Biomagnetic monitoring of Atmospheric particulate Pollution through Roadside tree leaves in Aizawl city, Mizoram and their temporal and spatial variations

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Abstract

Particulate matter (PM) is one of the six criteria pollutants in terms of adverse impact on human health. It has been demonstrated that magnetic measurement is an important means in PM pollution study through plant leaves. Plants species are found as effective biomonitors and may act as natural filters by trapping and retaining PM on their leaf surfaces. In the present study, the magnetic properties [Magnetic susceptibility ($\chi$), Anhysteretic remanent magnetization (ARM) and Saturation isothermal remanent magnetization (SIRM)] of three roadside plant leaves (Bougainvillea spectabilis, Cassia fistula and Lantana camara) at four spatially distant sites were measured in order to compare their capability to accumulate PM. Further, the aim of this study was to assess PM pollution at selected sites and to establish the relationship between magnetic properties and PM in Aizawl city. The results indicated significant correlation between the concentration of ambient PM and magnetic measurement ($\chi$, ARM and SIRM) of the selected roadside plant leaves. Similarly, significant correlations between magnetic parameters ($\chi$, ARM and SIRM) and Fe concentrations have been demonstrated. Present study may be a novel contribution in the field of bio-magnetic 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 three magnetic parameters ($\chi$, ARM and SIRM). Study concluded that bio-magnetic monitoring as an application of environmental geomagnetism may act as proxy for ambient PM pollution and may act as an eco-sustainable tool for environmental management in urban and peri-urban regions.

Keywords: Biomonitoring, vegetation, particulates, human health, magnetic properties.

Introduction

Plants are considered as a good biological indicator of air pollution and thus, are widely used in environmental studies. Plants leaves were proved to be good collector of PM\textsuperscript{1-4}. Biomonitoring of particulate pollution through magnetic properties of tree leaves is a reliable, rapid and inexpensive alternative to existing atmospheric pollution monitoring techniques\textsuperscript{5,7}.

Atmospheric particulate matter is one of the most problematic air pollutants in view of their adverse impacts on human health. Atmospheric pollutants exist in both gaseous and pollutants form\textsuperscript{3}. Many studies highlighted the importance of PM10, which, due to their small size, can penetrate deep into the human lung and cause cardio vascular diseases\textsuperscript{4,9-13}. Alongside PM10s are further grain size divisions of PM2.5 and PM0.1 (2.5 µm and 0.1 µm, respectively, again relative to their aerodynamic diameters). 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\textsuperscript{4,14,15}. The urban population is mainly exposed to high levels of air pollution because of motor vehicle emissions, which is also the main source of fine and ultrafine particles\textsuperscript{4,16,17}.

In light of the said deleterious impacts of PM, it is pertinent to investigate the feasible and eco-sustainable green technologies. Although, there are many existing physical and chemical devices for assessment of air pollution, however, biomonitoring is an efficient tool in urban areas. Biological monitors are organisms that provide quantitative information on some aspects of the environment. In this regard, the air cleansing capacity of urban trees presents an alternative approach to foster an integrated approach to the sustainable management of urban ecosystem\textsuperscript{4}. In urban and peri-urban regions higher plants are fruitful for monitoring dust or PM pollution as lichens and mosses are absent in polluted urban regions\textsuperscript{4,18}. Further, urban trees and shrubs planted in street canyons and along road side proved to be effective dust capturing tools\textsuperscript{1,2,17}. Spreading widely in urban area and easily collected, tree leaves could improve the scanning resolution in the spatial scale\textsuperscript{19,20}. Tree leaves are efficient passive pollution collectors, as they provide a large surface area for PM deposition, a large number of samples and sampling sites\textsuperscript{21}. Therefore, urban angiosperm trees offer positive biological, ecological and aerodynamic effects in comparison to lower group of plants\textsuperscript{1,2,4,22}.
Biomagnetic monitoring with the urban roadside tree leaves, is very novel approach in the field of PM pollution science. The concept of environmental magnetism as a proxy for atmospheric pollution levels has been reported by several researchers based on analysis of soils and street or roof dust\textsuperscript{[23-30]} and vegetation samples\textsuperscript{[2,31]}, however, scanty researches have emphasized the use of plant leaves in monitoring the dust or PM\textsuperscript{[1,2,4,29,32-41]}. In this paper, we carry out a primary magnetic study on PM pollution in Aizawl City, Mizoram. The rapid urbanization, fast, drastic increases in vehicles on the roads and other activities including soil erosion, mining, stone quarrying and shifting cultivation in Aizawl, has lead to increases in the concentration of particulates pollutions in the atmosphere. Since the rocks of Aizawl are very fragile, the weathered rock dust may also get deposited on plant leaves. The present study aims to investigate the magnetic properties of different roadside plant leaves at four spatially distant sites in order to compare their capability to accumulate particulates and trying to map the PM pollution, to provide essential data for the recognition and control of air quality as well as for further environmental study.

**Material and Methods**

**Description of Study site:** Mizoram (21° 56' - 24° 31' N and 92° 16' - 93° 26' E) is one of the eight states under northeast India (figure 1), and it covers an area of 21,081 km\textsuperscript{2}. The tropic of cancer divides the state into two almost equal parts. The state is bordered with Myanmar to the east and south, Bangladesh to the west, and by the states of Assam, Manipur and Tripura to the north. The altitude is approaching to near the Myanmar border. The forest vegetation of state falls under three major categories i.e., tropical wet evergreen forest, tropical semi-evergreen forest and sub- tropical pine forest\textsuperscript{42}. Aizawl district comes under Indo-Burma hotspot region of North East India\textsuperscript{43,44}, highly diverse plant species having varying leaf morphology can be sampled for dust deposition and study of magnetic parameters. Mostly the diversity of tropical evergreen plants prevails along the roadsides of Aizawl district, and therefore, they can retain the pollutants throughout the year, thus, offering no seasonal constraint.

Aizawl (21°58'-21°85' N and 90° 30'-90° 60' E), the capital of the state is 1132 meter above sea level (asl). The altitude in Aizawl district varies from 800 to 1200 meter asl. The climate of the area is typically monsoonic. The annual average rainfall is amounting to ca. 2350 mm. The area experiences distinct seasons. The ambient air temperature normally ranges from 20 to 30\degree C in summer and 11 to 21\degree C in winter\textsuperscript{45}. It is well known that meteorological data may also affect the air pollutants including dust or particulate deposition, therefore average meteorological data of the study area recorded during the study period are mentioned in table 1.

![Figure-1](image-url)

**Figure-1**

Map of the Study Area, Aizawl, Mizoram, North East India
The study was carried out in Aizawl district which was categorized in to four sub-sites. Site1. Durtlang: Durtlang is a connecting road between Mizoram and Assam and is one of the main and busy roads of the city with high traffic density. Vehicles are the main source of pollution at this site. Site 2. Zarkawt: Zarkawt is a commercial place in the city of Aizawl. Because of high traffic density the emission of dust particles is usually very high in this area. Site3. Ramrikawn: Ramrikawn is very densely located commercial area with markets, bus as well as taxi stand and Food Corporation of India (FCI). FCI provides space for food storage for whole of Mizoram state. Due to existence of FCI in Ramrikawn area there is a frequent pollution in MZU campus. University buses, taxis, trucks or trolleys coming with construction materials are the main sources of pollution in MZU campus. However, the load of vehicles is very low and less frequent in comparison to other sites. Therefore, we selected MZU as reference or control site in order to compare the results recorded from other sites.

**Sampling:** Sampling was conducted during the months of September-December 2012 (period of almost negligible rain as shown in (table 1). Tree leaves were collected from three species on dry sunny days. The recorded plants were Bougainvillea spectabilis, Cassia fistula and Lantana camara. These three plants samples were selected for the study because of their abundance, convenience for sampling and their socioeconomic importance for local people. Moreover, these plants have already been investigated for their suitability in efficient dust capturing. Also, these plants are evergreen therefore, offers no seasonal constraint. At each site, 5-10 leaves of similar size from branches facing roadside were plucked through random selection in early hours of morning (08 AM to 12 AM) and placed in polythene bags. Leaves were collected from the tree on the side nearest to the road at a height of approximately 2 m to avoid possible contamination from ground splash. Preference was usually given to oldest leaves from the newest twig in order to select leaves of similar age and exposure time. The leaves were brought to laboratory of Department of Environmental Science, Mizoram University. Leaves were dried at 35 °C and recorded the dried weight; samples were prepared for magnetic analysis, which involved packing the dried leaves into 10–cc plastic sample pots.

**Table 1**

<table>
<thead>
<tr>
<th>Study period</th>
<th>Temperature</th>
<th>Rainfall</th>
<th>Humidity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maximum °C</td>
<td>Minimum °C</td>
<td>(mm)</td>
</tr>
<tr>
<td>September, 2012</td>
<td>27.93</td>
<td>20.34</td>
<td>10.32</td>
</tr>
<tr>
<td>October, 2012</td>
<td>27.77</td>
<td>19.12</td>
<td>11.14</td>
</tr>
<tr>
<td>November, 2012</td>
<td>26.96</td>
<td>15.23</td>
<td>0</td>
</tr>
<tr>
<td>December, 2012</td>
<td>24.61</td>
<td>13.44</td>
<td>0</td>
</tr>
<tr>
<td>Average</td>
<td>26.81</td>
<td>17.03</td>
<td>5.36</td>
</tr>
</tbody>
</table>

The magnetic parameters such as Magnetic susceptibility (χ), Anhysteretic remanet magnetisation (ARM) and Saturation isothermal remanent magnetisation (SIRM) were carried out 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 magnetic susceptibility reflects the total composition of the dust deposited on the leaves, with a prevailing contribution from ferromagnetic minerals, which have much higher susceptibility values than paramagnetic and diamagnetic minerals, such as, clay or quartz. A Bartington (Oxford, England) MS-2B dual frequency susceptibility meter was used and measurements were taken. The sensitivity of this instrument was in the range of 10⁻⁶.

ARM indicates the magnetic concentration and is also sensitive to the presence of fine grains ~ 0.04 – 1 μm. Thus, falling within the respirable size range of PM2.5 and having the potential to have a high burden of toxicity. 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.

SIRM indicates the total concentration of magnetic grains and can be used as a proxy of PM concentration. SIRM involves measuring the magnetic remanence of samples once removed from an induced field. Using a Molspin Pulse Magnetiser, a saturation isothermal remanent magnetisation (SIRM) of 800 mT in the forward field was induced in the samples. At this high magnetisation field, all magnetic grains within the sample become magnetised. The instruments used for ARM and SIRM were fully automated.
The ratio of IRM-300 and SIRM was defined as the S-ratio\(^{51}\). The S-ratio 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\(^{52}\).

**Suspected particulate matter (SPM) and respirable suspended particulate matter (RSPM) monitoring:** Sampling was done using ‘High Volume Sampler’ (Envirotech APM 460) eight hour daily for SPM and RSPM in the months of September-December, 2012 with a frequency of once in a week. SPM in the atmosphere was determined using high volume method and RSPM in the ambient air was determined using the cyclonic flow technique.

**Heavy metal (Fe):** Pertaining to Fe analysis leaf samples of selected plants were oven dried at 80°C for 48 hours and digested with aqua-regia and analysed with Atomic Absorption Spectrophotometer (AAS).

**Statistical analysis:** Correlation coefficient values were calculated at each site using SPSS software (SPSS Inc., version 10.0) to evaluate the relationship between PM and magnetic properties of selected tree leaves, in order to assess this method as a proxy for particulate pollution and the suitability of leaves as depositories of particulate pollution.

**Results and Discussion**

The ambient PM concentration recorded at spatially distant sites is shown in table 2. The ambient PM concentrations were recorded highest at Ramrikawn, followed by Zarkawt and Durtlang, while lowest values were recorded for MZU campus. The average magnetic data collected throughout the 4-month sampling period is presented in tables 3, 4 and 5, respectively for *Bougainvillea spectabilis*, *Cassia fistula* and *Lantana camara* tree leaves.

**Table-2**

<table>
<thead>
<tr>
<th>Sampling location</th>
<th>SPM (µg m(^{-3}))</th>
<th>RSPM (µg m(^{-3}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Durtlang</td>
<td>199.04</td>
<td>172.71</td>
</tr>
<tr>
<td>Zarkawt</td>
<td>219.13</td>
<td>190.09</td>
</tr>
<tr>
<td>Ramrikawn</td>
<td>250.07</td>
<td>220.12</td>
</tr>
<tr>
<td>MZU Campus</td>
<td>130.12</td>
<td>100.09</td>
</tr>
</tbody>
</table>

**Table-3**

<table>
<thead>
<tr>
<th>Site</th>
<th>(\chi_{\chi}) (10(^{-7}) m(^{3})kg(^{-1}))</th>
<th>ARM (10(^{5})Am(^{2})kg(^{-1}))</th>
<th>SIRM (10(^{5}) Am(^{2})kg(^{-1}))</th>
<th>ARM/(\chi_{\chi})</th>
<th>SIRM/(\chi_{\chi})</th>
<th>S-ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Durtlang</td>
<td>15.12 ± 0.31</td>
<td>14.22 ± 0.44</td>
<td>188.24 ± 0.35</td>
<td>0.94</td>
<td>12.44</td>
<td>0.912</td>
</tr>
<tr>
<td>Zarkawt</td>
<td>22.21 ± 0.51</td>
<td>19.12 ± 0.81</td>
<td>248.11 ± 0.12</td>
<td>0.86</td>
<td>11.17</td>
<td>0.921</td>
</tr>
<tr>
<td>Ramrikawn</td>
<td>24.42 ± 0.31</td>
<td>23.72 ± 0.22</td>
<td>281.43 ± 0.18</td>
<td>0.97</td>
<td>11.52</td>
<td>0.931</td>
</tr>
<tr>
<td>MZU Campus</td>
<td>12.33 ± 0.11</td>
<td>10.38 ± 0.11</td>
<td>141.33 ± 0.21</td>
<td>0.84</td>
<td>11.46</td>
<td>0.867</td>
</tr>
</tbody>
</table>

**Table-4**

<table>
<thead>
<tr>
<th>Site</th>
<th>(\chi_{\chi}) (10(^{-7}) m(^{3})kg(^{-1}))</th>
<th>ARM (10(^{5})Am(^{2})kg(^{-1}))</th>
<th>SIRM (10(^{5}) Am(^{2})kg(^{-1}))</th>
<th>ARM/(\chi_{\chi})</th>
<th>SIRM/(\chi_{\chi})</th>
<th>S-ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Durtlang</td>
<td>14.19 ± 0.32</td>
<td>12.23 ± 0.17</td>
<td>167.57 ± 0.31</td>
<td>0.86</td>
<td>11.80</td>
<td>0.895</td>
</tr>
<tr>
<td>Zarkawt</td>
<td>21.14 ± 0.11</td>
<td>17.69 ± 0.22</td>
<td>232.09 ± 0.12</td>
<td>0.83</td>
<td>10.97</td>
<td>0.912</td>
</tr>
<tr>
<td>Ramrikawn</td>
<td>23.42 ± 0.14</td>
<td>22.32 ± 0.36</td>
<td>277.41 ± 0.41</td>
<td>0.95</td>
<td>11.84</td>
<td>0.941</td>
</tr>
<tr>
<td>MZU Campus</td>
<td>11.13 ± 0.02</td>
<td>09.18 ± 0.19</td>
<td>133.76 ± 0.29</td>
<td>0.82</td>
<td>12.01</td>
<td>0.881</td>
</tr>
</tbody>
</table>

**Table-5**

<table>
<thead>
<tr>
<th>Site</th>
<th>(\chi_{\chi}) (10(^{-7}) m(^{3})kg(^{-1}))</th>
<th>ARM (10(^{5})Am(^{2})kg(^{-1}))</th>
<th>SIRM (10(^{5}) Am(^{2})kg(^{-1}))</th>
<th>ARM/(\chi_{\chi})</th>
<th>SIRM/(\chi_{\chi})</th>
<th>S-ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Durtlang</td>
<td>14.03 ± 0.11</td>
<td>12.56 ± 0.41</td>
<td>153.42 ± 0.71</td>
<td>0.89</td>
<td>10.93</td>
<td>0.891</td>
</tr>
<tr>
<td>Zarkawt</td>
<td>20.75 ± 0.18</td>
<td>20.05 ± 0.08</td>
<td>244.31 ± 0.12</td>
<td>0.96</td>
<td>11.77</td>
<td>0.931</td>
</tr>
<tr>
<td>Ramrikawn</td>
<td>23.21 ± 0.08</td>
<td>22.01 ± 0.17</td>
<td>271.51 ± 0.29</td>
<td>0.94</td>
<td>11.69</td>
<td>0.944</td>
</tr>
<tr>
<td>MZU Campus</td>
<td>11.48 ± 0.16</td>
<td>10.03 ± 0.22</td>
<td>119.55 ± 0.11</td>
<td>0.87</td>
<td>10.41</td>
<td>0.861</td>
</tr>
</tbody>
</table>
In Durtlang, it was found that the magnetic susceptibility (χ) value of *Bougainvillea spectabilis* is 15.12±0.31 (10⁻⁷ m³ kg⁻¹), ARM is 14.22±0.44 (10⁻⁵ Am² kg⁻¹) and SIRM is 188.24±0.35 (10⁻⁶ Am² kg⁻¹). Similarly, *Cassia fistula* has got the value of 14.19±0.32 (10⁻⁷ m³ kg⁻¹) for magnetic susceptibility (χ), 12.23±0.17 (10⁻⁵ Am² kg⁻¹) for ARM and 167.57±0.31 (10⁻⁶ Am² kg⁻¹) for SIRM. And the magnetic susceptibility (χ), ARM and SIRM values were 14.03 ± 0.11 (10⁻⁷ m³ kg⁻¹), 12.56 ± 0.41 (10⁻⁵ Am² kg⁻¹) and 153.42 ± 0.71 (10⁻⁶ Am² kg⁻¹) respectively for *Lantana camara*.

In Zarkawt, the magnetic susceptibility (χ), ARM and SIRM values are 22.21±0.51 (10⁻⁷ m³ kg⁻¹), 19.12±0.81 (10⁻⁵ Am² kg⁻¹) and SIRM 248.11±0.12 (10⁻⁵ Am² kg⁻¹) respectively for *Bougainvillea spectabilis*. For *Cassia fistula* magnetic susceptibility (χ) value is 21.14±0.11 (10⁻⁷ m³ kg⁻¹), ARM value is 17.69±0.22 (10⁻⁵ Am² kg⁻¹) and SIRM value is 232.09±0.12 (10⁻⁵ Am² kg⁻¹). And the magnetic susceptibility (χ), ARM and SIRM values were 20.75 ± 0.18 (10⁻⁷ m³ kg⁻¹), 20.05 ± 0.08 (10⁻⁵ Am² kg⁻¹) and 244.31 ± 0.12 (10⁻⁶ Am² kg⁻¹) respectively for *Lantana camara*.

In Ramrikawn, it was found that the magnetic susceptibility (χ) value of *Bougainvillea spectabilis* is 24.42±0.31 (10⁻⁷ m³ kg⁻¹), ARM is 23.72±0.22 (10⁻⁵ Am² kg⁻¹) and SIRM is 281.43±0.18 (10⁻⁵ Am² kg⁻¹). Similarly, *Cassia fistula* has got the value of 23.42±0.14 (10⁻⁷ m³ kg⁻¹) for magnetic susceptibility (χ), 22.32±0.36 (10⁻⁵ Am² kg⁻¹) for ARM and 277.41±0.41(10⁻⁵ Am² kg⁻¹) for SIRM. And the magnetic susceptibility (χ), ARM and SIRM values were 23.21 ± 0.08 (10⁻⁷ m³ kg⁻¹), 22.01 ± 0.17 (10⁻⁵ Am² kg⁻¹) and 271.51 ± 0.29 (10⁻⁶ Am² kg⁻¹) respectively for *Lantana camara*.

In MZU campus, the magnetic susceptibility (χ), ARM and SIRM values are 12.33±0.11 (10⁻⁷ m³ kg⁻¹), 10.38±0.11(10⁻⁵ Am² kg⁻¹) and 141.33±0.21(10⁻⁵ Am² kg⁻¹) respectively for *Bougainvillea spectabilis*. For *Cassia fistula* magnetic susceptibility (χ) value is 11.13±0.02 (10⁻⁷ m³ kg⁻¹), ARM value is 09.18±0.19 (10⁻⁵ Am² kg⁻¹) and SIRM value is 133.76±0.29 (10⁻⁵ Am² kg⁻¹). And the magnetic susceptibility (χ), ARM and SIRM values were 11.48 ± 0.16 (10⁻⁷ m³ kg⁻¹), 10.03 ± 0.22 (10⁻⁵ Am² kg⁻¹) and 119.55 ± 0.11 (10⁻⁶ Am² kg⁻¹) respectively for *Lantana camara*. Several researches revealed that magnetic susceptibility may be used as a proxy to monitor the regional distribution of air PM pollution. The values of ARM/χ and SIRM/χ can reflect the grain size of magnetic minerals. From the study it was observed that ARM/χ and SIRM/χ values are low at all study sites (table 3, 4 and table 5). Low values of ARM/χ and SIRM/χ indicate relatively large grain size magnetic particles in leaf samples. S-ratio of leaf samples ranges from 0.861 to 0.944 (table 3, 4 and 5), with an average of 0.907, which means that these leaf samples are dominated by ‘soft’ magnetic minerals with a low coercive force, but a minor part of ‘hard’ magnetic minerals with a relatively high coercive force also exists.

From the findings recorded in table 3, 4 and 5 we can infer the magnetic values for all plants species display similar trends, with Ramrikawn representing highest, while MZU campus representing the lowest concentration data. Further, results indicates that Ramrikawn and Zarkawt experiences the highest deposition of magnetic grains, originating from PM.χ, ARM and SIRM values were high for *Bougainvillea spectabilis* when compared with *Cassia fistula* and *Lantana camara*. However, spatial trends of all the three magnetic parameters displayed similar trend with Ramrikawn, having maximum value and MZU campus recording lowest value. The correlation coefficients indicated significant relationship between the concentration of PM and magnetic measurement of the three roadside plant leaves (table 6, 7 and 8). In literature, Hanserd et al. also studied atmospheric particle pollution emitted by a combustion plant with tree leaves, and found that SIRM of leaf samples had a significant correlation with PM10 collected by a particle collector. Hu et al. also observed significant correlation of magnetic parameters (magnetic susceptibility, ARM and SIRM) with air pollutants particularly heavy metals. Further, Kardel et al. also recorded significant correlation between leaf SIRM and ambient PM concentration. In India also several researches demonstrated significant correlation between magnetic parameter and PM.

### Table 6

<table>
<thead>
<tr>
<th>Magnetic parameter</th>
<th>SPM (R²)</th>
<th>RSPM (R²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>χ</td>
<td>0.843</td>
<td>0.820</td>
</tr>
<tr>
<td>ARM</td>
<td>0.904</td>
<td>0.883</td>
</tr>
<tr>
<td>SIRM</td>
<td>0.922</td>
<td>0.904</td>
</tr>
</tbody>
</table>

### Table 7

<table>
<thead>
<tr>
<th>Magnetic parameter</th>
<th>SPM (R²)</th>
<th>RSPM (R²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>χ</td>
<td>0.856</td>
<td>0.834</td>
</tr>
<tr>
<td>ARM</td>
<td>0.867</td>
<td>0.843</td>
</tr>
<tr>
<td>SIRM</td>
<td>0.869</td>
<td>0.845</td>
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</table>

### Table 8

<table>
<thead>
<tr>
<th>Magnetic parameter</th>
<th>SPM (R²)</th>
<th>RSPM (R²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>χ</td>
<td>0.840</td>
<td>0.816</td>
</tr>
<tr>
<td>ARM</td>
<td>0.824</td>
<td>0.800</td>
</tr>
<tr>
<td>SIRM</td>
<td>0.836</td>
<td>0.813</td>
</tr>
</tbody>
</table>
The average magnetic concentration data (table 3, 4 and table 5) demonstrates that the accumulation of PM on tree leaves varies across the four locations. The results suggest that Ramrikawn and Zarkawt experiences the heaviest loads of particulates in comparison to the low-depositions sites Durtlang and MZU campus. This suggests that localized conditions like environmental, metrological or anthropogenic may be influencing or disturbing particulate deposition or it may reflect differences in the ability of leaf species to capture particulates. Ramrikawn recorded the highest values of magnetic parameters which may be attributed to heavy vehicles load (due to location of food corporation of India), street dust and dust from fragile rocks. Zarkawt and Durtlang may have vehicular pollution as only source of PM while MZU campus, being an Institutional area is relatively free from vehicular pollution and other anthropogenic activities.

Significant correlation coefficients have been recorded between PM and magnetic parameters of plant leaves which indicated that roadside dust comprised of magnetic particles (table 6,7 and 8). It was also observed that all magnetic parameters were showing significant correlation with Fe (table 9). Sant’Ovaia et al. also demonstrated positive significant correlation of magnetic parameters (magnetic susceptibility and SIRM) with Fe. The observations indicated that magnetic properties of dust loaded particles act as a proxy for ambient PM pollution levels.

### Table-9
Concentration of Fe (mg kg⁻¹) with standard deviation (S.D) of the leaf samples

<table>
<thead>
<tr>
<th>Sampling site</th>
<th>Bougainvillea spectabilis</th>
<th>Cassia fistula</th>
<th>Lantana camara</th>
</tr>
</thead>
<tbody>
<tr>
<td>Durtlang</td>
<td>14.95 ± 0.32</td>
<td>13.41 ± 0.09</td>
<td>12.77 ± 0.32</td>
</tr>
<tr>
<td>Zarkawt</td>
<td>16.01 ± 0.11</td>
<td>14.51 ± 0.34</td>
<td>14.46 ± 0.12</td>
</tr>
<tr>
<td>Ramrikawn</td>
<td>17.54 ± 0.31</td>
<td>16.72 ± 0.21</td>
<td>14.32 ± 0.46</td>
</tr>
<tr>
<td>MZU Campus</td>
<td>12.81 ± 0.27</td>
<td>10.17 ± 0.72</td>
<td>10.23 ± 0.22</td>
</tr>
</tbody>
</table>

### Conclusion

Biomagnetic monitoring has received attention in the field of PM pollution science because it is an inexpensive tool and also provides an alternative proxy method to conventional air pollution monitoring. According to our preliminary results from the study on tree leaves in Aizawl city, we can conclude that; i. Magnetic properties of tree leaves change significantly in different functional areas. Magnetic concentration data suggest that the deposition of PM on tree leaves varies due to different traffic behaviour between sites and due to other activities like soil erosion, mining and stone quarrying etc. ii. The magnetic properties of tree leaves in Aizawl city revealed that the magnetic fraction of dust is dominated by multidomain magnetite-like ferromagnetic particles. iii. Magnetic survey of tree leaves is recommended as an innovative tool in the field of PM pollution.

### Acknowledgements

Authors are thankful to the Department of Biotechnology (DBT) and Department of Science and Technology (DST), for providing financial assistance in the form of research project (vide project no. BT/PR-11889/BCE/08/730/2009 and SR/FTP/ES-83/2009, respectively).

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