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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 (χ), 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 (χ, ARM and SIRM) of the selected roadside plant leaves. Similarly, significant correlations between magnetic parameters (χ, 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 (χ, 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, they are widely used in environmental studies. Plants leaves were proved to be good collector of PM[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[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[8]. 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[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[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[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[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[4,18]. Further, urban trees and shrubs planted in street canyons and along road side proved to be effective dust capturing tools[1,2,17]. Spreading widely in urban area and easily collected, tree leaves could improve the scanning resolution in the spatial scale[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[21]. Therefore, urban angiosperm trees offer positive biological, ecological and aerodynamic effects in comparison to lower group of plants[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[23-30] and vegetation samples[2,31], however, scanty researches have emphasized the use of plant leaves in monitoring the dust or PM[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 (21^0 56’- $24^0$31’N and 92^0 16’- $93^0$26’E) is one of the eight states under northeast India (figure 1), and it covers an area of 21,081 km^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[42]. Aizawl district comes under Indo-Burma hotspot region of North East India[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 ($21^0$58’- $21^0$85’ N and $90^0$30’- $90^0$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 30^0 C in summer and 11 to 21^0C in winter[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.

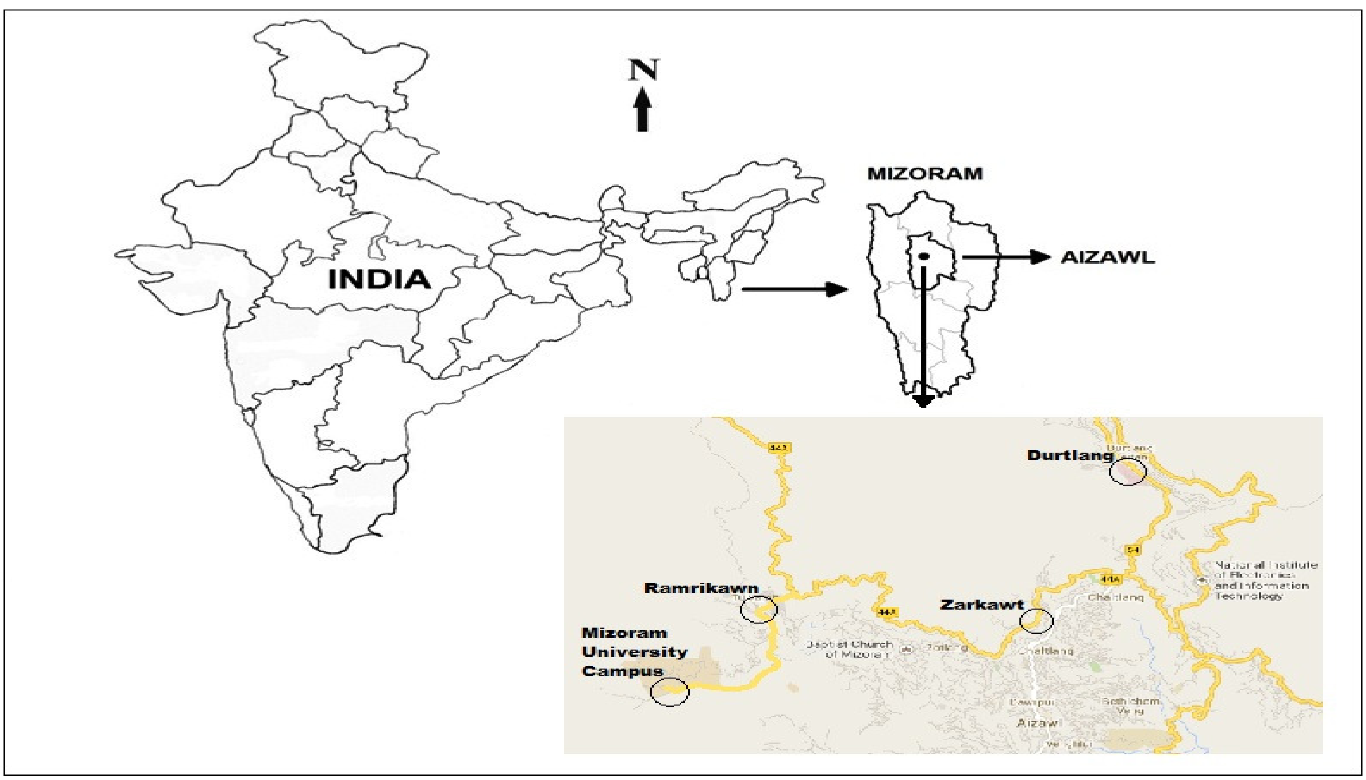

Figure-1
Map of the Study Area, Aizawl, Mizoram, North East India

Table-1
Meteorological data of the study area i.e. Aizawl, Mizoram

Study period	Temperature		Rainfall (mm)	Humidity (%)
	Maximum ^{0}C	Minimum ^{0}C		
September, 2012	27.93	20.34	10.32	90.22
October, 2012	27.77	19.12	11.14	82.32
November, 2012	26.96	15.23	0	69.54
December, 2012	24.61	13.44	0	67.19
Average	**26.81**	**17.03**	**5.36**	**77.31**

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 movement of heavy duty vehicles coming from all parts of India through National highway of Pushpak (NH-54). As there is a public bus and taxi stand, vehicular movement is usually high in Ramrikawn area. Stone quarrying activity is also found in this area which leads to emission of dust particles. Biomass burning through shifting cultivation is very common in this region [43,44] and may also be a source of suspended particulate matter pollution. In view of these pollution sources we selected Ramrikawn as polluted area for investigation. Site 4. Mizoram University Campus (MZU): MZU campus is an institutional area. Vehicles including bus, taxi, truck etc. are the main source of pollution in MZU campus. University buses, taxis, trucks or trollies 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. In our recent research[17] we recorded maximum dust deposition during winter season, so we took winter season for our study purpose.

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[17,22]. 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 ºC and recorded the dried weight; samples were prepared for magnetic analysis, which involved packing the dried leaves into 10 –cc plastic sample pots[46].

Magnetic parameters: The magnetic parameters such as Magnetic susceptibility (χ), Anhysteretic remanent 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[21,46,47] . A Bartington (Oxford, England) MS-2B dual frequency susceptibility meter was used[48] 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[49]. Thus, falling within the respirable size range of PM2.5 and having the potential to have a high burden of toxicity[6]. 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[46].

SIRM indicates the total concentration of magnetic grains[47] and can be used as a proxy of PM concentration[50]. 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[6]. 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].

Suspended 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 showing the average Suspended Particulate Matter (SPM) and Respirable Particulate Matter (RSPM) recorded from different sites during the study period

Sampling location	SPM (μg m^{-3})	RSPM (μg m^{-3})
Durtlang	199.04	172.71
Zarkawt	219.13	190.09
Ramrikawn	250.07	220.12
MZU Campus	130.12	100.09

Table-3
Summary of the magnetic data (mean and standard deviation) for roadside dusts on *Bougainvillea spectabilis* tree leaves in the different sampling sites

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

Table-4
Summary of the magnetic data (mean and standard deviation) for roadside dusts on *Cassia fistula* tree leaves in the different sampling sites

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

Table-5
Summary of the magnetic data (mean and standard deviation) for roadside dusts on *Lantana camara* tree leaves in the different sampling sites

Site	χ (10^{-7} m^3 kg^{-1})	ARM (10^{-5} Am^2 kg^{-1})	SIRM (10^{-5} Am^2 kg^{-1})	ARM/ χ (10^2Am^{-1})	SIRM/ χ (10^2Am^{-1})	S-ratio
Durtlang	14.03 ± 0.11	12.56 ± 0.41	153.42± 0.71	0.89	10.93	0.891
Zarkawt	20.75 ± 0.18	20.05 ± 0.08	244.31 ± 0.12	0.96	11.77	0.931
Ramrikawn	23.21 ± 0.08	22.01 ± 0.17	271.51± 0.29	0.94	11.69	0.944
MZU Campus	11.48 ± 0.16	10.03 ± 0.22	119.55 ± 0.11	0.87	10.41	0.861

In Durtlang, it was found that the magnetic susceptibility (χ) value of *Bougainvillea spectabilis* is 15.12±0.31 (10^{-7} m^3 kg^{-1}), ARM is 14.22±0.44 (10^{-5} Am^2 kg^{-1}) and SIRM is 188.24±0.35 (10^{-5} Am^2 kg^{-1}). Similarly *Cassia fistula* has got the value of 14.19±0.32 (10^{-7} m^3 kg^{-1}) for magnetic susceptibility (χ), 12.23±0.17 (10^{-5} Am^2 kg^{-1}) for ARM and 167.57±0.31 (10^{-5} Am^2 kg^{-1}) for SIRM. And the magnetic susceptibility (χ), ARM and SIRM values were 14.03 ± 0.11 (10^{-7} m^3 kg^{-1}), 12.56 ± 0.41 (10^{-5} Am^2 kg^{-1}) and 153.42 ± 0.71 (10^{-5} Am^2 kg^{-1}) respectively for *Lantana camara.*

In Zarkawt, the magnetic susceptibility (χ), ARM and SIRM values are 22.21±0.51 (10^{-7} m^3 kg^{-1}), 19.12±0.81 (10^{-5} Am^2 kg^{-1}) and SIRM 248.11±0.12 (10^{-5} Am^2 kg^{-1}) respectively for *Bougainvillea spectabilis*. For *Cassia fistula* magnetic susceptibility (χ) value is 21.14±0.11 (10^{-7} m^3 kg^{-1}), ARM value is 17.69±0.22 (10^{-5} Am^2 kg^{-1}) and SIRM value is 232.09±0.12 (10^{-5} Am^2 kg^{-1})**.** And the magnetic susceptibility (χ), ARM and SIRM values were 20.75 ± 0.18 (10^{-7} m^3 kg^{-1}), 20.05 ± 0.08 (10^{-5} Am^2 kg^{-1}) and 244.31 ± 0.12 (10^{-5} Am^2 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} m^3 kg^{-1}), ARM is 23.72±0.22 (10^{-5} Am^2 kg^{-1}) and SIRM is 281.43±0.18 (10^{-5} Am^2 kg^{-1}). Similarly *Cassia fistula* has got the value of 23.42±0.14 (10^{-7} m^3 kg^{-1}) for magnetic susceptibility (χ), 22.32±0.36 (10^{-5} Am^2 kg^{-1}) for ARM and 277.41± 0.41(10^{-5} Am^2 kg^{-1}) for SIRM. And the magnetic susceptibility (χ), ARM and SIRM values were 23.21 ± 0.08 (10^{-7} m^3 kg^{-1}), 22.01 ± 0.17 (10^{-5} Am^2 kg^{-1}) and 271.51 ± 0.29 (10^{-5} Am^2 kg^{-1}) respectively for *Lantana camara.*

In MZU campus, the magnetic susceptibility (χ), ARM and SIRM values are 12.33±0.11 (10^{-7} m^3kg^{-1}), 10.38±0.11(10^{-5} Am^2kg^{-1}) and 141.33±0.21(10^{-5} Am^2kg^{-1}) respectively for *Bougainvillea spectabilis*. For *Cassia fistula* magnetic susceptibility (χ) value is 11.13±0.02 (10^{-7} m^3 kg^{-1}), ARM value is 09.18±0.19 (10^{-5} Am^2 kg^{-1}) and SIRM value is 133.76±0.29 (10^{-5} Am^2 kg^{-1}). And the magnetic susceptibility (χ), ARM and SIRM values were 11.48 ± 0.16 (10^{-7} m^3 kg^{-1}), 10.03 ± 0.22 (10^{-5} Am^2 kg^{-1}) and 119.55 ± 0.11 (10^{-5} Am^2 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[1,21,40].

The values of ARM/χ and SIRM/χ can reflect the grain size of magnetic minerals[47,49]. 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 [3]. 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[53].

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, Hansard et al[41] 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[54] also observed significant correlation of magnetic parameters (magnetic susceptibility, ARM and SIRM) with air pollutants particularly heavy metals. Further, Kardel et al[36] also recorded significant correlation between leaf SIRM and ambient PM concentration. In India also several researches demonstrated significant correlation between magnetic parameter and PM[33,37].

Table-6
Correlation between magnetic measurements (*Bougainvillea spectabilis)* with SPM and RSPM

Magnetic parameter	SPM (R^2)	RSPM (R^2)
χ	0.843	0.820
ARM	0.904	0.883
SIRM	0.922	0.904

Table-7
Correlation between magnetic measurements (*Cassia fistula)* with SPM and RSPM

Magnetic parameter	SPM (R^2)	RSPM (R^2)
χ	0.856	0.834
ARM	0.867	0.843
SIRM	0.869	0.845

Table-8
Correlation between magnetic measurements (*Lantana camara)* with SPM and RSPM

Magnetic parameter	SPM (R^2)	RSPM (R^2)
χ	0.840	0.816
ARM	0.824	0.800
SIRM	0.836	0.813

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[6]. 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[21] 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

Mean concentration of Fe (mg kg^{-1}) ± S.D			
Sampling site	***Bougainvillea spectabilis***	***Cassia fistula***	***Lantana camara***
Durtlang	14.95 ± 0.32	13.41± 0.09	12.77 ± 0.32
Zarkawt	16.01 ± 0.11	14.51 ± 0.34	14.46 ± 0.12
Ramrikawn	17.54 ± 0.31	16.72 ± 0.21	14.32 ± 0.46
MZU Campus	12.81 ± 0.27	10.17 ± 0.72	10.23 ± 0.22

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.

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References

1. Moreno E., Sagnotti L., Dinare_s-Turell J., Winkler A. and Cascella A., Biomonitoring of traffic air pollution in Rome using magnetic properties of tree leaves, *Atmospheric Environment,* **37**, 2967-2977 **(2003)**
2. Urbat M., Lehndorff E. and Schwark L., Biomonitoring of air quality in the Cologne conurbation using pine needles as a passive samplerdpart 1: magnetic properties, *Atmospheric Environment,* **38**, 3781-3792 **(2004)**
3. Yin G., Hu S., Cao L., Roesler W. and Appel E., Magnetic properties of tree leaves and their significance in atmospheric particle pollution in Linfen city, China, *Chinese Geographical Science,* **23(1)**, 59-72 **(2013)**
4. Rai P.K., Environmental magnetic studies of particulates with special reference to biomagnetic monitoring using roadside plant leaves, *Atmospheric Environment*,7**2**, 113-129 **(2013)**
5. Walden J., Sample collection and preparation, In J. Walden, F. Oldfield & J. P. Smith (Eds.), Environmental magnetism: a practical guide. Technical guide no. 6 (pp: 26-34). Cambridge, England: Quaternary Research Association **(1999)**
6. Power A.L., Worsley A.T. and Booth C., Magneto-biomonitoring of intra-urban spatial variations of particulate matter using tree leaves, *Environ Geochem Health*, **31**, 315-325 **(2009)**
7. Maher B.A. and Matzka J., Magnetic biomonitoring of roadside tree leaves; identification of spatial and temporal variation in vehicle derived particulates, *Atmospheric Environment*, **33**, 4565-4569 **(1999)**
8. Bucko M.S., Magiera T., Johanson B., Petrovsky E. and Pesonen L.J., Identification of magnetic particulates in road dust accumulated on roadside snow using magnetic, geochemical and micro-morphological analysis, *Environmental Pollution*, **159**, 1266-1276 **(2011)**
9. Le Tertre A., Medina S., Samoli E., Forsberg B., Michelozzi P. and Boumghar A., Short-term effects of particulate air pollution on cardiovascular diseases in eight European cities, *Journal of Epidemiology and Community Health,* **56**, 773-779 **(2002)**

10. Janssen N.A.H., Lanki T., Hoek G., Vallius M., De Hartog J.J. and Van Grieken R., Associations between ambient, personal and indoor exposure to fine particulate matter constituents in Dutch and Finnish panels of cardiovascular patients, *Occupational and Environmental Medicine*, **62**, 868-877 **(2005)**

11. Jerrett M., Buzzelli M., Burnett R.T. and DeLuca P.F., Particulate air pollution, social confounders, and mortality in small areas of an industrial city, *Social Science and Medicine*, **60**, 2845-2863 **(2005)**

12. Rai P.K., Dust deposition capacity of certain roadside plants in Aizawl, Mizoram: Implications for environmental geomagnetic studies, In: Recent Advances in Civil Engineering S.B. Dwivedi et al. (Eds), 66-73 **(2011a)**

13. Rai P.K., Biomonitoring of particulates through magnetic properties of road-side plant leaves, In: Advances in Environmental Chemistry D. Tiwari (Ed.), Excel India Publishers, New Delhi, 34-37 **(2011b)**

14. Morawska L. and Zhang J., Combustion sources of particles. 1. Health relevance and source signatures, *Chemosphere*, **49**, 1045-1058 **(2002)**

15. Englert N., Fine particles and human health—a review of epidemiological studies, *Toxicology Letters*, **149**, 235-242 **(2004)**

16. Sharma K., Singh R., Barman S.C., Mishra D., Kumar R., Negi M.P.S., Mandal S.K., Kisku G.C., Khan A.H., Kidwai M.M. and Bhargava S.K., Comparison of trace metals concentration in PM_{10} of different location of Lucknow city, India, *Bulletin of Environmental Contamination and Toxicology*, **77**, 419-426 **(2006)**

17. Rai P.K. and Panda L.S., Dust capturing potential and air pollution tolerance index (APTI) of some road side tree vegetation in Aizawl, Mizoram, India: an Indo-Burma hot spot region, *Air Qual Atmos Health*, **7(1)**, 193-101 **(2014)**

18. Faiz Y., Tufail M., Javed M.T., Chaudhry M.M. and Siddique N., Road dust pollution of Cd, Cu, Ni, Pb and Zn along Islamabad Expressway, Pakistan, *Microchemical Journal*, **92**, 186-192 **(2009)**

19. Mitchell R., Maher B.A. and Kinnersley R., Rates of particulate pollution deposition onto leaf surfaces: Temporal and interspecies magnetic analyses, *Environmental Pollution*, **158(5)**, 1472-1478 **(2010)**

20. Gang Y., Shouyun Hu Liwan C., Wolfgang R. and Erwin A., Magnetic properties of tree leaves and their significance in atmospheric particle pollution in Linfen City, China, *Chinese Geographical Science*, **23(1)**, 59-72 **(2013)**

21. Sant'Ovaia H., Lacerda M.J. and Gomes C., Particle pollution - An environmental magnetism study using biocollectors located in northern Portugal, *Atmospheric Environment*, **61**, 340-349 **(2012)**

22. Rai P.K., Panda L.S., Chutia B.M. and Singh M.M., Comparative assessment of air pollution tolerance index (APTI) in the industrial (Rourkela) and non industrial area (Aizawl) of India: An eco-management approach, *African Journal of Environmental Science and Technology*, **7(10)**, 944-948 **(2013)**

23. Hay K.L., Dearing J.A., Baban S.M.J. and Loveland P., A preliminary attempt to identify atmospherically derived pollution particles in English topsoils from magnetic susceptibility measurements, *Physics and Chemistry of the Earth*, **22**, 207-210 **(1997)**

24. Maher B.A., Magnetic properties of modern soils and Quaternary loessic paleosols: paleoclimatic implications, *Palaeogeography, Palaeoclimatology, Palaeoecology,* **137**, 25- 54 **(1998)**

25. Hoffmann V., Knab M. and Appel E., Magnetic susceptibility mapping of roadside pollution, *Journal of Geochemical Exploration*, **66**, 313-326 **(1999)**

26. Shu J., Dearing J., Morse A., Yu L. and Li C., Magnetic properties of daily sampled total suspended particulates in Shanghai, *Environmental Science and Technology*, **34**, 2393- 2400 **(2000)**

27. Xie S., Dearing J.A. and Bloemendal J., The organic matter content of street dust in Liverpool, UK, and its association with dust magnetic properties, *Atmospheric Environment*, **34**, 269-275 **(2000)**

28. Xie S., Dearing J.A., Boyle J.F., Bloemendal J. and Morse A.P., Association between magnetic properties and element concentrations of Liverpool street dust and its implications, *Journal of Applied Geophysics*, **48**, 83-92 **(2001)**

29. Jordanova N.V., Jordanova D.V., Veneva L., Yorova K. and Petrovsky E., Magnetic response of soils and vegetation to heavy metal pollution - a case study, *Environmental Science and Technology*, **37**, 4417-4424 **(2003)**

30. Hanesch M., Rantitsch G., Hemetsberger S. and Scholger R., Lithological and pedological influences on the magnetic susceptibility of soil: their consideration in magnetic pollution mapping, *Geophysical Journal International*, **382(23)**, 351-363 **(2007)**

31. Kletetschka G., Zila V. and Wasilewski P.J., Magnetic anomalies on the tree trunks, *Studia Geophysica et Geodaetica*, **47**, 371-379 **(2003)**

32. Matzka J. and Maher B.A., Magnetic biomonitoring of roadside tree leaves: identification of spatial and temporal variations in vehicle-derived particulates, *Atmospheric Environment*, **33**, 4565-4569 **(1999)**

33. Pandey S.K., Tripathi B.D., Prajapati S.K., Mishra V.K., Upadhyay A.R., Rai P.K. and Sharma A.P., Magnetic properties of vehicle derived particulates and amelioration by Ficus infectoria: a keystone species, *Ambio: A Journal on Human Environment*, **34(8)**, 645-647 **(2005)**

34. Maher B.A., Mooreb C. and Matzka J., Spatial variation in vehicle-derived metal pollution identified by magnetic and elemental analysis of roadside tree leaves, *Atmospheric Environment*, **42**, 364-373 **(2008)**

35. Maher B.A., Rain and Dust: Magnetic Records of Climate and Pollution, *Elements*, **5**, 229-234 **(2009)**

36. Kardel F., Wuyts K., Maher B.A., Hansard R. and Samson R., Leaf saturation isothermal remanent magnetization (SIRM) as a proxy for particulate matter monitoring: inter-species differences and in-season variation, *Atmospheric Environment*, **45**, 5164-5171 **(2011)**

37. Prajapati S.K., Pandey S.K. and Tripathi B.D., Magnetic biomonitoring of roadside tree leaves as a proxy of vehicular pollution, *Environmental Monitoring and Assessment*, **120**, 169-175 **(2006)**

38. Sharma A.P., Rai P.K. and Tripathi B.D., *Magnetic biomonitoring of roadside tree leaves as a proxy of vehicular pollution.* In: Lakshmi, Vyas (Ed.), Urban Planing and Environment: Strategies and Challenges, Mc Millan Advanced Research Series, 326-331 **(2007)**

39. Gautam P., Blaha U., Appel E. and Neupane G., Environmental magnetic approach towards the quantification of pollution in Kathmandu urban area, Nepal, *Physics and Chemistry of the Earth, Parts A/B/C*, **29 (13e14)**, 973-984 **(2004)**

40. Gautam P., Blaha U. and Appel E., Magnetic susceptibility of dust-loaded leaves as a proxy of traffic-related heavy metal pollution in Kathmandu city, Nepal, *Atmospheric Environment*, **39**, 2201-2211 **(2005)**

41. Hansard R., Maher B.A. and Kinnersley R., Biomagnetic monitoring of industry-derived particulate pollution, *Environmental Pollution*, **159(6)**, 1673-1681**(2011)**

42. Champion H. and Seth S.K., *A revised survey of forest types of India.* Government of India Press, Delhi **(1968)**

43. Rai P.K., Comparative Assessment of Soil Properties after Bamboo Flowering and Death in a Tropical Forest of Indo-Burma Hot spot, *Ambio: A Journal on Human Environment,* **38(2)**, 118-120 **(2009)**

44. Rai P.K., Assessment of Multifaceted Environmental Issues and Model Development of an Indo - Burma Hot Spot Region, *Environmental Monitoring and Assessment*, **184**,113-131 **(2012)**

45. Laltlanchhuang S.K., Studies of the impact of disturbance on secondary productivity of forest ecosystem with special reference to surface, sub-surface litter insect and other non-insect groups, M.Sc. dissertation. Mizoram University **(2006)**

46. Maher B.A. and Thompson R., Quaternary, Climates, Environments and Magnetism*,* Cambride University Press, 390 pp **(1999)**

47. Evans M.E. and Heller F., Environmental magnetism: principles and applications of enviromagnetics (International Geophysics), London: Academic Press. Elsevier, 299 **(2003)**

48. Dearing J., Magnetic susceptibility*,* In Walden, J., Oldfield, F. & Smith, J. P. (Eds.), Environmental magnetism: a practical guide. Technical guide no. 6 (35-62), Cambridge, England: Quaternary Research Association **(1999)**

49. Thompson R. and Oldfield F., Environmental magnetism*,* Allen and Unwin, London, 227 pp **(1986)**

50. Muxworthy A. R., Matzka J., Davila A.F. and Petersen N., Magnetic signature of daily sampled urban atmospheric particles, *Atmospheric Environment*, **37**, 4163-4169 **(2003)**

51. King J.W. and Channell J.E.T., Sedimentary magnetism, environmental magnetism and magnetostratigraphy, *Reviews of Geophysics*, **29**, 358-370 **(1991)**

52. Thompson R., Modelling magnetization data using SIMPLEX. Phys, *Earth planet. Inter*, **42**,113-127 **(1986)**

53. Robinson S.G., The late Pleistocene palaeoclimatic record of North Atlantic deep-sea sediments revealed by mineral-magnetic measurements, *Physics of the Earth and Planetary Interiors*, **42(1-2)**, 22-47**(1986)**

54. Hu S.Y., Duan X.M., Shen M.J., Blaha U., Roesler W., Yan H.T., Appel E. and Hoffmann V., Magnetic response to atmospheric heavy metal pollution recorded by dust-loaded leaves in Shougang industrial area, western Beijing, *Chinese Science Bulletin*, **53(10)**, 1555-1564 **(2008)**