Article

Biomagnetic monitoring of particulate matter (PM) through leaves of an invasive alien plant *Lantana camara* in an Indo-Burma hot spot region

Prabhat Kumar Rai, **BikuMoniChutia**

School of Earth Science & Natural Resource Management Mizoram Central University, Aizawl, India

E-mail: prabhatrai24@gmail.com

Received 17 September 2015; Accepted 25 October 2015; Published online 1 March 2016

Abstract

Present study was performed in urban forests of Aizawl, Mizoram, North East India falling under an Indo-Burma hot spot region of existing ecological relevance and pristine environment. Phyto-sociolology of invasive weeds has been performed and results revealed that *Lantana camara* was the most dominant invasive weed. Further, the air quality studies revealed high suspended particulate matter (SPM) as well as respirable suspended particulate matter (RSPM) in ambient air of Aizawl, Mizoram, North East India. Bio-magnetic monitoring through plant leaves has been recognised as recent thrust area in the field of particulate matter (PM) science. We aimed to investigate that whether magnetic properties of *Lantana camara* leaves may act as proxy of PM pollution and hence an attempt towards it's sustainable management. Magnetic susceptibility (χ), Anhyste reticremanent magnetization (ARM) and Saturation isothermal remanent magnetization (SIRM) of *Lantana camara* plant leaves were assessed and concomitantly correlated these magnetic properties with ambient PM in order to screen this invasive plant which may act as proxy for ambient PM concentrations. Results revealed high χ, ARM, SIRM of *Lantana camara* leaves and moreover, these parameters were having significant and positive correlation with ambient SPM as well as RSPM. Therefore, present study recommended the use of *Lantana camara* as bio-magnetic monitor which may further have sustainable management implications of an invasive plant.

Keywords invasion; bio-magnetic monitoring; sustainable management; Indo-Burma hot spot; human health; particulate matter.

Environmental Skeptics and Critics
ISSN 2224-4263
URL: http://www.iaees.org/publications/journals/environsc/online-version.asp
RSS: http://www.iaees.org/publications/journals/environsc/rss.xml
E-mail: environsc@iaees.org
Editor-in-Chief: WenJun Zhang
Publisher: International Academy of Ecology and Environmental Sciences

1 Introduction

Plant invasion is the priority threat to global biodiversity and hence deleterious to both ecology and economy of any nation. Invasive plants or weeds transmogrify the landscapes of urban forests and duly affect its phytosociology as well as diversity of native species in a complex intricate manner (Rai, 2013a). Various hypotheses have been proposed to understand the basic mechanism of succession in order to device sustainable management strategy, however, no one describe it in its totality (Rai, 2013b, 2015a, 2015b, 2015c, 2015d).

Lantana camara is an important weed of agro and forest ecosystems, where it forms dense thickets that livestock cannot penetrate (Lüi, 2011; Rai, 2015d). The leaves are toxic when ingested by most domestic livestock or native mammals, although toxicity varies greatly between strains (Goulson and Derwent, 2004). In Australia (Leigh and Briggs, 1992; Groves and Willis, 1999), like other countries, plant invasion has been associated with the extinction of several valuable endemic plant species like *Lantana camara* (Gooden et al., 2009).

Lantana camara is the dominant invasive species in many parts of Rajasthan resulting from landscape modernization (Robbins, 2001). Rai (2009a, 2013a, 2012a, 2015d) ecologically investigated *Lantana camara, Mikania micrantha, Ageratum conyzoides* in forests of an Indo-Burma hot spot region. In aquatic ecosystems of India several invasive plants like *Eichhornia crassipes* has been reported (Rai, 2008, 2009b, 2012a).

Lantana camara inspite of being an invasive species has got several advantages. Osunkoya and Perrett (2011) demonstrated that under *Lantana* infested soil, moisture, pH, Ca, total and organic C, and total N were significantly elevated, while sodium, chloride, copper, iron, sulfur, and manganese, many of which can be toxic to plant growth if present in excess levels, were present at lower levels in soils compared to soils lacking *L. camara*. *Lantana* has got many benefits also e.g. lantana addition improves soil hydraulic properties to the benefit of the wheat crop in a rice–wheat cropping sequence (Bhushan and Sharma, 2005; Rai, 2013a). Further, it may act on other invasives e.g. the growth of the aquatic weed *Eichhornia crassipes* and the alga *Microcystis aeruginosa* may be inhibited by fallen leaves of *Lantana camara* (Kong et al., 2006; Rai, 2013b). Fleshy-fruited invasive plants provide food that supports indigenous frugivore populations (Gosper and Vivian, 2006; Rai, 2013a) and Gosper and Vivian-Smith (2006) using *Lantana camara* as a target species suggested that using the fruit characteristics of the invasive plant may assist to select replacement indigenous plants that are functionally similar from the perspective of frugivores.

Pollination success in diverse habitats e.g. in the case of *Lantana camara, Ligustrum robustum, Mimosa pigra* through profuse nectar and prolonged flower production (Ghazoul, 2002) aid in their invasion success. As demonstrated in the case of *Lantana camara,* forest gap/canopy openness plays a major role in invasive spread therefore canopy intactness may be the one of the prime management strategy which is rather difficult to maintain (Totland et al., 2005; Rai, 2013a). Many invasive aquatic plants like *Eichhornia crassipes* and also terrestrial shrub *Lantana Camara* reported to be very good in heavy metal as well as particulate pollution phytoremediation (Rai, 2008; Rai, 2009a; Rai, 2012b; Rai and Panda, 2014). Thus, the utilization of invasive plants in pollution abatement phyto-technologies may assist in their sustainable management.

Unfortunately, urban ecosystems of ecologically sensitive regions like Indo-Burma hot spot are under severe air pollution stress (Rai, 2012a).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 (Rai et al., 2014; Rai, 2015b). Air pollution emanating from PM is particularly deleterious as they lead to various cardio-pulmonary diseases through oxidative stress (Rai, 2013a, Rai, 2015b).

Pertaining to bio-magnetic monitoring, it is worth to mention that initial researches demonstrated biogenic ferrimagnets be present in the organisms like termites (Maher, 1998) and bacteria (Fassbinder et al., 1990). However, it is now well established through cascade of researches that urban PM may also contain magnetic particles along with other air pollutants (Pandey et al., 2005; Maher, 2009; Rai, 2013a; Rai et al., 2014).

In the light of abovementioned, present study attempts to investigate the bio-magnetic monitoring potential of *Lantana camara* through magnetic measurements of plant leaves and concomitantly correlate these to ambient air quality (SPM and RSPM).

2 Materials and Methods

Mizoram is the site of particular ecological relevance as it falls under an Indo-Burma hot spot region (Fig. 1). In Mizoram, land use change through shifting cultivation is very frequent which may exacerbate the problem of biological invasions (Rai, 2012b). The phyto-sociological studies were performed at Aizawl, Mizoram, North East India during the month of November to December, 2013. It is worth to mention that sites were selected in accordance with varying disturbance intensity. To perform phyto-sociological studies quadrats of 10m×10m in size has been randomly used. Quantitative/phyto-sociological parameters such as % frequency, density, abundance and total basal cover of each species present in quadrats has been recorded and analysed as per the methods of Kershaw (1973) and Misra (1968).

Pertaining to air quality parameters, study was conducted quarterly i.e., summer, rainy, and winter during 2013 to 2014.

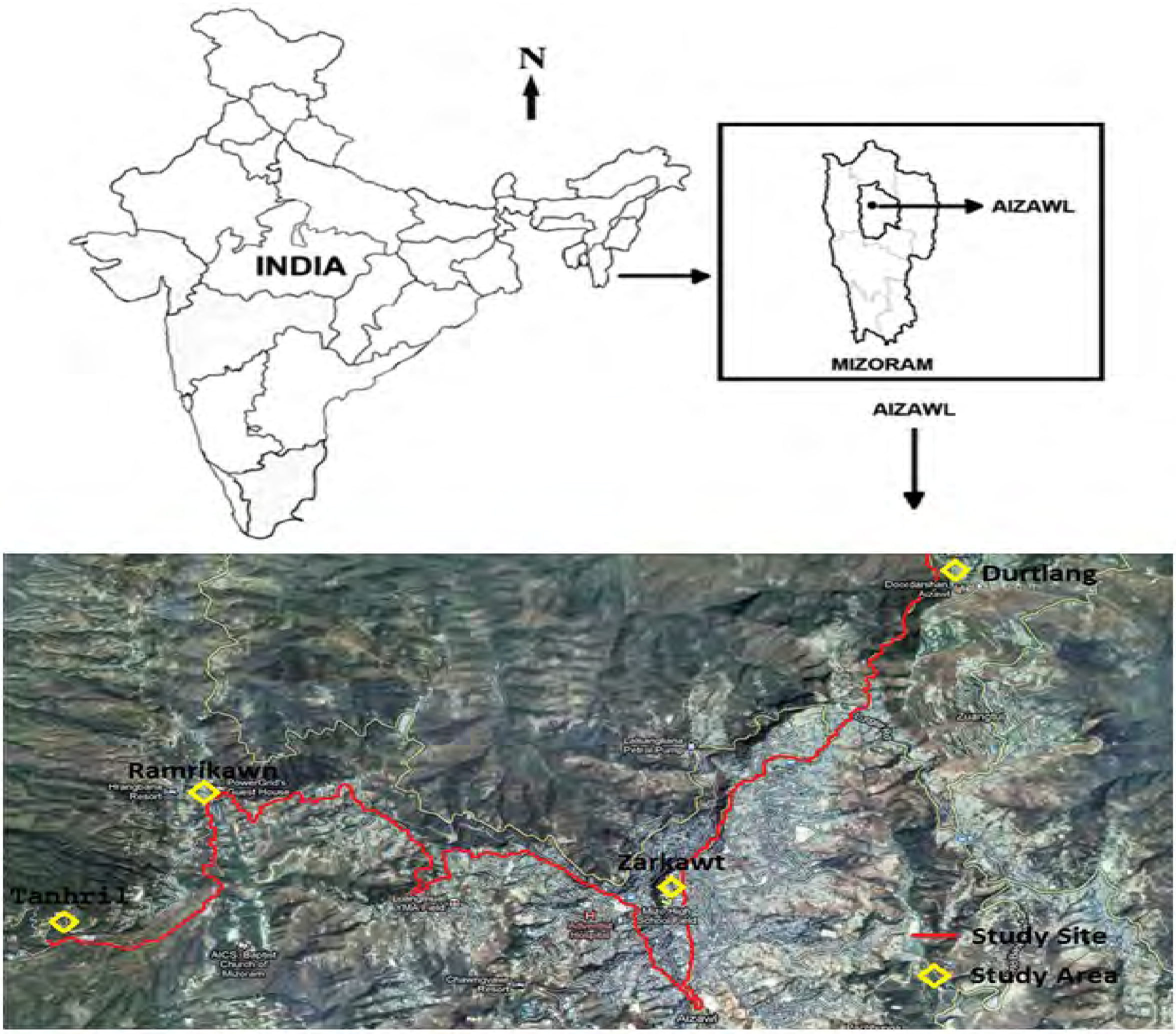

Fig. 1 Map of the study area, Aizawl, Mizoram, North East India.

2.1 Suspended particulate matter (SPM) and Respirable suspended particulate matter (RSPM)

Air pollutants such as suspended particulate matter (SPM) and respirable suspended particulate matter (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 to 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 m^3/min.

As mentioned earlier biomagnetic monitoring study was carried out in Aizawl district from four different sampling points (Fig. 1). Site1. Durtlang (Urban area); Site2. Zarkawt (Urban area); Site3. 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, in our recent research (Rai and Panda, 2014) we recorded maximum dust deposition during winter season. This suggests that localized 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 (Rai et al., 2014).

At each site, 5 leaves of almost similar size from branches facing roadside are plucked through random selection in early hours of forenoon time (08 AM to 12 AM) and placed in polythene bags. Leaves are 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 is usually given to oldest leaves from the newest twig in order to select leaves of similar age and exposure time. 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 (Walden, 1999).

The magnetic parameters such as magnetic susceptibility (χ), anhyste reticremanent magnetization (ARM) and saturation isothermal remanent magnetization (SIRM) were performed with dried leaves at K.S. Krishnan Geomagnetic Research Lab of Indian Institute of Geomagnetism, Allahabad, Uttar Pradesh, India.

The magnetic susceptibility indicates the total composition of the dust captured on the leaves, with a prevailing contribution from ferromagnetic minerals, which could show higher susceptibility values than paramagnetic and diamagnetic minerals, such as, clayor quartz (Maher and Thompson, 1999; Evans and Heller, 2003; Sant'Ovaia et al., 2012). A Bartington (Oxford, England) MS-2B dual frequency susceptibility meter was used (Dearing, 1999) in measurements.

ARM indicates the magnetic concentration and is also sensitive to the presence of fine grains ~0.04–1 μm (Thompson and Oldfield, 1986). Thus, falling within the respirable size range of $PM_{2.5}$; are possessed with high burden of toxicity (Power et al. 2009). 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 magnetizes the fine magnetic grains and the amount of magnetization 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 (Walden 1999).

SIRM reflects the total concentration of magnetic grains (Evans and Heller 2003) and can be used as a proxy of PM concentration (Muxworthy et al. 2003). SIRM involves with measuring the magnetic remanence of samples once removed from an induced field. Using a Molspin Pulse Magnetizer, a saturation isothermal remanent magnetization (SIRM) of 800 mT in the forward field was induced with the samples. At this high magnetization field, all magnetic grains within the sample become magnetized (Rai et al., 2014). 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-300and SIRM is defined as the S-ratio (King et al., 1991). The S-ratio mainly reflects the relative proportion of anti ferromagnetic 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 anti ferromagnetic minerals, generally goethite or haematite (Thompson, 1986).

2.2 Statistical analysis

All statistical calculations were performed using Statistical Programme for Social Science (SPSS version 11.2) and SAS software.

3 Results and Discussion

Lantana camara was found to be the most dominant invasive weed as revealed through phytosiciological studies (Table 1). The average seasonal values of two air pollutants (SPM and RSPM) recorded at four study sites throughout one year sampling period is presented in Table 2. The ambient PM concentrations were recorded highest at Ramrikawn, followed by Zarkawt and Durtlang, while lowest values were recorded for Tanhril area. The values of particulate pollutants were lowest in rainy season which may be because of large precipitations whereas summer and winter seasons were characterized by nearly same concentration at all four different study sites. During winter season there is increased atmospheric stability, which in turn allows for less general circulation and thus more stagnant air masses. It prevents an upward movement of air, hence atmospheric mixing is retarded and pollutants are trapped near the ground. Secondly, cold starts in winter lead to longer period incomplete combustion and longer warm up times for catalytic converter, which generate more pollution (Shukla et al., 2010). Vehicular exhaust, construction work, commercial activities; practice of jhum cultivation, bad road condition may be the reason for the augmented concentration of air pollutants at different study sites. In the present study, the quantity of RSPM and SPM at four different the sites were much higher than the prescribed limits of Central Pollution Control Board of India during summer and winter season. The present concentrations of the air pollutants specifically particulate pollutants are well enough to affect human health of the area. Elevated levels of SPM and RSPM in air can cause respiratory diseases like asthma, cancer, blood pressure etc (Rai, 2015b).

Table 1 List of invasive weeds recorded at the four sites of Aizawl, Mizoram, North East India (An Indo-Burma hot spot region).

Name of Species	Q1	Q2	Q3	Q4	Q5	No. of Individuals	Density	Freq.	Abund.	Basal Area	Basal Cover	Relative Density	Relative Freq.	Relative Abund.	IVI
Lantana camara	+	+	-	+	+	20	4	80	5	78.55	314.2	4.95	8.51	34.26	47.72
Ageratum conizoides	+	+	+	+	+	65	13	100	13	7.06	91.78	16.09	10.64	10.01	36.73
Spilanthes oleracea	+	+	+	+	+	70	14	100	14	3.14	43.96	17.33	10.64	4.79	32.76
Biden biternata	+	+	-	+	+	32	6.4	80	8	19.63	125.632	7.92	8.51	13.70	30.13
Spilanthes sp.	-	-	+	-	+	14	2.8	40	7	4.9	13.72	3.47	4.26	1.50	9.22
Mikania micrantha	+	+	+	+	+	31	6.2	100	6.2	7.06	43.772	7.67	10.64	4.77	23.08
Clerodendron infortunatum	+	+	-	-	-	8	1.6	40	4	78.55	125.68	1.98	4.26	13.70	19.94
Imperata cylindrica	+	+	+	+	+	42	8.4	100	8.4	4.9	41.16	10.40	10.64	4.49	25.52
Par eng (local name) Unidentified	+	+	+	-	-	19	3.8	60	6.3	3.14	11.932	4.70	6.38	1.30	12.39
Merremia umbellatum	+	+	+	-	+	22	4.4	80	5.5	19.63	86.372	5.45	8.51	9.42	23.37
Panicum conjugatum	+	+	+	-	+	32	6.4	80	8	1.76	11.264	7.92	8.51	1.23	17.66
Kyllingia brevifolia	+	-	+	+	+	49	9.8	80	12.2	0.78	7.644	12.13	8.51	0.83	21.47

Table 2 The average concentration of two air pollutants (SPM and RSPM) at different study sites during 2013 - 14.

Air Pollutants	**Ramrikawn**			**Tanhril**			**Zarkawt**			**Durtlang**			**CPCB standard** (Residential and Rural area)
	Summer	**Winter**	**Rainy**	**Summer**	**Winter**	**Rainy**	**Summer**	**Winter**	**Rainy**	**Summer**	**Winter**	**Rainy**	
SPM (μg m^{-3})	263.12± 0.01	260.01± 0.12	98.04± 0.04	210.91± 0.16	207.07± 0.41	42.9± 0.21	223.51± 0.11	229.21± 0.02	93.01± 0.29	220.22± 0.24	224.07± 0.01	87.03± 0.32	200
RSPM(μg m^{-3})	228.09± 0.23	232.23± 0.19	71.21± 0.83	102.31± 0.02	109 .28± 0.04	20.18± 0.12	189.03± 0.08	200.61± 0.41	63.18± 0.19	183.41± 0.03	190.15± 0.11	56.91± 0.05	100

SPM- Suspended particulate matter, RSPM- Respirable suspended particulate matter, CPCB -Central Pollution Control Board, New Delhi, India.

Table 3 Summary of the magnetic data (mean and standard deviation) for roadside dusts on *Lantana camara* leaves in the different sampling sites.

Sites	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	
	2013-14 (Winter)	2013-14 (Summer)	2013-14 (Winter)	2013-14 (Summer)	2013-14 (Winter)	2013-14 (Summer)	2013-14 (Winter)	2013-14 (Summer)	2013-14 (Winter)	2013-14 (Summer)	2013-14 (Winter)	2013-14 (Summer)
Ramrikawn	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	0.951	0.944
Tanhril	19.72± 0.41	11.81± 0.07	7.19± 0.18	10.81± 0.17	140.41± 0.44	132.77±0.05	0.36	0.91	7.12	11.24	0.954	0.867
Zarkawt	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
Durtlang	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

The average magnetic data collected throughout the one year sampling period is presented in Table 3 for *Lantana camara* tree leaves. In Ramrikawn, the magnetic susceptibility (χ), ARM and SIRM values of *Lantana camara* were 37.09±0.81 (10^{-7} m^3 kg^{-1}), 8.24±0.31 (10^{-5} Am^2 kg^{-1}) and 203.70±0.52 (10^{-5} Am^2 kg^{-1}) for winter season and 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 summer season. In Tanhril, the magnetic susceptibility (χ), ARM and SIRM values of *Lantana camara* were 19.72±0.41 (10^{-7} m^3 kg^{-1}), 7.19±0.18 (10^{-5} Am^2 kg^{-1}) and 140.41±0.44 (10^{-5} Am^2 kg^{-1}) for winter season and 11.81±0.07 (10^{-7} m^3 kg^{-1}), 10.81±0.17 (10^{-5} Am^2 kg^{-1}) and 132.77±0.05 (10^{-5} Am^2 kg^{-1}) respectively for summer season. In Zarkawt, the magnetic susceptibility (χ), ARM and SIRM values of *Lantana camara* were 33.87±0.54 (10^{-7} m^3 kg^{-1}), 8.19±0.41 (10^{-5} Am^2 kg^{-1}) and 201.42±0.26 (10^{-5} Am^2 kg^{-1}) for winter season and 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 summer season. In Durtlang, the magnetic susceptibility (χ), ARM and SIRM values of *Lantana camara* were 28.59±0.39 (10^{-7} m^3 kg^{-1}), 4.48±0.29 (10^{-5} Am^2 kg^{-1}) and 153.21±0.31 (10^{-5} Am^2 kg^{-1}) for winter season and 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 summer season.

Table 4 Correlation between magnetic measurements of *Lantana camara* with SPM and RSPM at different study sites during 2013-14.

Magnetic Parameter	SPM(R^2)		RSPM(R^2)	
	Winter	Summer	Winter	Summer
χ	0.815	0.688	0.955	0.733
ARM	0.160	0.646	0.032	0.688
SIRM	0.665	0.663	0.695	0.689

The high dispersion degrees of susceptibility and remanent magnetism mainly result from the sampling sites in different functional areas. Samples collected in the rural area (Tanhril) show low susceptibility and remanent magnetism, where tree leaves sampled in city (Zarkawt and Durtlang) and peri-urban (Ramrikawn) area show higher values. The values of ARM/ χ and SIRM/ χ can reflect the grain size of magnetic minerals (Evans and Heller, 2003). The results show that the ARM/ χ and SIRM/ χ values are found to be low at all studied sites (Table 2). ARM/ χ values are ranged from 0.15 to 0.96 (10^2Am^{-1}) and SIRM/ χ values are ranged from 5.35 to 11.77 (10^2Am^{-1}) respectively for all study sites. Low values of ARM/ χ and SIRM/ χ indicate relatively large grain size of magnetic particles present in leaf samples (Yin et al. 2013). S-ratio of *Lantana camara* leaf samples are ranging from 0.867 to 0.963 (Table 3) for four different study sites, 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 (Robinson, 1986).

From the findings recorded in Table 3, we can conclude that 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. The spatial trends of these three magnetic parameters display similar trends having Ramrikawn at maximum value and Tanhril area at lowest value. The correlation coefficients indicated significant relationship between the concentration of PM and magnetic measurement for *Lantana camara* tree leaves (Table 3). Hansard et al. (2011) 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 PM_{10}. Hu et al. (2008) also observed a good correlation of magnetic parameters (χ, ARM and SIRM) with air pollutants particularly heavy metals. Further, Kardel et al. (2011) recorded significant correlation between leaf SIRM and ambient PM concentrations. The other studies also demonstrated a significant correlation between magnetic parameter and PM as studied elsewhere (Pandey et al., 2005; Prajapati et al., 2006). Muxworthy et al. (2003) advocated that the value of SIRM is strongly correlated with the PM mass. This is not only act as a proxy for PM monitoring but also is a viable alternative to magnetic susceptibility since the samples are magnetically too weak.

The average magnetic concentration data (Table 3) demonstrate that the accumulation of PM on tree leaves varies across the four 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 Tanhril area. Ramrikawn recorded the highest values of magnetic parameters which may be attributed to heavy vehicular load (due to presence 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 Tanhril, being a village area is relatively free from vehicular pollution and other anthropogenic activities.

The processes which are responsible for large particulate deposition on leaves are sedimentation under gravity, diffusion and turbulent transfer giving rise to impaction and interception (Speak et al., 2012). Mitchell et al. (2010) emphasized complex dependence of deposition velocities (*v*d) on different variables such as particle size and density, terrain vegetation and chemical species. Further, landscape geography and architecture may also affect particulate concentration and its deposition on vegetation. Also, the dust collection capacity of plants depends on shape and surface geometry of plant leaves, leaf size and characteristics such as roughness, porosity, plant height, canopy and aspect and distance from emission road and buildings (Sternberg et al., 2010).

Acknowledgements

Authors wish to acknowledge the Department of Biotechnology (DBT) New Delhiand Science and Engineering Research Board (SERB) of 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).

References

Bhushan L, Sharma PK. 2005. Long-term effects of *Lantana* residue additions on water retention and transmission properties of a medium-textured soil under rice–wheat cropping in northwest India. Soil Use and Management, 21: 32-37

Dearing JA. 1999. Environmental magnetic susceptibility: Using the Bartington MS2 system. British Library Cataloguing in Publication Data.

Evans ME, Heller F. 2003. Environmental magnetism: principles and applications of enviromagnetics (International Geophysics). Academic Press, London, UK

Fassbinder JWE, Stanjek H, Vali H. 1990. Occurrence of magnetic bacteria in soil. Nature, 34: 161-163

Ghazoul J. 2002. Flowers at the front line of invasion? Ecological Entomology, 27: 638-640

Gooden B, French K, Turner PJ. 2009. Invasion and management of a woody plant, *Lantana camara* L., alters vegetation diversity within wet sclerophyll forest in southeastern Australia. Forest Ecology and Management, 257: 960–967

Gosper CR, Vivian SG. 2006. Selecting replacements for invasive plants to support frugivores in highly modified sites: A case study focusing on *Lantana camara*. Ecological Management and Restoration, 7(3): 197-203

Goulson D, Derwent LC. 2004. Synergistic interactions between an exotic honeybee and an exotic weed: pollination of *Lantana camara* in Australia. Weed Research, 44: 195-202

Groves RH, Willis AJ. 1999. Environmental weeds and loss of native plant biodiversity: some Australian examples. Australian Journal of Environment Management, 6: 164-71

Hansard R, Maher BA, Kinnersley R. 2011. Biomagnetic monitoring of industry-derived particulate pollution. Environmental Pollution, 159(6): 1673-1681

Hu SY, Duan XM, Shen MJ. 2008. 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

Kardel F, Wuyts K, Maher BA, Hansard R, Samson R. 2011. 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

Kershaw RA. 1973. Quantitative and Dynamic Plant Ecology. Edward Arnold Ltd, London, UK

King JW, Channell JET. 1991. Sedimentary magnetism, environmental magnetism and magnetostratigraphy. Reviews of Geophysics, 29: 358-370

Kong CH, Wang P, Zhang CX, Zhang MX, Hu F. 2006. Herbicidal potential of allelochemicals from *Lantana camara* against *Eichhornia crassipes* and the *alga Microcystis aeruginosa*. European Weed Research Society, 46: 290–295

Leigh JH, Briggs JD. 1992. Threatened Australian Plants: Overview and Case Studies. Australian National Parks and Wildlife Service, Canberra, Australia

Lüi XR. 2011. Quantitative risk analysis and prediction of potential distribution areas of common lantana (*Lantana Camara*) in China. Computational Ecology and Software, 1(1): 60-65

Maher BA. 1998. Magnetic biomineralisation in termites. Proceedings of the Royal Society of London, 265: 233-237

Maher BA. 2009. Rain and Dust: Magnetic Records of Climate and Pollution. Elements, 5: 229-234

Maher BA, Thompson R. 1999. Quaternary, Climates, Environments and Magnetism. Cambride University Press

Mishra R. 1968. Ecology Work Book. Oxford and IBH Publishing Co, New Delhi, India

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

Muxworthy AR, Matzka J, Davila AF, Petersen N. 2003. Magnetic signature of daily sampled urban atmospheric particles. Atmospheric Environment, 37: 4163-4169

Osunkoya OO, Perrett C. 2011. *Lantana camara* L. (Verbenaceae) invasion effects on soil physicochemical properties. Biology and Fertility of Soils, 47: 349-355

Pandey SK, Tripathi BD, Prajapati SK, Mishra VK, Upadhyay AR, Rai PK, Sharma AP. 2005. Magnetic properties of vehicle derived particulates and amelioration by *Ficusinfectoria*: a keystone species. Ambio: A Journal on Human Environment, 34(8): 645-647

Power AL, Worsley AT, Booth C. 2009. Magneto-biomonitoring of intraurban spatial variations of particulate matter using tree leaves. Environmental Geochemistry and Health, 31: 315-325

Prajapati SK, Pandey SK, Tripathi BD. 2006. Magnetic biomonitoring of roadsidetree leaves as a proxy of vehicular pollution. Environmental Monitoring and Assessment, 120: 169-175

Rai PK. 2008**.** Heavy-metal pollution in aquatic ecosystems and its phytoremediation using wetland plants: An eco-sustainable approach. International Journal of Phytoremediation, 10(2): 133-160

Rai PK. 2009a. 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

Rai PK. 2009b. Heavy metal phytoremediation from aquatic ecosystems with special reference to macrophytes. Critical Reviews in Environmental Science and Technology, 39(9): 697-753

Rai PK. 2012a**.** An eco-sustainable green approach for heavy metals management: two case studies of developing industrial region. Environmental Monitoring and Assessment, 184: 421-448

Rai PK. 2012b. Assessment of multifaceted environmental issues and model development of an indo-burma hot spot region. Environmental Monitoring and Assessment, 184:113-131

Rai PK. 2013a. Plant invasion ecology: Impacts and Sustainable management, Nova Science Publisher, New York, pp. 196

Rai PK. 2013b. Environmental magnetic studies of particulates with special reference to bio magnetic monitoring using roadside plant leaves. Atmospheric Environment, 72: 113-129

Rai PK. 2015a. Concept of plant invasion ecology as prime factor for biodiversity crisis: Introductory review. International Research Journal of Environmental Sciences, 4(5): 85-90

Rai PK. 2015b. Invasion in different ecosystems, continents and global impacts on biodiversity: Multifaceted review on sustainable green approach. International Journal of Green & Herbal Chemistry (Accepted; In Press)

Rai PK. 2015c. What makes the plant invasion possible? Paradigm of invasion mechanisms, theories and attributes. Environmental Skeptics and Critics, 4(2): 36-66

Rai PK. 2015d. Plant invasion ecology of an Indo-Burma hot spot region along the disturbance gradient: A case study. International Research Journal of Environmental Sciences, 3

Rai PK, Panda LS. 2014. Dust capturing potential and air pollution tolerance index (APTI) of some roadside tree vegetation in Aizawl, Mizoram, India: An Indo-Burma hot spot region. Air quality, Atmosphere and Health, **7**(1): 193-101

Rai PK, Chutia BM, Patil SK. 2014. Monitoring of spatial variations of particulate matter (PM) pollution through bio-magnetic aspects of roadside plant leaves in an Indo-Burma hot spot region. Urban Forestry & Urban Greening, 13: 761-770

Robbins P. 2001. Tracking invasive land covers in India or why our landscapes have never been modern. Annals of the Association of American Geographers, 91: 637-659

Robinson SG. 1986. 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

Sant'Ovaia H, Lacerda MJ, Gomes C. 2012. Particle pollution - An environmental magnetism study using biocollectors located in northern Portugal. Atmospheric Environment, 61: 340-349

Shukla V, Dalal P, Chaudhry D. 2010. Impact of vehicular exhaust on ambient air quality of Rohtak city, India. Journal of Environmental Biology, 31(6): 929-932

Speak AF, Rothwell JJ, Lindley SJ, Smith CL. 2012. Urban particulate pollution reduction by four species of green roof vegetation in a UK city. Atmospheric Environment, 61: 283-293

Sternberg T, Viles H, Cathersides A, Edwards M. 2010. Dust particulate deposition by ivy (*Hedera helix* L.) on historic walls in urban environment. Sci. Total Environment, 409: 162-168

Thompson R. 1986. Modelling magnetization data using SIMPLEX. Physics of the Earth and Planetary Interiors, 42: 113-127

Thompson R, Oldfield F. 1986. Environmental magnetism. Allen and Unwin, London, 227 pp. trunks. Studia Geophysica et Geodaetica, 47: 371-379

Totland O, Nyeko P, Bjerknes A, Hegland SJ, Nielsen A. 2005. Does forest gap size affects population size, plant size, reproductive success and pollinator visitation in *Lantana camara*, a tropical invasive shrub? Forest Ecology and Management, 215: 329–338

Walden J. 1999. Sample collection and preparation. In: Environmental Magnetism: A Practical Guide. Technical Guide No. 6. 26-34, Quaternary Research Association, Cambridge, UK