora of policies as well as instrumentation technologies with high cost issue and other limitations, [6] urban roadside plants are inextricably linked with eco-sustainability. [2,6,9]

Deposition of PM pollutants on leaf surface induces structural and functional changes. [2] Although, plants are very important to maintain urban ecosystem health, however, may be severely affected by PM pollution. [2,4,6,12–18] Air Pollution Tolerance Index (APTI) as well as Anticipated Performance Index (API) and impact of PM pollutants on heavy metals and enzyme activity (peroxidase and catalase) of urban roadside plant species may assist in screening of tolerant plants which may be further recommended for green belt development assisting in urban ecosystem restoration. [2,4,17]

Pertaining to bio-magnetic monitoring, it is worth to mention that initial researches demonstrated biogenic ferrimagnets be present in the organisms like termites [19] and bacteria. [20] However, it is now well established through cascade of researches that urban PM may also contain magnetic particles along with other air pollutants. [6,21–27] Another research in hilly Himalayan region measured magnetic susceptibility (χ) of soils, sediments and roadside materials, in and outside the Kathmandu urban area and magneto-mineralogical analyses as well as scanning electron microscopy on magnetic extracts, grain size fractions or bulk samples of road dust and soils, suggest lithogenic magnetite like minerals and anthropogenic magnetic spherules to be the dominant contributors to the χ signal. [28] Magnetic minerals derived from diverse sources are particularly deleterious to human health in view of their small size and thus their ability to be inhaled inside lungs and get dissolved in alveolar environment leading to several pulmonary as well as cardiovascular diseases. [6]

Existing conventional technologies for PM pollution abatement have several limitations; however, bio-magnetic monitoring is an eco-friendly device in urban areas. [6] In this perspective, urban roadside plants presents an eco-sustainable approach. [4,6]
Lichens, bryophytes or mosses and certain conifers were may also act as bio-monitoring tool of air pollution in recent times.\cite{4,6} However, in urban and peri-urban regions angiospermic plants are mostly suitable for monitoring dust or PM pollution as lichens and mosses are often sensitive and absent.\cite{4,6,29} Further, urban trees and shrubs planted in street canyons proved to be efficient dust capturing tools.\cite{17,30,31} Spreading widely in urban area and easily collected, tree leaves could improve the scanning resolution in the spatial scale.\cite{4,32,33} With the rapid, cost-effective, and non-destructive feature of environmental geomagnetism measurement, the magnetic properties of tree leaves as proxy in monitoring and mapping of PM pollution have drawn increasing attention.\cite{4,34} Therefore, urban angiosperm trees offer positive biological, ecological impacts in comparison to lower plants.\cite{4,6,16,30,31}

Several researches demonstrated the magnetic properties of soil, roof and street dust,\cite{35–41}, and parts of plant other than plant leaves like tree bark,\cite{4,31,42} however, a growing body of literature have emphasised the use of plant leaves in monitoring the dust or PM.\cite{4,6,24,27,30,31} Thus, in view of this, magnetic bio-monitoring studies of roadside plant leaves were conducted in Singrauli industrial region as well as Varanasi urban region of India,\cite{6,26,43,44} in some cities of Portugal and mountain areas of Nepal.\cite{45} Further, different researches enriched the bio-magnetic monitoring literature in European countries.\cite{46–48} However, the diversity of plants investigated for their bio-magnetic monitoring potential is limited mostly to plants prevailing in temperate conditions, and therefore, field is ripe for the investigation in context of tropical plants.\cite{6}

Aizawl, the capital city of Mizoram observed the increase in the number of vehicles and hence PM.\cite{9} Therefore, vehicular pollution may be the primary contributor of particulates, specifically respirable suspended particulate matter (RSPM), having human health implications. Our preliminary study in Aizawl \cite{4,49} recorded the level of suspended particulate matter (SPM) and RSPM above permissible limit of National Ambient Air Quality Standards. Further, PM below the size of 10 μm (PM$_{10}$), are specifically hazardous to human health,\cite{50} therefore their monitoring is pertinent.\cite{9}

Apart from vehicular dust generation other sources are soil erosion, mining and stone quarrying activities prevailing particularly in peri-urban and rural regions of Aizawl.\cite{9} Furthermore, increasingly, air-borne PM emitted from geologic media pose threats to human health as well as the environment.\cite{9,29} Also, the rocks of Aizawl are very fragile; therefore, weathered rock dust may also get deposited on plant leaves. In Indian sub-continent several researches demonstrated significant correlation between magnetic parameters and PM,\cite{26,43} however, they analysed single magnetic parameter while in present study we included several parameters.\cite{4}

Several studies have been performed on the impacts of air pollution with selected plants only in urban polluted regions,\cite{2,6,15,51–53} however, no systematic study on bio-monitoring as well as bio-magnetic monitoring has been done in urban portion of ecologically sensitive hilly regions like Aizawl, Mizoram, North East India which is also an integral part of extremely diverse Indo-Burma hot spot region of Myers.\cite{49,54} Further, plant’s response may alter under varying pollution stress; however, till date no study has been done in ecologically sensitive hilly regions of Indo-Burma hot spot region to study the impacts of PM pollution on urban roadside plants with their possible phyto-technological innovation.
In the light of abovementioned discussion, present study deals with the quantification of air pollutants in the ambient air, assess the impacts of air pollutants with special reference to PM deposition on plant leaves, heavy metals, and enzymatic activities of some common urban roadside plant species in an Indo-Burma hot spot region. Further, the second part of study attempts to study the bio-magnetic monitoring implications and screen the potent plants which may act as proxy of ambient PM.

2. Methodology

2.1. Site description

Mizoram (21°56′–24°31′N and 92°16′–93°26′E) is one of the seven sisters state under North East India (Figure 1), and it occupies an area of 21,081 km². The forest vegetation of state falls under three major categories, that is, tropical wet evergreen forest, tropical semi-evergreen forest and sub-tropical pine forest.[55] Aizawl district comes under Indo-Burma hotspot region of North East India,[54,56] having variety of diverse plant species possess varying leaf morphology which can be utilised in sampling of dust deposition and hence, the study of magnetic parameters. The diversity of tropical evergreen plants prevails along the roadsides of Aizawl district, and therefore, it can retain the pollutants throughout the year; offering no seasonal constraint.[9]

This study was conducted quarterly, that is, summer, rainy, and winter during 2013–2014. Twelve common roadside plants namely *Ficus bengalensis*, *Ficus religiosa*, *Mangifera indica*, *Bougainvillea spectabilis*, *Psidium guajava*, *Hibiscus rosa-sinensis*, *Lantana camara*, *Delonix regia*, *Artocarpus heterophyllus*, *Cassia auriculata*, *Bauhinia variegata* and *Lagerstroemia speciosa* of mixed habits, including shrubs, small trees and large trees were selected.

Figure 1. Map of the study area, Aizawl, Mizoram, North East India (An Indo-Burma hotspot region). Source of the study area map is Google map.
for the study for their dust deposition and biochemical studies thus, dust deposition and biochemical parameters were studied on seasonal basis (Table 1). APTI and enzymatic activity (catalase and peroxidase) were studied in winter and summer season at Ramrikawn (RKN-Med; peri-urban area and Mizoram University MZU-Low; a rural area). The plants were selected due to their abundance, ease of sampling and their livelihood importance for local people. The species and characteristics of the selected plants at both the study sites with their leaf characteristics are given in Table 1. At each sampling site, three individual of each selected plant species were marked and 5–10 leaf samples per plant species are collected from the lower branches (at a height of 2–4 m) facing towards roadside in early hours of morning (8 am to 12 am) through random selection and were put in polythene bags, kept in ice box, brought to the laboratory and enzyme activity was studied immediately. The leaf samples were preserved at −20°C for various biochemical analyses within 24 h of their harvesting.

While for bio-magnetic monitoring ten plants were selected at four differentially polluted sites (as the magnetic properties were negligible for the rest two plants). For study of magnetic parameters of plant leaves, the leaves are brought in to laboratory of Department of Environmental Science, Mizoram University. Leaves are dried at 35°C and recorded the dried weight; samples are prepared for magnetic analysis, which involves in packing the dried leaves into the 10 cc plastic sample pots.[4]

2.2. SPM and RSPM

Air pollutants such as SPM and RSPM were analysed for the four selected sites was monitored by using ‘High Volume Air Sampler’ (Envirotech model, APM-460NL) with gaseous attachment (Envirotech model, APM-411TE) regulating eight hours per day in the year of 2013–2014 with a frequency of twice in a season. The apparatus was kept at a height of 2 m from the surface of the ground. Once the sampling was over, the samples were brought to the laboratory and concentration of different pollutants was determined. RSPM were trapped by glass fibre filter papers (GF/A) of Whatman and SPM were collected in the separate containers at average air flow rate of 1.5 m³ min⁻¹.

2.3. Dust deposition

Three replicates of fully mature leaves of each species were marked. The upper dorsal surface of all these leaves were cleansed using a fine brush and the dust were collected in pre-weighed tracing paper with maximum care. The selected leaves were cut from the petiole and carefully taken to quantify dust accumulation. The individual leaf area was calculated by tracing marginal outline on a graph paper and average from three leaves was taken into consideration. The samples were weighed using an electrical digital balance and the amount of dust was calculated using the equation:

\[
W = \frac{W_2 - W_1}{A},
\]

where

- \(W\) = Dust content (in milligrams per square centimetre),
- \(W_1\) = initial weight of tracing paper,
- \(W_2\) = final weight of tracing paper with dust and
- \(A\) = total area of leaf in (cm²).[17]
| Sl. no. | Scientific name | Common name | Family          | Habit   | Nature        | Leaf characteristics                                                                 | Uses                                      |
|--------|----------------|-------------|-----------------|---------|---------------|--------------------------------------------------------------------------------------|-------------------------------------------|
| 1.     | *F. benghalensis* Linn. | Bengal fig, Indian banyan, Indian fig | Moraceae       | Tree    | Evergreen     | The leaves are large, leathery, entire, ovate or elliptic, Coriaceous, Rough on the upper side | Medicinal, fodder, timber, making paper pulp |
| 2.     | *P. guajava* Linn. | Apple guava, common guava | Myrtaceae       | Small Tree | Evergreen     | Aromatic leaves, opposite, entire, broad, hard, concave and directed horizontal       | Medicinal, dyeing silk and cotton, for making handicraft and turnery |
| 3.     | *B. spectabilis* Willd. | Paper flower | Nyctaginaceae   | Shrub   | Evergreen or semi-evergreen | Simple, alternate, oval in shape, tapering to a point, smooth, slightly folded margin | Ornamental |
| 4.     | *M. indica* Linn. | Mango       | Anacardiaceae   | Tree    | Evergreen     | Spirally arranged on branches, linear-oblong, short petiole, and thick surface        | Edible, medicinal and timber               |
| 5.     | *L. camara* Linn. | Big sage, tick berry, wild sage. | Verbenaceae     | Shrub   | Evergreen     | Textured surface covered with rough hairs, wavy margin, and short petiole             | Medicinal, ornamental, Furniture making and firewood |
| 6.     | *H. rosa-sinensis* Linn. | China rose, Chinese hibiscus, shoe flower | Malvaceae       | Shrub   | Evergreen     | Toothed leaves, alternately arranged, large, smooth, shiny and long petiole           | Ornamental, edible, medicinal, cosmetics, fibre |
| 7.     | *L. speciosa* Linn. | Banaba plant, giant crape-myrtle, pride of India. | Lythraceae      | Medium-sized tree | Deciduous     | Oblong, large, short petiole and Leathery.                                         | Medicinal, ornamental, furniture making and tea preparation |
| 8.     | *F. religiosa* Linn. | Bo tree, Bodhi tree, peepal, sacred fig | Moraceae       | Tree    | Deciduous or semi-evergreen | Cordate in shape with a distinctive extended drip tip, long petiole, smooth and shiny | Medicinal |
| 9.     | *D. regia* Raf. | Flamboyant tree, flam tree, peacock flower, royal Poinciana | Fabaceae/Leguminosae | Tree    | Deciduous     | Elegant, lacy, fernlike, small leaf area, and smooth                                 | Ornamental, medicinal and fuel wood       |
| 10.    | *C. auriculata* Linn. | Avaram or Ranawara | Fabaceae        | Shrub   | Evergreen     | Alternate, small leaf area, smooth, flat surface and slender,                         | Medicinal, landscaping roadways and home gardens |
| 11.    | *A. heterophyllus* Lam. | Jackfruit, jaca, nangka | Meraceae       | Tree    | Evergreen     | Oblong, oval, or elliptic, glossy, smooth and flat surface                          | Edible, timber, fodder, making furniture, latex, medicinal |
| 12.    | *Bauhinia variegata* Linn. | Orchid tree, mountain ebony | Fabaceae/Leguminosae | Tree    | Deciduous     | Leaves are Cow’s Hoof shaped, broad, hard, weep downward and flat surface           | Medicinal, edible, dye making and ornamental |
2.4. Heavy metal analysis

Trace elements (Fe, Cu and Zn) were extracted by digesting leaf samples with 1 mL of 50% perchloric acid, 5 mL concentrated nitric acid and 1 mL concentrated sulphuric acid at moderate heat. The concentrations of Fe, Cu and Zn in the extract were determined by using an Atomic absorption spectrophotometer (model 370A, PERKIN ELMER).

2.5. Estimation of enzyme activity (catalase and peroxidase)

For the determination of some antioxidant enzyme activities, enzyme extraction procedure was prepared according to Nayyar and Gupta with some modification in relation to quantity of reaction mixture (1000 µl), enzyme extract (50 µl) and concentration of H$_2$O$_2$ (10 mM). Aforesaid components may vary in quantitative perspective in varying protocols.

Catalase activity was determined according to Aebi by monitoring the decomposition of H$_2$O$_2$. In 1 mL of reaction mixture contain potassium phosphate buffer (pH 7.0), 50 µl of enzyme extract and 10 mM H$_2$O$_2$ to initiate the reaction. The reaction was measured at 240 nm for 5 min and H$_2$O$_2$ consumption was calculated using extinction coefficient, 43.6 M$^{-1}$cm$^{-1}$ and was expressed in units per mg protein.

Peroxidase activity was determined using the guaicol oxidation method by Chance and Machly. 3 mL reaction mixture contains 10 mM potassium phosphate buffer (pH 7.0), 8 mM guaicol and 50 µl enzyme extract. The reaction was initiated by adding 10 mM H$_2$O$_2$. The increase in absorbance was recorded within 5 min at 470 nm due to the formation of tetra guaicol. A unit of peroxidase activity was expressed as the change in absorbance per min and specific activity as enzymes units per mg soluble protein (extinction coefficient 6.39 mM$^{-1}$cm$^{-1}$).

2.6. APTI and API of plant species

APTI plays a significant role to determine resistivity and susceptibility of plant species against pollution level. To evaluate the tolerance level of plant species to air pollution used four leaf parameters (i.e. relative water content, pH, chlorophyll content and ascorbic acid) to derive an empirical number indicating the APTI. The APTI was calculated using the formula as given below.

$$\text{APTI} = [A(T + P) + R] \times 10,$$

where,

$A$ = Ascorbic acid (mg g$^{-1}$),
$T$ = total chlorophyll (mg g$^{-1}$ -f.w.),
$P$ = pH of the leaf extract and
$R$ = relative water content of leaf (%).

By combining the resultant APTI values with some relevant biological and socio-economic characters (plant habit, canopy structure, type of plant, laminar structure and economic value), the API was calculated for different species. Based on these characters, different grades (+ or −) are allotted to plants. Different plants are scored according to their grades.

2.7. Magnetic parameters

As mentioned earlier bio-magnetic monitoring study was carried out in Aizawl district from four different sampling points (Figure 1). Site 1: Durtlang (Urban area); Site 2: Zarkawt
(Urban area); Site 3: Ramrikawn (peri-urban area); Site 4: Mizoram University Campus (MZU). MZU campus is an institutional area with low traffic density. Therefore, we selected MZU as reference or control site in order to compare the results recorded from other sites. Further, we took winter season as dust or PM tends to concentrate during this season through atmospheric inversion [60] particularly during morning hours. Further, in our recent research [17] we recorded maximum dust deposition during winter season. This suggests that localised conditions like environmental, meteorological or anthropogenic may be influencing or disturbing particulate deposition or it may reflect differences in the ability of leaf species to capture particulates.[9]

The magnetic parameters such as $\chi$, anhysteretic remanent magnetisation (ARM) and saturation isothermal remanent magnetisation (SIRM) were performed with dried leaves in 10 cc plastic sample pots at K.S. Krishnan Geomagnetic Research Lab of Indian Institute of Geomagnetism, Allahabad, Uttar Pradesh, India.

The $\chi$ indicates the total composition of the dust deposited on the leaves, with a prevailing contribution from ferromagnetic minerals, which could show higher susceptibility values than paramagnetic and diamagnetic minerals, such as, clay or quartz,[61,62 Supp. Ref] A Bartington (Oxford, England) MS-2B dual frequency susceptibility metre was used [63 Supp. Ref] in measurements.

ARM indicates the magnetic concentration and is also sensitive to the presence of fine grains $\sim$0.04–1 $\mu$m.[64 Supp. Ref] Thus, falling within the respirable size range of PM$_{2.5}$; are possessed with high burden of toxicity.[65 Supp. Ref] ARM was induced in samples using a Molspin (Newcastle-upon-Tyne, England) A.F. Demagnetiser, whereby a DC biasing field is generated in the presence of an alternating field, which peaks at 100 milli-Tesla (mT). The nature of this magnetic field magnetises the fine magnetic grains and the amount of magnetisation retained within the sample (remanence) when removed from the field was measured using a Molspin1A magnetometer. The samples were then demagnetised to remove this induced field in preparation for the subsequent magnetic analysis.[66 Supp. Ref]

SIRM reflects the total concentration of magnetic grains [62 Supp. Ref] and can be used as a proxy of PM concentration,[67 Supp. Ref] SIRM involves with measuring the magnetic remanence of samples once removed from an induced field. Using a Molspin Pulse Magnetiser, a saturation SIRM of 800 mT in the forward field was induced with the samples. At this high magnetisation field, all magnetic grains within the sample become magnetised. [4] SIRM is actually the highest level of magnetic remanence that can be induced in a particular sample through application of high magnetic field; Unit – Am$^2$. The instruments used for ARM and SIRM are fully automated.

The ratio of IRM-300 and SIRM is defined as the S-ratio.[68 Supp. Ref] The S-ratio mainly reflects the relative proportion of antiferromagnetic to ferrimagnetic minerals in a sample. A ratio close to 1.0 reflects almost pure magnetite while ratios of <0.8 indicate the presence of some antiferromagnetic minerals, generally goethite or haematite.[69 Supp. Ref]

2.8. Statistical analysis

All statistical calculation was performed using Statistical Programme for Social Science (SPSS version 11.2) and SAS software.
3. Result and discussion

Ambient air quality of Aizawl revealed high PM Concentrations ((both SPM as well as RSPM)) particularly during winter and summer season (Table 2).

High dust deposition was recorded for all the plant species at the RKN-Med (Ramri-kawn) site and the trend of dust trapping capacity among the plant species was *F. bengalensis* > *P. guajava* > *B. spectabilis* > *M. indica* > *L. camara* > *H. rosa-sinensis* > *L. speciosa* > *A. heterophyllus* > *F. religiosa* > *D. regia* > *C. auriculata* > *B. variegata* (Figure 2).

Analysis of the dust or PM collected from the leaf surface indicated the presence of some high concentration of toxic heavy metals such as Fe, Cu and Zn. Significant positive correlation recorded between dust deposition and heavy metals (Fe, Cu and Zn) at both MZU-Low and RKN-Med site (Table 2). High concentrations of heavy metals in plants of RKN-Med site may be due to heavy traffic frequency and more commercial and domestic activities when compared the MZU-Low site. Verma and Singh [61] also demonstrated high metals concentration at heavy polluted sites in Lucknow, India compared to low polluted site while using *F. religiosa* and *Thevetia nerifolia* as bio-monitoring tool.

The accumulated metal concentrations in leaves of plants differ from one species to another in response to dust or PM accumulation.[17] Foliage of *F. bengalensis* recorded maximum accumulation of Fe (26.1 mg kg\(^{-1}\)) and Cu (19.5 mg kg\(^{-1}\)) while *C. auriculata* (12.1 mg kg\(^{-1}\)) showed lowest accumulation of Fe. *B. variegata* (1.88 mg kg\(^{-1}\)) recorded lowest accumulation of Cu. However, as far as accumulation of Zn was concerned, it was recorded maximum (48.2 mg kg\(^{-1}\)) in *M. indica* while *B. variegata* showed lowest accumulation of 11.3 mg kg\(^{-1}\) Cu at Ramrikawn site (Figure 3).

Higher plants act as bio monitors of aerial heavy metal contamination because of their bio accumulative properties.[54,56,60] Higher plants not only intercept metals from atmospheric deposition, but also accumulate them from the soil.[60] Air-borne heavy metals, when deposited on soil, are taken up by the plants through their root system and

![Figure 2](image-url) **Figure 2.** Dust deposition capacity of selected plant species at MZU-Low and RKN-Med site during the study period (November, 2011–February, 2012). Values are mean ± SE (n = 3).
Table 2. The average concentration of two air pollutants (SPM and RSPM) at four different study sites during 2013–2014.

| Air pollutants | Ramrikawn | Tanhril | Zarkawt | Durtlang | CPCB standard |
|----------------|-----------|---------|---------|----------|---------------|
|                | Summer    | Winter  | Rainy   | Summer   | Winter       | Rainy       | Summer | Winter | Rainy | Summer | Winter | Rainy | Summer | Winter | Rainy |          |
| SPM (µg m⁻³)   | 263.12 ±  | 260.01 ± | 98.04 ± | 210.91 ± | 207.07 ± 42.9 ± | 223.51 ± | 229.21 ± | 93.01 ± | 220.22 ± | 224.07 ± | 87.03 ± | 200     |
|                | 0.01      | 0.12    | 0.04    | 0.16     | 0.41       | 0.21       | 0.11    | 0.02   | 0.29   | 0.24    | 0.01    | 0.32    |          |
| RSPM (µg m⁻³)  | 228.09 ±  | 232.23 ± | 71.21 ± | 102.31 ± | 109.28 ± 20.18 ± | 189.03 ± | 200.61 ± | 63.18 ± | 183.41 ± | 190.15 ± | 56.91 ± | 100     |
|                | 0.23      | 0.19    | 0.83    | 0.02     | 0.04       | 0.12       | 0.08    | 0.41   | 0.19   | 0.03    | 0.11    | 0.05    |          |

Notes: SPM, Suspended particulate matter; RSPM, respirable suspended particulate matter; CPCB, Central Pollution Control Board, New Delhi, India.
Figure 3. Accumulation of heavy metals by twelve selected plant species at MZU-Low and RKN-Med site during the study period (November, 2011–February, 2012). (a – Concentration of Fe; b – concentration of Cu; c – concentration of Zn). (a) Concentration of Fe in the leaf sample of the study sites during the study period (November, 2011–February, 2012). (b) Concentration of Cu in the leaf sample of the study sites during the study period (November, 2011–February, 2012). (C) Concentration of Zn in the leaf sample of the study sites during the study period (November, 2011–February, 2012).
translocated to other parts of the plant through active uptake mechanism.[17,54,56,60] However, in certain cases through other mechanisms metals may adhere as plaques on root surfaces without uptake and translocation to other parts of the plant.[17] Alfani et al. [71] observed that metal concentration was significantly higher in leaves from the urban roadside plants. They [71] also observed a positive correlation between leaf deposition and leaf metal accumulations. Therefore, plants growing along the roadsides may also work as phyto remediator of air-borne metals released from the vehicles and street dust.[9,17,60] Presence of these heavy metals in the dust or PM may also play an important role in disturbing the various physiological, biochemical and metabolic processes in plants. [6,9,17,60]

Figures 4 and 5 demonstrated the catalase and peroxidase enzyme activities in the plant leaf samples. The average activity of catalase and peroxidase enzymes was increased in all the plant species at RKN-Med site. Significant and positive correlation of enzyme catalase and peroxidase with dust deposition of plant species at both MZU-Low (MZU, i.e. Mizoram University with low PM concentrations compared to Medium PM concentrations at Ramrikawn, i.e. RKN-Med site) and RKN-Med site was observed (Table 2). P. guajava (36.11 ± 0.06 U mg\(^{-1}\) protein) showed highest catalase concentration and D. regia (4.10 ± 0.01 U mg\(^{-1}\) protein) showed lowest catalase concentration. Highest peroxidase concentration was recorded in D. regia (0.18 ± 0.02 U mg\(^{-1}\) protein) and lowest in L. speciosa (0.04 ± 0.03 U mg\(^{-1}\) protein).

In plant cells, electron may be transferred through chloroplast or mitochondrial electron transfer system. These electrons can produce ROS, when come into contact with oxygen molecules.[18] ROS are extremely reactive and cytotoxic to all organisms [72]
causing peroxidative destruction of cellular constituents.\cite{73,74} Stress such as air pollution enhances ROS formation in plant cell resulting in oxidative stress.\cite{75,76,77}

The plant cells have several antioxidative enzymes (\textit{superoxide dismutase (SOD), glutathione reductase, catalase and peroxidase}) and low-molecular antioxidants such as ascorbic acid, glutathione, \(\alpha\)-tocopherol, flavonoids and carotenoids to protect plants against these oxidative stressors.\cite{78–81}

Pollution load increases catalase and peroxidase content in this study may be a function of ROS production in response to air pollution stress. \cite{18} ROS or free radical production under pollution stress would increase the scavenging properties of enzymatic and non-enzymatic metabolites, particularly catalase and peroxidase, as well as other compounds such as ascorbate, carotenoid, SOD \cite{18} based on dosage and plant physiological status. Varshney and Varshney \cite{82} reported increase in peroxides activity in plants under a variety of stresses like mechanical injury and attack by pathogen or an influence of environmental pollution. The increase in peroxidase and catalase activity varies with the plant species and the concentration of pollutants.\cite{18}

At different study sites, \textit{F. bengalensis} is evaluated as the best variety, \textit{P. guajava} as excellent and \textit{M. indica} is judged to be very good, while \textit{L. speciosa} was recognised as good performer. The API of the examined plant species at both the sites showed that \textit{Ficus bengalensis}, \textit{P. guajava}, \textit{M. indica} and \textit{L. speciosa} have similar API value (Table 3). These plants can be consider the most tolerant plant to grow in polluted areas which may afford protection from pollution stress while the economic and aesthetic values of these trees are well known and thus they may be recommended for future plantation in the industrial and urban areas to combat atmospheric particulate pollution.

Screening of appropriate plant species might be useful for plantations, to mitigate atmospheric pollution. Ecological conservation and pollution abatement through Green Belt are two major components which are vital for any activity, whether proposed existing

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{Figure5.png}
\caption{Peroxidase activity of twelve plant species at RKN-Med (peri-urban) and MZU-Low (rural) site during the study period (November, 2011–February, 2012). Values are mean ± SE \((n = 3)\).}
\end{figure}
| Plant species                  | API value | Tree habit | Canopy structure | Type of tree | Laminar structure | Economic Importance | Total Plus | % Score | API gradation | Assessment |
|-------------------------------|-----------|------------|------------------|--------------|------------------|---------------------|------------|---------|---------------|------------|
| *F. bengalensis* Linn.        | ++++      | ++         | ++               | +            | ++               | +                   | 15         | 93.75   | 7             | Best       |
| *F. religiosa* Linn.          | +         | ++         | +                | +            | ++               | −                   | 9          | 56.25   | 3             | Moderate   |
| *M. indica* Linn.             | +++       | ++         | ++               | +            | ++               | −                   | 12         | 75.00   | 5             | Very Good  |
| *B. spectabilis* Willd.       | ++++      | +          | −                | +            | ++               | +                   | 9          | 56.25   | 3             | Moderate   |
| *P. guajava* Linn.            | ++++      | +          | ++               | +            | ++               | +                   | 14         | 87.50   | 6             | Excellent  |
| *Hibiscus rosasinensis* Linn. | +++       | +          | −                | +            | ++               | +                   | 9          | 56.25   | 3             | Moderate   |
| *L. camara* Linn.             | ++        | −          | −                | −            | +                | +                   | 7          | 43.75   | 2             | Poor       |
| *D. regia* Raf.               | +         | ++         | ++               | −            | −                | −                   | 6          | 37.50   | 1             | Very Poor  |
| *A. heterophyllus* Lam.       | ++        | +          | +                | +            | −                | +                   | 9          | 56.25   | 3             | Moderate   |
| *C. auriculata* Linn.         | +         | +          | −                | −            | −                | +                   | 4          | 25.00   | 0             | Not recommended |
| *B. variegate* Linn.          | +         | +          | +                | −            | ++               | −                   | 7          | 43.75   | 2             | Poor       |
| *L. speciosa* Linn.           | ++        | +          | +                | −            | ++               | +                   | 9          | 56.25   | 3             | Moderate   |
or under expansion stage. An evaluation of APTI and API might be very useful in the screening of appropriate plant species, useful for plantations to mitigate atmospheric pollution and maintain a social-aesthetic balance in environment surrounding industrial and urban areas.

The result form a basis for the selection of tolerant species fit for industrial and urban sites continuously exposed to elevated level of particulate pollutants. Therefore, roadside plants of present study i.e. *P. guajava*, *F. bengalensis* and *M. indica* with high API and APTI value can be used as sink and mitigators of air pollutants originating from multifaceted sources at heavily polluted sites while *B. variegata* and *D. regia* with low APTI and API value may act as bio indicators of air (particulate) pollutants. On the basis of above data a suggestive ecological model around a polluted site is proposed to ensure a relatively pollution free environment worth for human habitation. Plants with some economic and aesthetic value, dense canopy and large leaf area may be selected for green belt development in industrial/urban areas. The present study is a strong first step and warrants further efforts which may paves the way to screen the feasibility of this plants in context of their potentiality to be planted in other urban areas with varying pollution load.

Pertaining to bio-magnetic monitoring, $\chi$ values of Ramrikawn site ranged from $20.22 \pm 0.07$ to $49.71 \pm 0.07 \left(10^{-7} \text{ m}^3 \text{ kg}^{-1}\right)$ in winter with maximum in *F. bengalensis* ($49.71 \pm 0.21 \left(10^{-7} \text{ m}^3 \text{ kg}^{-1}\right)$) and minimum in *Bauhinia variegata* ($20.22 \pm 0.07 \left(10^{-7} \text{ m}^3 \text{ kg}^{-1}\right)$); $15.33 \pm 0.37$ to $28.36 \pm 0.74 \left(10^{-7} \text{ m}^3 \text{ kg}^{-1}\right)$ in summer with maximum in *A. heterophyllus* ($28.36 \pm 0.74 \left(10^{-7} \text{ m}^3 \text{ kg}^{-1}\right)$) and minimum in *Bauhinia variegata* ($15.33 \pm 0.37 \left(10^{-7} \text{ m}^3 \text{ kg}^{-1}\right)$).

The minimum and maximum values of $\chi$ in MZU site ranged from $11.13 \pm 0.02 \left(10^{-7} \text{ m}^3 \text{ kg}^{-1}\right)$, (*Cassia fistula*) to $25.19 \pm 0.91 \left(10^{-7} \text{ m}^3 \text{ kg}^{-1}\right)$ (*F. bengalensis*) and $7.73 \pm 0.11 \left(10^{-7} \text{ m}^3 \text{ kg}^{-1}\right)$ (*Bauhinia variegata*) to $15.07 \pm 0.71 \left(10^{-7} \text{ m}^3 \text{ kg}^{-1}\right)$ (*A. heterophyllus*) during the winter and summer, respectively.

Similarly the values of $\chi$ in Zarkawt site ranges from $17.27 \pm 0.91 \left(10^{-7} \text{ m}^3 \text{ kg}^{-1}\right)$ (*F. religiosa*) to $43.08 \pm 0.21 \left(10^{-7} \text{ m}^3 \text{ kg}^{-1}\right)$ (*M. indica*) and $13.23 \pm 0.55 \left(10^{-7} \text{ m}^3 \text{ kg}^{-1}\right)$ (*Bauhinia variegata*) to $26.77 \pm 0.09 \left(10^{-7} \text{ m}^3 \text{ kg}^{-1}\right)$ (*M. indica*) during the winter and summer, respectively.

$\chi$ values of Durtlang site ranged from $14.19 \pm 0.12$ to $36.77 \pm 0.09 \left(10^{-7} \text{ m}^3 \text{ kg}^{-1}\right)$ in winter with maximum in *F. bengalensis* ($36.77 \pm 0.09 \left(10^{-7} \text{ m}^3 \text{ kg}^{-1}\right)$) and minimum in *C. fistula* ($14.19 \pm 0.12 \left(10^{-7} \text{ m}^3 \text{ kg}^{-1}\right)$); $10.11 \pm 0.43$ to $23.19 \pm 0.74 \left(10^{-7} \text{ m}^3 \text{ kg}^{-1}\right)$ in summer with maximum in *M. indica* ($23.19 \pm 0.74 \left(10^{-7} \text{ m}^3 \text{ kg}^{-1}\right)$) and minimum in *Bauhinia variegata* ($10.11 \pm 0.43 \left(10^{-7} \text{ m}^3 \text{ kg}^{-1}\right)$). Several researches demonstrated that $\chi$ is a useful proxy parameter to monitor the regional distribution of air PM matter pollution or relative changes in an area.[30,34,45]

ARM values of Ramrikawn site ranged from $8.24 \pm 0.31$ to $44.96 \pm 0.17 \left(10^{-5} \text{ Am}^2 \text{ kg}^{-1}\right)$ in winter with maximum in *M. indica* ($44.96 \pm 0.17 \left(10^{-5} \text{ Am}^2 \text{ kg}^{-1}\right)$) and minimum in *Bauhinia variegata* ($8.24 \pm 0.31 \left(10^{-5} \text{ Am}^2 \text{ kg}^{-1}\right)$); $13.39 \pm 0.11$ to $26.52 \pm 0.19 \left(10^{-5} \text{ Am}^2 \text{ kg}^{-1}\right)$ in summer with maximum in *A. heterophyllus* ($26.52 \pm 0.19 \left(10^{-5} \text{ Am}^2 \text{ kg}^{-1}\right)$) and minimum in *C. fistula* ($13.39 \pm 0.11 \left(10^{-5} \text{ Am}^2 \text{ kg}^{-1}\right)$). Several researches demonstrated that $\chi$ is a useful proxy parameter to monitor the regional distribution of air PM matter pollution or relative changes in an area.[30,34,45]

The minimum and maximum values of ARM in MZU site ranged from $5.01 \pm 0.11 \left(10^{-5} \text{ Am}^2 \text{ kg}^{-1}\right)$ (*P. guajava*) to $21.76 \pm 0.82 \left(10^{-5} \text{ Am}^2 \text{ kg}^{-1}\right)$ (*F. bengalensis*) and $6.23 \pm 0.71 \left(10^{-5} \text{ Am}^2 \text{ kg}^{-1}\right)$ (*Bauhinia variegata*) to $13.21 \pm 0.11 \left(10^{-5} \text{ Am}^2 \text{ kg}^{-1}\right)$ (*P. guajava*) during the winter and summer, respectively.
Similarly the values of ARM in Zarkawt site ranges from 8.19 ± 0.41 (10−5 Am2 kg−1) \((L.\ camara)\) to 40.71 ± 0.42 (10−5 Am2 kg−1) \((F.\ bengalensis)\) and 10.27 ± 0.49 (10−5 Am2 kg−1) \((C.\ fistula)\) to 24.47 ± 0.26 (10−5 Am2 kg−1) \((M.\ indica)\) during the winter and summer, respectively.

ARM values of Durtlang site ranged from 4.46 ± 0.23 to 31.42 ± 0.51 (10−5 Am2 kg−1) in winter with maximum in \(F.\ bengalensis\) (31.42 ± 0.51) (10−5 Am2 kg−1) and minimum in \(P.\ guajava\) (4.46 ± 0.23) (10−5 Am2 kg−1); 9.01 ± 0.27 to 21.22 ± 0.11 (10−5 Am2 kg−1) in summer with maximum in \(F.\ bengalensis\) (21.22 ± 0.11) (10−5 Am2 kg−1) and minimum in \(Bauhinia\ variegata\) (9.01 ± 0.27) (10−5 Am2 kg−1).

SIRM values of Ramrikawn site ranged from 203.70 ± 0.52 to 314.52 ± 0.11 (10−5 Am2 kg−1) in winter with maximum in \(F.\ bengalensis\) (314.52 ± 0.11) (10−5 Am2 kg−1) and minimum in \(L.\ camara\) (203.70 ± 0.52) (10−5 Am2 kg−1); 165.11 ± 0.08 to 331.09 ± 0.66 (10−5 Am2 kg−1) in summer with maximum in \(A.\ heterophyllus\) (331.09 ± 0.66) (10−5 Am2 kg−1) and minimum in \(F.\ religiosa\) (165.11 ± 0.08) (10−5 Am2 kg−1).

The minimum and maximum values of SIRM in MZU site ranged from 112.42 ± 0.26 (10−5 Am2 kg−1) \((Bauhinia\ variegata)\) to 281.03 ± 0.52 (10−5 Am2 kg−1) \((P.\ guajava)\) during the winter and summer respectively.

Similarly the values of SIRM in Zarkawt site ranges from 201.11 ± 0.77 (10−5 Am2 kg−1) \((L.\ camara)\) to 281.03 ± 0.52 (10−5 Am2 kg−1) \((F.\ bengalensis)\) and 124.48 ± 0.14 (10−5 Am2 kg−1) \((F.\ religiosa)\) to 301.14 ± 0.23 (10−5 Am2 kg−1) \((P.\ guajava)\) during the winter and summer, respectively.

SIRM values of Durtlang site ranged from 149.11 ± 0.14 to 270.21 ± 0.64 (10−5 Am2 kg−1) in winter with maximum in \(F.\ bengalensis\) (270.21 ± 0.64) (10−5 Am2 kg−1) and minimum in \(C.\ fistula\) (149.11 ± 0.14) (10−5 Am2 kg−1); 103.21 ± 0.03 to 290.47 ± 0.26 (10−5 Am2 kg−1) in summer with maximum in \(F.\ bengalensis\) (290.47 ± 0.26) (10−5 Am2 kg−1) and minimum in \(C.\ fistula\) (103.21 ± 0.03) (10−5 Am2 kg−1).

The values of ARM/\(\chi\) and SIRM/\(\chi\) can reflect the grain size of magnetic minerals.[63,86 Supp. Ref] The results show that the ARM/\(\chi\) and SIRM/\(\chi\) values are found to be low at all studied sites (Tables 4–7). S-ratio of leaf samples are ranging from 0.801 to 0.982 (Tables 4–7), which indicates that these leaf samples are dominated by ‘soft’ magnetic minerals (predominantly Fe) with a low coercive force, associated partly with ‘hard’ magnetic minerals with a relatively high coercive force. Magnetic minerals are associated with pulmonary and cardiovascular diseases as they dissolve in alveolar environment [84] and get incorporated in magnetotactic bacteria.[89]

Fe of particle size 50 nm showed accumulation of \(Fe_3O_4\) nanoparticle.[91] Zerovalent Iron, which is the fourth most plentiful element in the Earth’s crust at nano-scale possesses very potent magnetic and catalytic properties. Iron nanoparticles (NPs)/nanocomplexes are widely used in the field of engineering, medicine, agriculture and environment. Iron NPs find application in removable electronic media, mobile phones, electrical components, sensors, transducers, targeted drug delivery, cancer treatment, magnetic resonance imaging, hyperthermia, water purification, etc.[88]. Iron plays a pivotal in living systems and it is difficult to comprehend any living system without iron. However, if present above threshold levels, ionic iron causes havoc in living systems.[88 Supp. Ref] Fe of micro or nanoparticle size was found to reduce seed germination in flax, barley and rye grass at 2000 and 5000 mg L−1. While \(Fe_3O_4\) nanoparticle in
| Plants                     | χ (10^{-7} m³ kg⁻¹) | ARM (10^{-5} Am² kg⁻¹) | SIRM (10^{-5} Am² kg⁻¹) | ARM/χ (10² Am⁻¹) | SIRM/χ (10² Am⁻¹) | S-ratio |
|---------------------------|---------------------|------------------------|-------------------------|-----------------|------------------|---------|
|                           | 2013–2014 (Winter) | 2013–2014 (Summer)    | 2013–2014 (Winter)      | 2013–2014 (Summer) | 2013–2014 (Winter) | 2013–2014 (Summer) |
| M. indica                 | 46.27 ± 0.71        | 27.27 ± 0.96           | 44.96 ± 0.17            | 26.01 ± 0.51     | 284.96 ± 0.72    | 301.71 ± 0.11    | 0.97  | 0.95  | 6.15  | 11.06 |
| A. heterophyllus          | 38.21 ± 0.42        | 28.36 ± 0.74           | 23.10 ± 0.31            | 26.52 ± 0.19     | 265.21 ± 0.61    | 331.09 ± 0.66    | 0.60  | 0.93  | 6.94  | 11.67 |
| F. bengalensis            | 49.71 ± 0.21        | 24.42 ± 0.31           | 43.01 ± 0.27            | 23.72 ± 0.22     | 314.52 ± 0.11    | 281.43 ± 0.18    | 0.86  | 0.97  | 6.32  | 11.52 |
| P. guajava                | 44.78 ± 0.15        | 26.12 ± 0.41           | 40.74 ± 0.49            | 24.09 ± 0.23     | 292.62 ± 0.77    | 290.53 ± 0.27    | 0.90  | 0.92  | 6.53  | 11.12 |
| L. camara                 | 37.09 ± 0.81        | 23.21 ± 0.08           | 8.24 ± 0.31             | 22.01 ± 0.17     | 203.70 ± 0.52    | 271.51 ± 0.29    | 0.22  | 0.94  | 5.49  | 11.69 |
| Bauhinia variegata        | 20.22 ± 0.07        | 15.33 ± 0.37           | 18.47 ± 0.97            | 14.35 ± 0.11     | 262.14 ± 0.94    | 177.14 ± 0.09    | 0.91  | 0.93  | 12.96 | 11.55 |
| C. auriculata             | 21.45 ± 0.25        | 15.43 ± 0.26           | 20.77 ± 0.14            | 13.39 ± 0.11     | 242.72 ± 0.09    | 180.11 ± 0.03    | 0.96  | 0.86  | 11.31 | 11.67 |
| H. rosa-sinensis          | 25.12 ± 0.38        | 19.77 ± 0.03           | 23.72 ± 0.22            | 17.56 ± 0.57     | 266.19 ± 0.36    | 191.11 ± 0.07    | 0.94  | 0.88  | 10.59 | 9.66  |
| F. religiosa              | 23.42 ± 0.14        | 18.74 ± 0.01           | 22.32 ± 0.36            | 16.52 ± 0.71     | 277.41 ± 0.41    | 165.11 ± 0.08    | 0.95  | 0.88  | 11.84 | 8.81  |
| B. spectabilis            | 28.42 ± 0.08        | 21.47 ± 0.56           | 29.32 ± 0.22            | 18.54 ± 0.29     | 273.41 ± 0.31    | 170.77 ± 0.52    | 1.03  | 0.86  | 9.62  | 7.95  |
Table 5. Summary of the magnetic data (mean and standard deviation) for roadside dusts on different selective plant leaves at Tanhril area during 2013–2014.

| Plants            | 2013–2014 (Winter) | 2013–2014 (Summer) | 2013–2014 (Winter) | 2013–2014 (Summer) | 2013–2014 (Winter) | 2013–2014 (Summer) | 2013–2014 (Winter) | 2013–2014 (Summer) | 2013–2014 (Winter) | 2013–2014 (Summer) |
|-------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|
|                   | χ (10⁻⁷ m³ kg⁻¹)   | ARM (10⁻⁵ Am² kg⁻¹) | SIRM (10⁻⁵ Am² kg⁻¹) | ARM/χ (10² Am⁻¹)   | SIRM/χ (10² Am⁻¹)   | S-ratio            |                    |                    |                    |                    |
| M. indica         | 23.71 ± 0.11       | 10.71 ± 0.24       | 177.41 ± 0.41      | 0.45               | 7.48               | 0.941              |                    |                    |                    |                    |
| A. heterophyllus  | 24.44 ± 0.27       | 20.24 ± 0.08       | 206.11 ± 0.37      | 0.82               | 8.43               | 0.919              |                    |                    |                    |                    |
| F. bengalensis    | 25.19 ± 0.91       | 21.76 ± 0.82       | 203.96 ± 0.56      | 0.86               | 8.09               | 0.901              |                    |                    |                    |                    |
| P. guajava        | 23.11 ± 0.21       | 5.01 ± 0.11        | 154.2 ± 0.17       | 0.21               | 6.66               | 0.954              |                    |                    |                    |                    |
| L. camara         | 19.72 ± 0.41       | 7.19 ± 0.18        | 140.41 ± 0.44      | 0.36               | 7.12               | 0.954              |                    |                    |                    |                    |
| Bauhinia variegata| 12.14 ± 0.03       | 10.23 ± 0.99       | 112.42 ± 0.26      | 0.84               | 9.26               | 0.877              |                    |                    |                    |                    |
| C. auriculata     | 11.13 ± 0.02       | 0.98 ± 0.19        | 133.76 ± 0.29      | 0.82               | 12.01              | 0.881              |                    |                    |                    |                    |
| H. rosa-sinensis  | 12.13 ± 0.11       | 10.18 ± 0.18       | 168.76 ± 0.18      | 0.83               | 13.91              | 0.982              |                    |                    |                    |                    |
| F. religiosa      | 11.41 ± 0.14       | 10.74 ± 0.19       | 122.47 ± 0.03      | 0.94               | 10.73              | 0.931              |                    |                    |                    |                    |
| B. spectablis     | 11.14 ± 0.09       | 9.38 ± 0.11        | 150.44 ± 0.15      | 0.84               | 13.50              | 0.873              |                    |                    |                    |                    |
Table 6. Summary of the magnetic data (mean and standard deviation) for roadside dusts on different selective plant leaves at Zarkawt area during 2013–2014.

| Plants           | χ (10⁻⁷ m³ kg⁻¹) | ARM (10⁻⁵ Am² kg⁻¹) | SIRM (10⁻⁵ Am² kg⁻¹) | ARM/χ (10² Am⁻¹) | SIRM/χ (10² Am⁻¹) | S-ratio |
|------------------|------------------|---------------------|----------------------|------------------|------------------|---------|
|                  | 2013–2014 (Winter) | 2013–2014 (Summer) | 2013–2014 (Winter) | 2013–2014 (Summer) | 2013–2014 (Winter) | 2013–2014 (Summer) |
| M. indica        | 43.08 ± 0.21      | 26.77 ± 0.09        | 40.27 ± 0.01         | 24.47 ± 0.26      | 271.21 ± 0.09     | 291.11 ± 0.26     | 0.93    | 0.91    | 6.29 | 10.87 | 0.960 | 0.941 |
| A. heterophyllus | 39.19 ± 0.42      | 24.20 ± 0.72        | 12.76 ± 0.29         | 22.94 ± 0.56      | 266.11 ± 0.61     | 277.56 ± 0.17     | 0.32    | 0.94    | 6.79 | 11.46 | 0.953 | 0.961 |
| F. bengalensis   | 43.19 ± 0.17      | 22.11 ± 0.51        | 40.71 ± 0.42         | 19.12 ± 0.81      | 281.03 ± 0.52     | 248.11 ± 0.66     | 0.94    | 0.86    | 6.50 | 11.22 | 0.960 | 0.921 |
| P. guajava       | 34.62 ± 0.29      | 26.11 ± 0.09        | 9.53 ± 0.38          | 24.27 ± 0.23      | 273.41 ± 0.63     | 301.14 ± 0.23     | 0.27    | 0.92    | 7.89 | 11.53 | 0.953 | 0.932 |
| L. camara        | 33.87 ± 0.54      | 20.75 ± 0.18        | 8.19 ± 0.41          | 20.05 ± 0.08      | 201.42 ± 0.26     | 244.31 ± 0.12     | 0.24    | 0.96    | 5.94 | 11.77 | 0.952 | 0.931 |
| Bauhinia variegata | 17.42 ± 0.92      | 13.23 ± 0.71        | 16.43 ± 0.03         | 11.27 ± 0.08      | 248.72 ± 0.6      | 170.26 ± 0.01     | 0.94    | 0.85    | 14.27 | 12.86 | 0.934 | 0.891 |
| C. auriculata    | 21.14 ± 0.11      | 13.23 ± 0.55        | 17.69 ± 0.22         | 10.27 ± 0.49      | 232.09 ± 0.12     | 168.23 ± 0.56     | 0.83    | 0.77    | 10.97 | 12.71 | 0.912 | 0.887 |
| H. rosa-sinensis | 26.14 ± 0.18      | 17.48 ± 0.13        | 24.69 ± 0.08         | 15.17 ± 0.19      | 256.09 ± 0.29     | 183.18 ± 0.44     | 0.94    | 0.86    | 9.79 | 10.47 | 0.972 | 0.938 |
| F. religiosa     | 17.27 ± 0.91      | 16.27 ± 0.17        | 16.23 ± 0.31         | 13.49 ± 0.13      | 203.91 ± 0.13     | 124.48 ± 0.14     | 0.93    | 0.82    | 11.80 | 7.65  | 0.940 | 0.930 |
| B. spectabilis   | 22.07 ± 0.39      | 18.31 ± 0.91        | 20.12 ± 0.21         | 15.42 ± 0.79      | 238.72 ± 0.28     | 168.11 ± 0.65     | 0.91    | 0.84    | 10.81 | 9.18  | 0.901 | 0.938 |
Table 7. Summary of the magnetic data (mean and standard deviation) for roadside dusts on different selective plant leaves at Durtlang area during 2013–2014.

| Plants              | $\chi$ (10$^{-7}$ m$^3$ kg$^{-1}$) | ARM (10$^{-5}$ Am$^2$ kg$^{-1}$) | SIRM (10$^{-5}$ Am$^2$ kg$^{-1}$) | ARM/$\chi$ (10$^2$ Am$^{-1}$) | SIRM/$\chi$ (10$^2$ Am$^{-1}$) | S-ratio |
|---------------------|------------------------------------|----------------------------------|----------------------------------|--------------------------------|-------------------------------|---------|
|                     | 2013–2014 (Winter) | 2013–2014 (Summer) | 2013–2014 (Winter) | 2013–2014 (Summer) | 2013–2014 (Winter) | 2013–2014 (Summer) | 2013–2014 (Winter) | 2013–2014 (Summer) | 2013–2014 (Winter) | 2013–2014 (Summer) | 2013–2014 (Winter) | 2013–2014 (Summer) |
| M. indica           | 34.27 ± 0.24          | 23.19 ± 0.74          | 31.17 ± 0.62          | 20.92 ± 0.07          | 242.45 ± 0.21          | 227.29 ± 0.61          | 0.90          | 0.90          | 7.07          | 9.80          | 0.933          | 0.932          |
| A. heterophyllus    | 29.01 ± 0.38          | 20.11 ± 0.14          | 5.09 ± 0.73           | 18.52 ± 0.29          | 153.83 ± 0.34          | 197.44 ± 0.21          | 0.17          | 0.90          | 7.07          | 9.80          | 0.961          | 0.924          |
| F. bengalensis      | 36.77 ± 0.09          | 23.17 ± 0.19          | 31.42 ± 0.51          | 21.22 ± 0.11          | 270.21 ± 0.64          | 290.47 ± 0.26          | 0.85          | 0.91          | 7.34          | 12.53         | 0.943          | 0.917          |
| P. guajava          | 26.81 ± 0.25          | 15.12 ± 0.31          | 4.46 ± 0.23           | 14.22 ± 0.44          | 153.11 ± 0.27          | 188.24 ± 0.35          | 0.16          | 0.94          | 5.17          | 12.44         | 0.962          | 0.912          |
| L. camara           | 28.59 ± 0.39          | 14.03 ± 0.11          | 4.48 ± 0.29           | 12.56 ± 0.41          | 153.21 ± 0.31          | 153.42 ± 0.71          | 0.15          | 0.89          | 5.35          | 10.93         | 0.963          | 0.891          |
| Bauhinia variegata  | 17.23 ± 0.13          | 10.11 ± 0.43          | 15.97 ± 0.14          | 9.01 ± 0.27           | 171.01 ± 0.24          | 128.17 ± 0.52          | 0.92          | 0.89          | 9.12          | 12.67         | 0.907          | 0.889          |
| C. auriculata       | 14.19 ± 0.12          | 12.42 ± 0.72          | 12.91 ± 0.44          | 10.42 ± 0.99          | 149.11 ± 0.14          | 103.21 ± 0.03          | 0.90          | 0.83          | 10.50         | 8.30          | 0.938          | 0.897          |
| H. rosa-sinensis    | 16.12 ± 0.23          | 13.32 ± 0.72          | 14.47 ± 0.38          | 11.48 ± 0.56          | 192.77 ± 0.11          | 110.02 ± 0.11          | 0.89          | 0.86          | 11.95         | 8.25          | 0.931          | 0.891          |
| F. religiosa        | 14.19 ± 0.32          | 11.72 ± 0.24          | 12.23 ± 0.17          | 10.48 ± 0.14          | 167.57 ± 0.31          | 114.11 ± 0.31          | 0.86          | 0.89          | 11.80         | 9.73          | 0.895          | 0.842          |
| B. spectabilis      | 17.19 ± 0.07          | 13.14 ± 0.77          | 15.23 ± 0.04          | 11.07 ± 0.14          | 201.57 ± 0.21          | 168.23 ± 0.18          | 0.88          | 0.84          | 11.72         | 12.80         | 0.925          | 0.917          |
size range of 20 nm with 62–500 mg/L showed no toxic effect in pumpkin cucumber and lettuce.[91] Microorganisms such as bacteria have developed mechanism to detoxify the immediate cell environment by reducing toxic metal species into metal NPs.[84 Supp. Ref] It is well established that microorganisms have evolved mechanism(s) to counter excess of iron.[88] Blakemore [89] discovered novel iron-rich particles in the range of 40–100 nm in magnetotactic microorganisms and believed that these particles are released after death/lysis of cells, which then accumulate in sediments.[88] Fe NPs formation in *Hordeum vulgare* and *Rumex acetosa* plants revealed that large scale synthesis of Fe NPs for environmental remediation and hazardous waste treatment applications.[90]

Ramrikawn site shows slightly higher magnetic values comparing to the other sites. On the other hand, Ramrikawn and Zarkawt experiences relatively higher deposition of magnetic grains, originating from PM. *χ, ARM and SIRM* values are found to be higher for *F. bengalensis, M. indica, A. heterophyllus, P. guajava* and *L. camara* comparing to other plants. The spatial trends of these three magnetic parameters display similar trends having Ramrikawn at maximum value and MZU area at lowest value. The correlation coefficients indicated significant relationship between the concentration of PM and magnetic measurement for ten plant leaves (Supplementary Tables 10–19). Hansard et al. [47] studied atmospheric particle pollution emitted by a combustion plant using the tree leaves. Results show that a significant correlation is obtained between the SIRM and PM10. Rai et al. [4] also observed a good correlation of magnetic parameters (*χ, ARM and SIRM*) with air pollutants particularly heavy metals. Further, Kardel et al. [48] recorded significant correlation between leaf SIRM and ambient PM concentrations. The other studies also demonstrated a significant correlation between magnetic parameter and PM.[26,43]

The average magnetic concentration data (Tables 4–7) demonstrate that the accumulation of PM on tree leaves varies at different studied locations. The results suggest that Ramrikawn and Zarkawt experience the heaviest load of particulates in comparison to the low-deposition sites of Durtlang and MZU area. Ramrikawn recorded the highest values of magnetic parameters which may be attributed to heavy vehicular load, street dust and dust from fragile rocks. Zarkawt and Durtlang may have vehicular pollution as only source of PM while MZU, being a rural area is relatively free from vehicular pollution and other anthropogenic activities. *F. bengalensis, M. indica, A. heterophyllus, P. guajava* and *L. camara* leaves were rougher when compared to *Bauhinia variegata, C. fistula, H. rosa-sinensis, F. religiosa* and *B. spectabilis* which may be attributed to its high magnetic concentrations.

Sitewise, plants from Ramrikawn, Zarkawt and Durtlang showed high pollutant magnetic concentration due to tall buildings which may tend to concentrate the pollutants through the low dispersal of pollutants. At MZU site dispersal of particulates may take place due to lack of high buildings and multilane condition. Further, at Ramrikawn site there exist narrow as well as poor roads with heavy traffic, street dust load and tall buildings.

Finally, Supplementary Tables 10–19 clearly indicates the positive and significant correlation of magnetic measurements/properties of different plants with SPM and RSPM at four different study sites. Plants like *M. indica, F. benghalensis, P. guajava* and *A. heterophyl- lus* were found to be efficient in bio-magnetic monitors because all the magnetic properties (*χ, ARM and SIRM*) were high and significantly correlated with ambient PM.
4. Conclusions

Urban roadside plants of present study i.e. F. bengalensis, F. religiosa, M. indica, B. spectabilis, P. guajava, H. rosa-sinensis, L. camara, D. regia, A. heterophyllus, C. auriculata, B. variegata and L. speciosa may be used as control of PM pollutants originating from multifaceted sources after further research at heavily polluted urban sites. The present study is a strong first step and warrants further effort which may paves the way to screen the feasibility of these plants in context of their potentiality to be planted in other urban areas with varying pollution load. It will further enhance the conservation of biodiversity of these plants and their wide utilisation as well as sustainable management in respect of green belt development.[83–86 Supp. Ref] In nutshell, the use of urban roadside plants as bio indicators or biomarker is an inexpensive and convenient technique and thus offers an eco-sustainable green tool for urban ecosystem restoration. Results from second part of this work validate the magnetic analysis of roadside tree leaves as proxy indicators of PM pollution. Magnetic concentration data suggest that the deposition of PM on roadside tree leaves varies due to different traffic behaviour between sites and due to other activities like soil erosion, mining and stone quarrying etc. The magnetic analysis of dust loadings on roadside tree leaves provides an alternative proxy method to conventional pollution monitoring. Present study may be a novel contribution in the area of bio-magnetic as well as bio-monitoring as the previous related studies confined their quest mostly to temperate plants, concentrating on single magnetic parameter. However, in present study we have selected several bio-monitoring parameters (dust capturing potential, APTI, API, heavy metals, enzymatic activities) and three magnetic parameters (χ, ARM and SIRM). Study concluded that bio-monitoring as an eco-sustainable tool while bio-magnetic monitoring as an application of environmental geomagnetism may act as proxy for ambient PM pollution and may act as a cost-effective green tool for environmental management in urban and peri-urban regions. Moreover, tolerant roadside plants find their suitability for plantation in ecologically sensitive regions having implications for urban ecosystem restoration.

Disclosure statement

No potential conflict of interest was reported by the authors.

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