MONITORING OF PARTICULATE POLLUTION THROUGH BIO-MAGNETIC ASPECTS OF ROADSIDE PLANTS IN AIZAWL, MIZORAM

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DECLARATION

I, Shri Biku Moni Chutia hereby declare that the subject matter of this thesis entitled "**MONITORING OF PARTICULATE POLLUTION THROUGH BIO-MAGNETIC ASPECTS OF ROADSIDE PLANTS IN AIZAWL, MIZORAM**" is the record of work done by me, that the content of the thesis did not form basis for the award of any previous degree or to anybody else, and that I have not submitted the thesis in any other University/ Institute for any other degree.

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CHAPTER - 1

INTRODUCTION

1.1 Environment

"Environment" is the surrounding which constitutes all the conditions where organisms live and thus consists of air, water, soil, food and sunlight which are the basic needs of all living beings and the plant life to carry on their functions. In short, we can say that the environment consists of both biotic and abiotic substances which create favorable conditions for the existence and development of living organisms. Environment can be defined in a number of ways such as:

1. 'Environment refers to the sum total of conditions which surrounds man at a given point in space and time' (Park, 1980).
2. 'Environment is defined as a holistic view of the world as it functions at any point of time, with a multitude of spatial elemental and socio-economic systems distinguished by quality and attributes of space and mode of behaviour of abiotic and biotic forms (Dikshit, 1984).
3. 'Environment is the sum of all social, economical, biological, physical or chemical factors which constitute the surroundings of man, who is both creator and moulder of his environment' (Purohit and Ranjan, 2003).
4. 'Environment is that whole outer physical and biological system in which man and other organisms live with many interacting components' (Santra, 2013).

1.2 Components of Environment

The entire environment consists of both the biotic (living) and abiotic (non-living) components of the planet earth. The abiotic environment is subdivided into three broad categories they are:

(a) Lithospheric component

(b) Hydrospheric component

(c) Atmospheric component

Whereas the biotic component of the environment consists of biosphere including the plant component, animal (including man as physical man) component and micro-organismic components.

The entire environment is divided into four segments. These are:

(a) Atmosphere

(b) Hydrosphere

(c) Lithosphere

(d) Biosphere

1.3 Environmental Pollution

Environmental pollution is the unfavourable alteration of our surroundings, wholly or largely as a by product of man's actions, through direct or indirect effects of the changes in the energy pattern, radiation levels, chemical and physical constitution and abundance of organisms. Environmental pollution is a global problem and is common to both developed as well as developing countries which attracts the attention of human beings for its severe long term consequences. The decline in environmental quality as a consequence of pollution is evidenced by loss of vegetation, biological diversity, excessive amount of harmful chemical in the ambient atmosphere and in food grains, growing risks of environmental accidents and threat to life support system. Since pollution is viewed from different angles by different people but it is commonly agreed to be the outcome of urban-industrial and technological revolution and rapacious and speedy exploitation of natural resources, increased rate of exchange of matter and energy and ever increasing industrial wastes, urban effluents and consumer goods. Holdgate (1979), defined environmental pollution as the introduction by man, into the environment of substances or energy liable to cause interference with legitimate uses of environment. Singh (1991), has defined pollution in a very simple manner i.e. ‘Disequilibrium condition from equilibrium condition in any system’. This definition may be applied to all types of pollution ranging from physical to economic, political, social and religious pollution. Over past couple of decades, various sources of pollution were identified that altered the composition of water, air and soil of the environment. The substances, which cause pollution, are known as pollutants. A pollutant can be any chemical (toxic metal, radionuclides, organo-phosphorus compound, gases) or geochemical substances (dust, sediment), biological organism or product, or physical substance (heat, radiation, sound wave) that is released intentionally by man into the environment with actual or potential adverse, harmful or unpleasant or inconvenient effects. Such undesirable effect may be direct (affecting man) or indirect, being mediated via his resource organisms or climate changes.

Depending on the nature of pollutants and also subsequent pollution of environmental components, the pollution may be categorized under six major heads such as:

a) Air Pollution

b) Water Pollution

c) Soil/Land Pollution

d) Noise Pollution

e) Radioactive Pollution

f) Thermal Pollution

Among them Air pollution is one of the main type causing a serious problem making threat to the environment, human, plants, animals and all the living organisms.

1.4 Air Pollution

Air pollution is the introduction of particulates, biological molecules, or other harmful materials into Earth's atmosphere, causing disease, death to humans, damage to other living organisms such as food crops, or the natural or built environment. Air pollution may come from anthropogenic or natural sources (Assadi *et al.*, 2011).

The atmosphere is a complex natural gaseous system that is essential to support life on planet Earth. Stratospheric ozone depletion due to air pollution has been recognized as a threat to human health as well as to the Earth's ecosystems.

1.4.1 Pollutants

An air pollutant is a substance in the air that can have adverse effects on humans and the ecosystem. The substance can be solid particles, liquid droplets, or gases. A pollutant can be of natural origin or man-made. Pollutants are classified as primary or secondary. Primary pollutants are usually produced from a process, such as ash from a volcanic eruption. Other examples include carbon monoxide gas from motor vehicle exhaust, or the sulfur dioxide released from factories. Secondary pollutants are not emitted directly. Rather, they form in the air when primary pollutants react or interact. Ground level ozone is a prominent example of a secondary pollutant. Some pollutants may be both primary and secondary: they are both emitted directly and formed from other primary pollutants.

Major primary pollutants include:

- Sulfur oxides (SO_x),Nitrogen oxides (NO_x), Carbon monoxide (CO), Volatile organic compounds, Particulates,Toxic metals, Chlorofluorocarbons (CFCs), Ammonia (NH_3) and Radioactive pollutants etc.

Secondary pollutants include:

- Photochemical smog, Ozone (O_3) and Peroxyacetyl nitrate (PAN) etc.

Minor air pollutants include:

- A large number of minor hazardous air pollutants, A variety of persistent organic pollutants, which can attach to particulates.

1.4.2 Sources

There are various locations, activities or factors which are responsible for releasing pollutants into the atmosphere. These sources can be classified into two major categories.

1.4.2.1 Natural sources

- Dust from natural sources, usually large areas of land with few or no vegetation.
- Methane, emitted by the digestion of food by animals, for example cattle.
- Radon gas from radioactive decay within the Earth's crust. Radon is a colorless, odorless, naturally occurring, radioactive noble gas that is formed from the decay of radium. It is considered to be a health hazard. Radon gas from natural sources can accumulate in buildings, especially in confined areas such as the basement and it is the second most frequent cause of lung cancer, after cigarette smoking.
- Smoke and carbon monoxide from wildfires.
- Vegetation, in some regions, emits environmentally significant amounts of VOCs on warmer days. These VOCs react with primary anthropogenic pollutants—specifically, NO_x, SO_2, and anthropogenic organic carbon compounds — to produce a seasonal haze of secondary pollutants. Black gum, poplar, oak and willow are some examples of vegetation that can produce abundant VOCs. The VOC production from these species result in ozone levels up to eight times higher than the low-impact tree species.
- Volcanic activity, which produces sulfur, chlorine, and ash particulates.

1.4.2.2 Anthropogenic (man-made) sources

These are mostly related to the burning of multiple types of fuel.

- Stationary sources include smoke stacks of power plants, manufacturing facilities (factories) and waste incinerators, as well as furnaces and other types of fuel-burning heating devices. In developing and poor countries, traditional biomass burning is the major source of air pollutants; traditional biomass includes wood, crop waste and dung.

- Mobile sources include motor vehicles, marine vessels, and aircraft.

- Controlled burn practices in agriculture and forest management. Controlled or prescribed burning is a technique sometimes used in forest management, farming, prairie restoration or greenhouse gas abatement. Fire is a natural part of both forest and grassland ecology and controlled fire can be a tool for foresters. Controlled burning stimulates the germination of some desirable forest trees, thus renewing the forest.

- Fumes from paint, hair spray, varnish, aerosol sprays and other solvents.

- Waste deposition in landfills, which generate methane. Methane is highly flammable and may form explosive mixtures with air. Methane is also an asphyxiant and may displace oxygen in an enclosed space. Asphyxia or suffocation may result if the oxygen concentration is reduced to below 19.5% by displacement.

- Military resources, such as nuclear weapons, toxic gases, germ warfare and rocketry.

1.5 Particulate matter (PM)/Dust pollution

PMs are a mixture of particles and droplets in the air, consisting of a variety of components such as organic compounds, metals, acids, soil, and dust (U.S. Environmental Protection Agency 1996; Ciencewicki and Jaspers, 2007). PM is one of six ‘criteria pollutants’ designated by the US Clean Air Act of 1971 (Wilson *et al*., 2005). PM has been widely studied in recent years and the United Nation estimated that over 600 million people in urban areas worldwide were exposed to dangerous levels of traffic generated air pollutants (Cacciola *et al*., 2002).

PM is either directly emitted into the atmosphere from various natural and anthropogenic sources, or can be formed from gases through chemical reactions. Particulate matter air pollution is derived from vehicle emissions, forest fires, industrial, domestic and agricultural pollutants. A wide range of natural and anthropogenic emission sources contribute to particulate matter concentrations in the atmosphere such as windblown soil dust, marine and biogenic aerosol, road traffic and off-road vehicles, stationary combustion processes, industrial and construction processes, and combustion of agricultural waste (El-Fadel and Massoud, 2000). Fine particles are characterised by their etiology, their ability to remain suspended in the air and to carry material which is absorbed on the surface. The smaller the particle diameter, the longer it remain suspended in the air and the more hazardous it is.

Particulate matters (PMs) can be classified as coarse, fine and ultrafine depending upon their particle size. PMs measured in urban air used in health effects studies and for regulation are:

- Nuclei mode (smaller than 0.1 μm), often referred to as ultrafine particles (UFPs); they do not last long in the air since they deposit or rapidly form fine particles by coagulation.

- Accumulation mode (between 0.1 and approximately 1.0–2.5 μm) account for the majority of the mass of suspended particles and deposit slowly leading to a long atmospheric life time of 5 to 10 days and the build-up of visible haze. These particles may readily penetrate indoor spaces and are most strongly linked to adverse health effects.

- Coarse mode (larger than 1 μm), which extends upto 100 μm; they deposit relatively quickly with a lifetime of less than 2 days. (Robert *et al*., 2003).

Atmospheric PM with aerodynamic diameter <10mm (PM_{10}) or <2.5m ($PM_{2.5}$) are of considerable concern for public health (Schwartz *et al*., 1996; NEPC, 1998; Beckett *et al*., 1998 ; Borja-Aburto *et al*., 1998 ; Prajapati and Tripathi, 2008 a-b ; Rai, 2013, 2015). The ultrafine particles with typical dimension of nanometre-length scale are most hazardous (Wahlin *et al*., 2006) as it causes several life threatening diseases of varying dimension (Samet *et al*., 2000; Veranth *et al*., 2003; Brook *et al*., 2004; Wahlin *et al*., 2006; Rai, 2015). Ultrafine particles are responsible for the bulk of adverse health effects associated with particles in ambient air (Penttinen *et al*., 2001; Rai, 2013, 2015). Ultrafine PM is more potent than fine or coarse PM towards inducing cellular damage (Le *et al*., 2002) and also passes rapidly into the circulatory system (Nemmar *et al*., 2001). Suspended particulate matter (SPM) is of the greatest concern as it contributes 50% to total air pollution and causes respiratory disorders in human beings on prolonged exposure (Freer-Smith *et al*., 2004) as it include all airborne particles in the size range of 0.5μ to 100μ. Its effects attributed to mild eye irritation, mortality. Sirajuddin and Ravichandran (2010) also studied SPM related respiratory disorders such as nose block, sneezing, cough and hyperacidity in Tiruchirappalli, India. Bhattacharjee *et al*., 2012, noted that PM_S<4.6 μm and PM_S<1.1 μm are hazardous to human health due to its capacity to be inhaled into the bronchial region and deposited in the alveolar region. Epidemiologic findings suggest that short term particulate matter (PM) exposure can trigger acute or terminal health events whereas long term particulate matter (PM) exposure however could promote life shortening chronic illness. Additional evidence suggests that PM exposure over time can alter lung function, lung tissue and structure, air way responsiveness and respiratory defence mechanisms and can increase susceptibility to respiratory infection and damage respiratory cells (EPA, 1996 and 1997).

A second major concern is the ability of airborne particles to impact climate through absorption or scattering of solar radiation (Charlson *et al*., 1992; Haywood and Shine, 1995; Schwartz, 1996), alteration of cloud properties (Charlson *et al*., 1992; Jones *et al*., 1994; Boucher and Lohmann, 1995; Haywood and Boucher, 2000) and decreasing surface albedo after deposition to snow and ice (Hansen and Nazarenko, 2004; Jacobson, 2004; Roberts and Jones, 2004). With an atmospheric residence time ranging from days to weeks, particulate matter is not only a local concern but a global one, the generation of pollutants in one region impacting the air quality of another. There may be several kinds of airborne particulate such as dust, smoke, fume, mist, fog, smog, haze etc.

Dust causes some of the highest concentrations of ambient primary PM in many areas around the globe. Environmental contamination and human exposure with respect to dust pollution have dramatically increased during the past ten years (Faiz *et al*., 2009).Solid matter, which is composed of soil, anthropogenic metallic constituents, and natural biogenic materials, is called dust/particulate (Ferreira-Baptista and DeMiguel, 2005; Fathi and Clare, 2011; Rai, 2013). The particles of dust that deposit from the atmosphere and accumulate along roadsides are called road dust particles and originate from the interaction of solid, liquid and gaseous metals (Akhter and Madany, 1993; Faiz *et al*., 2009; Fathi and Clare, 2011, Rai, 2013). According to an estimate, dust pollution comprises around 40% of the total air pollution problem in India (Khan *et al.*, 1989; Rai *et al.*, 2014).

Dust pollution in the atmosphere, particularly of pollutant particles below 10 µm (PM_{10}), is of current concern worldwide due to adverse health effects associated with their inhalation (Morris *et al*., 1995; Oberdorster, 2000; Pope *et al*., 2004; Calderon-Garciduenas *et al*., 2004; Faiz *et al*., 2009; Rai, 2011a, 2011b, 2013, 2015). Moreover, PM in dust is thought to be the most harmful pollution component widely present in the environment (Bealey *et al*., 2007; Rai, 2013). Further, the implication of the intake of dust particles with high concentration of heavy metals poses potentially deleterious effects on the health of human beings (Faiz *et al*., 2009; Fathi and Clare, 2011).

1.6 Biomonitoring of air pollution

In view of abovementioned detrimental impacts of PM, it is quite obvious to investigate the feasible and eco-sustainable green technologies of its determination. Although, there are many conventional (physical and chemical) devices are discussed for the assessment of air pollution, however, biomonitoring is an efficient tool in urban areas (Rai, 2013). Biological monitors are organisms that provide quantitative information on some aspects of the environment, such as pollutant load in the atmosphere. 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 (Rai, 2013). Lichens, bryophytes or mosses and certain conifers are proved to be potent biomonitoring tool of air pollution in recent times. However, in urban and peri-urban regions higher plants are mostly suitable for monitoring of dust or PM pollution (Faiz *et al.*, 2009; Rai, 2013). Further, urban trees and shrubs planted in street canyons proved to be efficient dust capturing tools (Moreno *et al.*, 2003; Urbat *et al.*, 2004; Rai and Panda, 2014). Spreading widely in urban areas and easily collected, tree leaves could improve the scanning resolution in the spatial scale (Mitchell *et al.*, 2010; Gang *et al.*, 2013). Because of quick, economical, sensitive, efficient and non-destructive features of environmental magnetism measurements, the magnetic properties of tree leaves as proxy in monitoring and mapping of PM pollution have shown increasing attention during recent past (Gang *et al.*, 2013, Rai *et al.*, 2014). Moreover, tree leaves are efficient passive pollution collectors, as it provides a large surface area for particle deposition, a large number of samples and sampling sites and requires no protection from vandalism (Sant'Ovaia *et al.*, 2012). Therefore, urban angiosperm trees offer positive biological, ecological and aerodynamic effects in comparison to lower group of plants (Moreno *et al.*, 2003; Urbat *et al.*, 2004; Rai, 2013).

Biomagnetic monitoring with the urban roadside tree leaves, is found to be fruitful in the area of PM pollution science. The concept of environmental magnetism as a proxy for atmospheric pollution levels was reported by several researchers based on analysis of soils, street or roof dusts (Hay *et al.*, 1997; Hoffmann *et al.*,1999; Xie *et al.*, 2000, 2001), vegetation samples including tree bark samples etc (Kletetschka *et al.*, 2003; Urbat *et al.*, 2004). However, researchers have emphasized and demonstrated the usefulness of plant leaves in monitoring the dust or PM (Matzka and Maher,1999; Moreno *et al.*, 2003; Jordanova *et al.*, 2003; Urbat *et al.*, 2004; Pandey *et al.*, 2005; Maher, 2009). Maher and her group are leading in performing a cascade of magnetic studies in relation to the environmental pollution, thus extending it to a specialized sub-discipline of environmental geomagnetism (Matzka and Maher, 1999; Maher *et al.*, 2008). Thus, in view of this, magnetic biomonitoring studies of roadside plant leaves are performed in Singrauli and Varanasi region of India (Pandey *et al.*, 2005), in some cities of Portugal and hilly areas of Nepal etc. (Gautam *et al.*,2005). Additionally, a series of works in European countries is conducted as described elsewhere (e.g., Matzka and Maher, 1999; Maher, 2009).

The particles of dust that deposit from the atmosphere and accumulate along roadside are called road dust particles which originate from the interaction of solid, liquid and gaseous metals (Rai, 2013). Since the roadside vegetation obviously comes into direct contact with particulates, irrespective of the sources. Therefore, investigation carried out with tree/plant leaves provide an impetus in such environmental studies (Faiz *et al.*, 2009). However, the diversity of plants is investigated for the biomagnetic monitoring potential. Moreover, this study is limited mostly to the plants prevailing in temperate conditions, and therefore, quest is there to investigate it in context of tropical plants. Moreover, advancement in instrumentation or methodology in magnetic studies may improve the understanding of this research field (Rai, 2013).

1.7 Biomagnetic monitoring of particulates through roadside plant leaves

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 (Hay *et al.,* 1997; Hoffmann *et al.,* 1999; Shu *et al.,* 2000; Xie *et al.,* 2000; Gautam *et al.,* 2005; Jordanova *et al.,* 2003; Urbat *et al.,* 2004), and vegetation samples including tree bark (Kletetschka *et al.,* 2003; Urbat *et al.,* 2004), however, a cascade of researches have emphasized the use of plant leaves in monitoring the dust (Matzka and Maher, 1999; Moreno *et al.,* 2003; Jordanova *et al.,* 2003; Urbat *et al.,* 2004; Pandey *et al.,* 2005; Maher *et al.,* 2008; Maher, 2011; Rai, 2011b). Maher and her group were the leading ones in performing a cascade of magnetic studies in relation to environment, thus extending it into specialized discipline i.e. environmental geomagnetism (Maher, 1998 a,b; Maher and Dennis, 2001).

The fact that magnetic biomonitoring studies of plant leaves may act as proxy of ambient particulate pollution is well proved now and also emphasized at several places in this review. In conjunction with our small discussion on the advantages of biomonitoring through magnetic properties in earlier section, it is worth to mention that magnetic biomonitoring of pollutants by measurements taken from roadside tree leaves is potentially efficient, as samples are abundant and hundreds of samples can be collected and analysed within few days (Rai, 2011b). Leaves with large surface areas per unit of weight, favourable surface properties (a waxy coating), and a long lifespan, such as conifer needles or evergreen tree leaves, are considered to be good accumulators of PM from the atmosphere (Freer-Smith *et al.,* 1997; Alfani *et al.,* 2000). Leaves are potentially efficient receptors and biomonitors of particulate pollution, as they provide a large total surface for particle collection, numbers of samples and sample sites can be high (i.e. hundreds), and, in pollution contexts, the leaves themselves are insignificantly magnetic. Further, tree leaves also preclude sampling problems associated with the use of artificial particle collectors (including power requirements). Moreover, magnetic techniques are sensitive and rapid (e.g. Matzka and Maher, 1999; Muxworthy *et al.,* 2003; Maher *et al.,* 2008; Szonyi *et al.,* 2008; Hansard *et al.,* 2011). Magnetic measurements of leaves from several deciduous species can be inter-calibrated (Mitchell *et al.,* 2010), optimizing sampling density and resultant spatial resolution of the proxy PM_{10} data.

Thus, in view of this, magnetic biomonitoring studies of roadside plant leaves were performed in Singrauli Industrial region (Pandey *et al.,* 2005) and hilly areas of Nepal (Gautam *et al.,* 2005), in addition to a series of pioneer works in European countries by a few group led by Professor B.A. Maher (e.g. Matzka and Maher, 1999; Maher, 2009).

Magnetic properties of leaves (Muxworthy *et al.*, 2003; Moreno *et al.*, 2003; Urbat *et al.*, 2004; Pandey *et al.*, 2005; Maher *et al.*, 2008; Mitchell and Maher, 2009; Maher, 2009) have been used to identify the spread of pollution derived from vehicular emission.

Therefore, the biomagnetic monitoring, using tree leaves as sampling surfaces, can generate high spatial-resolution PM_{10} proxy data (Hansard *et al.*, 2011). Strong correlation has been demonstrated between magnetic properties i.e. leaf saturation remanent magnetization (SIRM) and/or magnetic susceptibility (χ) values and the amount of PM/dust on the leaf surface (e.g. Halsall *et al.,* 2008; Maher *et al.,* 2008; Szonyi *et al.,* 2008; Hansard *et al.*, 2011). Correlations between magnetic parameters of plant leaves and toxic metals, such as lead, zinc and iron, have also been investigated (e.g. Lu and Bai, 2006; Maher *et al.*, 2008; Morton-Bermea *et al.,* 2009; Hansard *et al.,* 2011). Also, studies (Shu *et al.,* 2001; Muxworthy *et al.,* 2003; Saragnese *et al.*, 2011) have found correlations between magnetic properties and levels of pollution (i.e., PM_{10} concentration and heavy metals).

While comparing the meteorological data and pollution data with reference to magnetic properties of urban particulates, Muxworthy *et al.* (2001), found that the magnetic hysteresis parameters generally had a stronger correlation with the meteorological data than with the pollution data.

Moreover, biomagnetic monitoring approach may provide a robust means to achieve measurement and sourcing of PM_{10} at unprecedented levels of spatial resolution and is applicable all around the world (Maher, 2009) (e.g. Shu *et al.,* 2001, in China; Gautam *et al.*, 2005, in Nepal; Pandey *et al.,* 2005, in India; Chaparro *et al.,* 2006, in Argentina; Kim *et al.*, 2007, in Korea; Szonyi *et al.,* 2008, in Europe). Magnetic biomonitoring (Matzka and Maher, 1999; Maher, 2009) seems to be a valuable means both to gain significantly enhanced spatial resolution for pollutant data, and test proposed particulate source or health linkages.

In general, the magnetic properties of roadside tree leaves is greater when compared to those lying within the city centre, as demonstrated in case of birch leaves (Matzka and Maher, 1999). Several studies have investigated the biomonitoring of PAH (Lehndorff and Schwark, 2004; Lehndorff *et al.,* 2006; Lehndorff and Schwark, 2009) and trace element/heavy metals (Lehndorff and Schwark, 2008) in particulates through the study of magnetic properties in pine trees. Strong correlation between the magnetic susceptibility of pine needles and their metal (Fe) content has been demonstrated due to deposition of fly ash particles (Schadlich *et al.,* 1995; Maher *et al.,* 2008). A significant correlation was identified by Maher *et al.* (2008) between lead, iron and leaf magnetic values in their study on PM.

1.8 Scope of the study

Rapid urbanization and continuously expanding population in and around Aizawl city, India have caused rapid increase in motor vehicles, which perhaps increases the particulate matters in the atmosphere of Aizawl. Aizawl district is located in an Indo-Burma hot spot region is connected to the National Highway road (NH 54;Pushpak) passing through the Airport, Silchar, Shillong and finally to Guawahati which harbours heavy vehicular fleet. Therefore, vehicular pollution is possibly a primary contributor of particulates, specifically respirable particulate matter (RSPM), having human health implications. A preliminary study in Aizawl (Lalrinpuii and Lalramnghinglova, 2008) shows a higher level of suspended particulate matter (SPM) and respirable particulate matter (RSPM). Further, PM below the size of 10 µm (PM_{10}), are specifically hazardous to human health (Saldiva *et al.*, 2002), therefore their monitoring is pertinent at least in this regions.

Apart from vehicular dust, the anthropogenic sources viz., soil erosion; mining and stone quarrying activities are important sources of air pollution prevailing in peri-urban and rural regions of Aizawl (Rai *et al.*, 2014). Furthermore, increasing, airborne dust particles emitted from geologic media pose threats to human health and the environment (Faiz *et al.*, 2009). Since the rocks of Aizawl are very fragile, the weathered rock dust may also be deposited on plant leaves. In India, several researches demonstrated significant correlation between magnetic parameter and PM (Pandey *et al.*, 2005; Prajapati *et al.*, 2006), however, they analyzed only one magnetic parameter, i.e., isothermal remanent magnetization (IRM). However, the present study is intended with three important parameters, i.e., magnetic susceptibility, ARM and SIRM as to provide an accurate and useful correlations. Therefore, present study aims to investigate the magnetic properties of ten roadside plant leaves at four spatially distant sites in order to compare their capability to accumulate particulates and to establish the relationship between magnetic properties and ambient PM.

1.8 Objectives

(1). To evaluate particulate matter at selected sites in Aizawl.

(2). To measure quality of particulates matter captured on leaves of selected roadside plants in Aizawl.

(3). To correlate ambient PM with magnetic properties of leave content.

CHAPTER- 2

REVIEW OF LITERATURE

Air pollution is a serious problem all over the world which causes adverse impact on human health (Rai, 2015) and other living beings. Particulate Matter ($PM_{2.5}$, PM_{10}), Ozone (O_3), Lead (Pb), Carbon Monoxide (CO), Benzene (C_6H_6), Nickel (Ni), Sulphur Dioxide (SO_2) and Nitrogen Dioxide (NO_2) are some of the parameters which have significant impact on environmental pollution (Dohare and Panday, 2014).

Prakash and Punyaseshudu (2015), investigated variations of SO_2, NO_2, SPM and RSPM since 5 years during summer and winter seasons in Agra. For this reason, data of daily air pollutants from four pollution monitoring stations i.e., Taj Mahal, Itam-ud-daulah, Rambagh and Nunhai areas in Agra were analyzed. The concentrations of these parameters were monitored by continuous monitoring equipment for a period of five years (from 2010 to 2014). There were significant monthly variations in concentrations of air quality parameters. Analysis showed that SO_2 and NO_2 levels are less compared to RSPM and SPM pollutants which are in acceptable limits of NAAQS standards, whereas RSPM and SPM levels exceeded the standards of NAAQS at all monitoring stations. It was also observed that the pollutant concentrations are high in all years of winter season compared to summer season due to stable atmospheric conditions. Also high concentrations of NO_2, RSPM and SPM pollutants were observed in Rambagh and Nunhai stations as compared to Taj Mahal and Itam-ud-daulah stations.

The study of Kamath and Lokeshappa (2014), presented the data of the ambient air quality status of residential, industrial and sensitive areas of Bangalore. SO_2, NO_X and RSPM were collected over six sites in Bangalore. It has been observed (Kamath and Lokeshappa, 2014) that the concentrations of the pollutants are high in summer in comparison to the pre monsoon and post monsoon seasons. From their study, it was observed that the RSPM levels at all selected sites exceeds the prescribed limits as stipulated by Central Pollution Control Board (CPCB) New Delhi. A part from this the SO_2 and NO_X levels in industrial areas remain under prescribed limits of CPCB.

Kapoor *et al.* (2013) calculated the mean concentrations of SO_2, NO_2, SPM and RSPM in urban, industrial and forest areas of Udaipur for two years i.e. from September, 2010 to August, 2012. Rajpura Dariba mines, Hindustan Zinc Smelter, Debari, Madri Industrial Area and Sukher are some places of Udaipur which was selected for Sampling. Minimum three recording was taking out in a day i.e. morning, noon and evening hours and polythene bags were used for bring the samples to laboratory. The concentration of NOx was measured by modified Jacob and Hochheiser while SOx was measured by Modified West and Gaeke method. CO was measured by carbon monoxide analyser and particulate matter was measured using filter paper. It has been observed that concentration of suspended particulate matter (SPM) ranges between 118.39 (rainy season) to 528.56 (summer season) $\mu g/m^3$. SO_2 ranges between 6.29 (rainy season) to 68.27 (winter season) $\mu g/m^3$, NO_2 ranges between 4.33 (rainy season) to 42.09 (winter season) $\mu g/m^3$ and CO between 304.62 (rainy season) to 1620.54 (winter season) $\mu g/m^3$ during the study period.

Khandbahale and Saler (2013), determined the levels of pollutants like SO_X, NO_X and SPM on three representative sites viz. Industrial (I), Commercial(C) and Residential(R) of

Nashik city. The selected sites for Ambient Air Quality Monitoring were places of maximum pollution and heavy traffic. A continuous sampling had been carried out at all three sites. Site 1:- VIP Company, MIDC areas, Satpur, Nashik: this site represents the industrial site. Site 2:- RTO colony tank, Pandit colony, Nashik: this site represents the residential area. Site 3:- NMC building, min road, Nashik: this site represents the commercial area. All the sites have two way traffic system, open loop signal control and high vehicle density. Level of SPM crossed the limit at all the sites but SO_X and NO_X were not exceeded the limit at all sites.

Harikrishnan *et al.* (2012) studied the ambient quality of air in Hosur, Tamil Nadu. Under the provision of the Air Act, 1981, the CPCB has introduced 4th version of National Ambient Air Quality Standard (NAAQS-2009). The aim of this revised national standard is to provide uniform air quality for all. There are 12 identified health based parameter which are to measure at national level. Three locations nearby Hosur Bus Stand, nearby SIPCOT II and nearby Gandhi road were selected for monitoring. These locations cover the major part of the Hosur where the busy roads meet and bus terminals through they are receiving higher emissions. The results showed that PM_{10} concentration varies between 45-127 $\mu g/m^3$ where $PM_{2.5}$ concentration was higher at all three locations. This value are higher than the 24 hrs PM_{10} (100 $\mu g/m^3$) and around higher than 24 hrs $PM_{2.5}$ (60 $\mu g/m^3$) National Ambient Air Quality Standard prescribed by the CPCB of India.

Balashanmugam *et al.* (2012) studied the quality of ambient air of Puducherry, India. For ambient air quality monitoring eight sites were selected which have heavy traffic and commercial areas. SPM, NO_2, SO_X, and CO are the parameter for which continuous sampling has been carried out and sites of monitoring were indira Gandhi signal (1), Rajiv Gandhi signal (2), Bus stand (3), Kanniyakoil (4), Nehru street (5), Tindivanam high road (6), Cuddalore main road (7), Muruga theatre junction (8). Monitoring of particulates was done by “High Volume Sampler”. Wattman filter paper GF/A (20.3cmX 25.4cm) of HVS was kept at 15-34^{o}C, 50% relative humidity for 24 hr and weighed. The filter paper was placed in HVS on the filter holder and air was drawn through a 410 cm^2 portion of the filter at a flow rate of 1.80 LPM (liquid flow rate) . The filter paper was removed after sampling and weighed. The mass concentration of particulate expressed in μg/m^3 and was calculated by measuring the mass of particulates collected and the volume of air sampled. For the monitoring of nitrogen oxides ambient air was continues drawn at a rate of 2 LPM through 35 ml of sodium hydroxide solution for 8 hr and Jacobs and Hochhesier method was used for estimation of NO_X. In the case of SOx tetrachloromercurate solution was used and ambient air was continuous drawn at a rate of 1.5 LPM for 8 hour through it. SPM concentration exceeded the limit at all the eight sampling sites. CO concentration crossed the limit at seven sites out of eight sites. SO_2 was within limit at all eight sites. NO_2 level crossed the limit at all eight sites.

Rohtak city is located at 70 km from Delhi having an area of 441100 hac. Six sites of sampling which are University campus, Delhi bye pass, Medical mor, New bus stand, Bhivani stand and Hissar rod. Ambient Air Quality monitoring was done using “High Volume Sampler”(Envirotech APM-415-411), 8 hour daily for suspended particulate matter and 4 hour daily for gaseous pollutants with a frequency of once in a week in winter, summer and monsoon. The work of Shukla *et al.* (2010) showed variation in the pollutant level during winter, summer and monsoon season in the city. The concentrations of SO_2 at University campus, Hissar road, Medical mor, New bus stand, Delhi bye pass and Bhiwani stand were 12.97, 32.03, 20.08, 22.68, 18.43 and 28.59 μg/m^3 in summer; 14.00, 38.52, 24.68, 22.13, 29.35 and 38.38 μg/m^3 in winter; and 9.25, 29.39, 17.62, 21.38, 18.41 and 27.21 μg/m^3 in monsoon seasons respectively. The levels of SO_2 were below the permissible limit (80 μg/m^3) as prescribed by NAAQS in all the three seasons at all six sites. SO_2 was found to be minimum at University campus in monsoon season and maximum in winter season at Hissar road (Shukla *et al.,* 2010). The concentrations of NO_2 at University campus, Hissar road, Medical mor, New bus stand, Delhi bye pass and Bhiwani stand were 42.59, 117.90, 79.99, 81.54, 86.26 and 118.35 μg/m^3 in winter; 40.02, 113.73, 79.13, 75.41, 84.36 and 105.14 μg/m^3 in summer and 37.59, 93.75, 54.04, 70.24, 63.53 and 89.90 μg/m^3 in monsoon seasons respectively . NO_2 level exceeds the prescribed NAAQS (80 μg/m^3) at New bus stand, Delhi bye pass, Bhiwani stand and Hissar road in winter, at Delhi bye pass, Bhiwani stand and Hissar road in summer and at Bhiwani stand and Hissar road in monsoon season. NO_2 level remains within safety limit (Shukla *et al.,* 2010) at Medical mor and University campus in all the three seasons. The mean NO_2 concentration was observed minimum at University campus in monsoon season and maximum at Bhiwani stand in winter season. The mean values of SPM at University campus, Hissar road, Medical mor, New bus stand, Delhi bye pass and Bhiwani stand were 354.93, 1216.37, 704.56, 686.86, 678.70 and 1025.39 μg/m^3 in summer; 404.54, 1310.76, 757.22, 756.87, 771.44 and 1146.13 μg/m^3 in winter and 245.14, 915.91, 593.86, 607.12, 414.72 and 785.74 μg/m^3 in monsoon seasons respectively. SPM was found to be lowest at University campus in monsoon season and highest at Hissar road in winter season. The level of SPM was observed above the safety limit (Shukla *et al.,* 2010) in all the three seasons at all the sites, except University campus in monsoon season.

The study of Meena *et al.* (2012) presented the data of the ambient air quality status of residential area of Himalayan region viz. Garhwal (New Tehri) and Kumaon (Muktheshwar) in state of Uttarakhand India. There were two manual station set up at both the place New

Tehri and Muktheswar. 24 hourly monitoring was carried out at each station and ambient air quality was monitored in two phases. First one was on December 2010 and second one on June 2011. Respirable dust sampler (APM- 460NL)/High Volume Sampler was used for monitoring of ambient air. Suspended particulate matter collected on EPM 2000 filter paper for 8 hr and gaseous sampling was conducted for 4 hr in respective of absorbing media. After the sampling following results were obtained: The concentration of various pollutants like PM_{10}, SO_X, NO_X, Benzo(a) Pyrene, Benzene, Toluene, Lead and Nickel in μg/m^3 were 15, 6.5, 6, 0.5,BDL, BDL, BDL, BDL at southy coat New Tehri, 27, 8, 6.25, 0.6, BDL, BDL, BDL, BDL at THDC, new Tehri,10, 4, 7, 1.15, at Hotel Krishna and 23, 4, 6.5, 0.2, BDL, BDL, BDL, BDL respectively for phase one. In phase I all the pollutants were within the limits as per (NAAQS-2009). In phase II monitoring the concentration of various pollutants like PM_{10}, SO_X, NO_X, Benzo (a) Pyrene, Benzene, Toluene, Lead and Nickel in μg/m^3 were 22, 4, 10, BDL, BDL, BDL, BDL, BDL at Southey coat New Tehri, 32, 4, 5, 1.5, BDL, BDL, BDL, BDL at THDC, New Tehri and 23, 4, 12, 1.5, BDL, BDL, BDL, BDL, at Mukteshwar respectively. The phase II monitoring was carried out in only 3 places instead of 4 places. In phase two monitoring it was found that all the parameters were within the limits of NAAQS-2009.

Kumar *et al.* (2011) made an attempt to express the Ambient Air Quality of Jaipur city in the form of Air Quality Index (AQI). For Ambient Air Quality monitoring twelve sites in residential, industrial and commercial areas of the city were selected. The study was carried out to evaluate Suspended Particulate Matter (SPM), Respirable Suspended Particulate Matter (RSPM), sulphur dioxide (SO_2) and oxides of nitrogen (NOx) by sampling for a period of 24 hrs in winter season of the year, 2009-2010. The results showed that SPM concentrations in the area of study were varied between maximum i.e. 854.33 μg/m^3 and minimum i.e. 79.81 μg/m^3. RSPM in the study area ranges between maximum of 340.85 μg/m^3 and minimum of 46.64 μg/m^3. This exceeds the CPCB prescribed values except Tilak Nagar. Sulphur dioxide in the study areas ranged between the minimum value i.e.11.67 μg/m^3 and maximum value i.e. 39.76 μg/m^3. Oxides of nitrogen in the study area ranged between maximum of 61.86 μg/m^3 and minimum of 16.55 μg/m^3. The Air Quality Index values in the study areas vary between maximum of 102.71 and minimum of 52.04. The results of air quality monitoring show that the pollution concentrations were highly variable at different sampling sites. Particulate pollutants concentration exceeded the permissible standards in all sites except Tilak Nagar. The concentrations of gaseous pollutants were observed to be within permissible limits in all the sites.

The ambient air quality of Pune city was carried out at selected location. Three locations SNDT college (karve road), Swargate (Jedhe Chowk) and Deccan (karve road) were selected. The selection of sites was based on the traffic density, pollution status and traffic congestions. The frequency of sampling was once in a week for six month i.e. from June 2006 to November 2006. The sampling was done at a height 10 m above road level. About 22 samples were collected from each sampling location i.e. total 66 number of samples. The sampling was done using calibrated Respirable dust sampler (RDS) (Envirotech model APM 460 BL) with a flow rate of 1.1m^3/min equipped with glass fiber filter paper (whatmann 41 GF/A). The parameters were lead oxide and particulate matter with size less than 10 micron (PM_{10}). The PM_{10} was monitored for 12 hrs and analyzed gravimetrically. Lead oxide concentration was determined spectrophotometrically (AAS). The average level of PM_{10} and lead oxide were 120.35 μg/m^3 and 0.65 μg/m^3 respectively. The results showed that lead oxide concentration was decreased and well within the ambient air quality standard of 0.75μg/m3 where as the PM_{10} concentration was very high as compare to 60 μg/m^3 of standard. (Gidde, 2007).

The research of Bhuyan *et al.* (2010) showed the use of Air Quality Index (AQI) describing air pollution in Choudwar area of Cuttack district. AQI was computed for ten sampling station in the choudwar area within the radius of 10kms from core zone. Agrahat (1), Nergundi Railway station (2), Narapada (3), Kapeleshwar (4), Khutuni (5), Ghantikhal (6), Near arati steel (7), Dautatabad(8), Kayalapada(9) and Gurudijhatia (10) are ten sites selected for air sampling. Out of these four stations (4, 5, 6, 7) are located in industrial belt and other six stations are located in rural area. During the study period SPM was found to be minimum (102.2 μg/m^3) at rural area i.e. site 3 in monsoon 2007 and maximum at industrial area i.e. site 4 in post monsoon 2007 and pre monsoon 2008. NO_2 was found to be minimum (12.8 μg/m^3) at rural area i.e. site 3 in pre monsoon 2007, 2008 and maximum (38.3 μg/m^3) at industrial site i.e. site 6 in post monsoon 2008. SO_2 was found to be minimum (0.8 μg/m^3) at rural area i.e. site 1 in pre monsoon 2007 and maximum (8.4 μg/m^3) at industrial area i.e. site 4 in post monsoon 2007, 2008. The average value of AQI at site 1, 2, 4,5,6,7 and 8 are 53.3, 57.7, 57.6, 69.0, 68.7, 70.9 and 53.6, respectively which shows Moderate air pollution and at site 3, 4 and 5 are 44.4, 49.7 and 48.6 which shows light air pollution.

Prakash and Bassin (2010), analyzed the status of ambient air in Delhi city by employing the Air Quality Index (AQI). 24 hourly average concentrations of four major pollutant such as SPM, RSPM, SO_2 and NO_2 were analyzed at three different locations (industrial at Mayapuri, commercial at town Hall and Residential at Sarojini) for a year 2009. Sampling was carried out using HVS and RDS at the flow rate of 0.8-1.3 m^3/min. average concentration of SPM at all three sites ranged between 160-1009 μg/m^3 at industrial, 160-1140 μg/m^3 at commercial and 72-831 μg/m^3 at residential site while RSPM varies from 62-664 μg/m^3 at industrial,48-619 μg/m^3 at commercial and 28-483 μg/m^3 at residential site. Average concentration of SO_2 and NO_2 at all the sites ranged between 2-28 μg/m^3 and 17-110 μg/m^3, at industrial,2-28 μg/m^3 and 15-107 μg/m^3 at commercial and 2-18 μg/m^3 and 16-94 μg/m^3 at residential sites respectively. The AQIs were calculated using IND-AQI procedure. The calculated AQI values for 24 hourly average NO_2 and SO_2 concentrations were categorized as good to moderate and good during the study period at all three sites. AQI value estimated for SPM showed about 62% in industrial, 55% in commercial and 47% in residential under very poor category while AQI values for RSPM varied about 54% in industrial,42% in commercial and 59% in residential sites under poor category. Over all AQI was found to fall under the category of poor to very poor due to RSPM and SPM respectively. Daily average concentration and AQI for particulate matter shows a maximum pollutant concentration during winter months and general trend of minimum values occurs in monsoon.

Ambient Air Quality in respect to SPM, NOx, SO_2 and CO was monitored over various parts of Calcutta by Mandal (2000). Urbanized areas of the western part of Calcutta was the most polluted area compared to other areas which is highly urbanized, closed to the Howrah Industrial Sector and with high density of population which lead to greater concentration of pollutants in this area.

In a study, conducted in the city Kanpur, it was found out that average pollution level in the city expressed in PM_{10} was 225.68 μg/cu-m during the year 2004 (Gupta, 2007). One of the monitoring stations i.e., Vikas Nagar registers wild fluctuations in the level of PM_{10}. It varies from 295 to 463µg/cu m during summer and from 42.5 to122 µg/cu-m during the monsoon and winter seasons respectively.

A study conducted on the ambient air quality of the city Lucknow during Diwali festival showed varied concentrations of PM_{10}, SO_2 and NO_x. In this study, PM_{10}, SO_2, NO_x and 10 trace metals associated with PM_{10} were estimated at four representative locations, during day and night times for Pre Diwali (day before Diwali) and Diwali day. On Diwali day 24 h average concentration of PM_{10}, SO_2, and NO_x was found to be 753.3, 139.1, and 107.3 µg /cu-m, respectively, and these concentrations were found to be higher at 2.49 and 5.67 times for PM_{10}, 1.95 and 6.59 times for SO_2 and 1.79 and 2.69 for NO_x, when compared with the respective concentration of Pre Diwali and normal day, respectively (Barman *et al.*, 2008).

In Indian cities airborne particulate matter seems to be a very serious problem (Agarwal *et al.,* 2006) even in sites of ecological relevance like Aizawl, Mizoram, NE India (Lalrinpuii and Lalramnghinglova, 2008; Rai and Chutia, 2014). Moreover, national studies also revealed that leaves are sensitive and highly exposed parts of a plant and may act as persistent absorbers of dust in a polluted environment. They act as pollution receptors and reduce dust concentration of the air (Nowak, 1994). The capacity of leaves as dust receptors depends upon their surface geometry, phyllotaxy, epidermal and cuticular features, leaf pubescence, and height and canopy of trees (Nowak, 1994).

Particulate matter (PM) in the atmosphere is a major environmental concern, especially with respect to its impact on human health (Revuelta *et al.*, 2014; Sgrigna *et al.,* 2015; Rai, 2015). In recent Anthropocene era, rapid pace of industrialization and urbanization has given birth to dust or particulate matter (PM) pollution, impact of which may be correlated with urban planning as well as topography of the particular region (Rai, 2011 a,b, Rai, 2013). Besides social and economic problems, the development model of the so-called Third World has caused serious degradation of air quality particularly in relation to huge emission of PM and hence posed challenges in the research fields of atmospheric science and technology. Environmental contamination and human exposure with respect to dust or PM pollution have dramatically increased during the past ten years (Faiz *et al.*, 2009). In the current phase of science and technology, roads act as reservoir of PM. Roads, have a wide variety of primary, or direct, ecological effects as well as secondary, or indirect, ecological effects on the landscapes that they penetrate (Coffin, 2007). The particles of dust that deposit from the atmosphere and accumulate along roadsides are called road dust particles and originate from the interaction of solid, liquid and gaseous metals (Akhter and Madany, 1993; Faiz *et al.*, 2009). Since the roadside vegetation obviously comes into direct contact with particulates, irrespective of the sources, it is quite obvious to investigate their pollution science, particularly in context of the role of plant leaves. Further, the implication of the intake of dust particles with high concentration of heavy metals poses potentially deleterious effects on the health of human beings (Faiz *et al.,* 2009). Moreover, apart from human health implications, there may be concomitant multifaceted impacts of dust particles or PM on global climate (Maher, 2009).

It is now well established through a series of researches that urban PM may also contain magnetic particles (Hunt *et al.,* 1984; Flanders, 1994; Morris *et al.,* 1995; Matzka and Maher, 1999; Petrovsky and Ellwood, 1999; Maher *et al.*, 2008; Rai, 2011 a, b). These are derived from the presence of iron impurities in fuels, which form upon combustion of a non-volatile residue, often a mix of strongly magnetic (magnetite-like) and weakly magnetic (haematite-like) iron oxides. Magnetite has been identified specifically as a combustion-derived component of vehicle exhaust materials (Abdul-Razzaq and Gautam, 2001; Maher *et al.*, 2008). Apart from vehicular emissions, other natural sources (rock dust, street dust, sediments etc.) may also contribute to magnetic minerals in the atmosphere (Maher *et al.*, 2008; Maher, 2009).

Magnetic minerals particularly those derived from vehicular combustion are having a size range of 0.1-0.7 µm (Pandey *et al.,* 2005; Maher, 2009). This grain size is particularly dangerous to humans because of its ability to be inhaled into the lungs ((Pandey *et al.,* 2005; Maher, 2009; Hansard *et al.,* 2011). Further, Matzka and Maher (1999) found that the grain size of magnetic particles from vehicle emissions to be of the order of 0.3- 3µ, a size of particular potential hazard to health. Iron often occurs as an impurity in fossil fuels during industrial, domestic, or vehicle combustion which ultimately forms a non-volatile residue, often comprising glassy spherules of magnetic nature, with easily measurable magnetization levels (Matzka and Maher, 1999). Also, combustion-related particles in vehicles, via exhaust emissions and abrasion or corrosion of engine and vehicle body material can generate non spherical magnetite particles (Pandey *et al.,* 2005; Maher, 2009).

Several researchers opined that environmental magnetism studies act as a proxy for vehicle derived pollutants through roadside plant leaves (Maher, 2009). Moreover, magnetic properties of PM may also act as a valuable tool in assessing the phenomenon of atmospheric climate change through the study of Chinese Loess Plateau. Dust or aerosol may act as indicators as well as agents of climate change, through radiative, cloud condensation and ocean biogeochemical effects (Watkins and Maher, 2003; Watkins *et al.,* 2007; Maher, 2011).

2.1 Particulate matter (PM)/dust pollution

Solid matter, which is composed of soil, anthropogenic metallic constituents, and natural biogenic materials, is called dust (Ferreira-Baptista and DeMiguel, 2005). The particulates belong to the class of poorly soluble particles that also encompasses carbon black, coal mine dust, and titanium dioxide (Borm *et al.,* 2004; Moller *et al.,* 2008). Measurements of the PM in ambient air are usually reported as the mass of particles with an aerodynamic diameter that is less than 2.5 µm ($PM_{2.5}$) or 10 µm (PM_{10}) (Zhu *et al.,* 2006). Aforesaid particle sizes are emphasized in view of their pertinent health impacts.

Dust pollution in the atmosphere, particularly of pollutant particles below 10 µm (PM_{10}), is of current concern worldwide due to adverse health effects associated with their inhalation (Morris *et al.,* 1995; Oberdorster, 2000; Calderon- Garciduenas *et al.,* 2004; Pope *et al.,* 2004; Faiz *et al.,* 2009). Moreover, PM in dust is thought to be the most harmful pollution component widely present in the environment, with no known level at which adverse human health effects occur (Bealey *et al.,* 2007).

Therefore, a well defined particulate pollution control policy structure is needed in view of their adverse impacts on flora and fauna, including human beings. Craig *et al.* (2008) made a guidance document in order to reflect critical science and policy aspects of air quality risk management including i) health effects, ii) air quality emissions, measurement and modelling, iii) air quality management interventions, and iv) clean air policy challenges and opportunities. It was based on findings of five annual meetings of the NERAM (Network for Environmental Risk Assessment and Management) International Colloquium Series on Air Quality Management (2001-2006) as well as researches of international repute.

As discussed earlier, that PM also comprises magnetic particles, therefore, it is necessary to characterize them and also to investigate their sources.

2.2 Sources of PM and characterization of magnetic particles

Sources of particulate pollution may be natural or anthropogenic in nature. Emission sources may include natural processes such as wildfires, volcano eruption and dust storms. The magnetic particles derived from multifaceted resources may be ferromagnetic, antiferromagnetic and ferrimagnetic depending on the nature of spin acquired on the application of magnetic fields.

Biogenic ferrimagnets are also reported to be present in the organisms like termites (Maher, 1998a,b) and bacteria (Fassbinder *et al.,* 1990). Man-made pollution encompass combustion processes used for heating, power production, industry, and traffic vehicles (Hansard *et al.,* 2011). Road traffic is considered to be one of the major sources of environmental pollution in urban areas, whereas other anthropogenic activities like power plants, metallurgy, mining, dust originating from fragile rocks are of minor importance (Bucko *et al.,* 2010, 2011). Although vehicles are the prime source of particulates (Maricq, 1999; Maher *et al.,* 2008), however, other sources may also come in to play depending on the geography of particular landscapes (Rai, 2011b).

It has been shown that vehicle derived pollutants simultaneously release deleterious fine-grained particulates and magnetic particles into the atmosphere (Pandey *et al.,* 2005). Apart from vehicle derived particulates, street dust, also contains larger particles of PM posing little health risk (Simonich and Hites, 1995; Rautio *et al.,* 1998a,b,c; Veijalainen, 1998; Bargagli,1998; Steinnes *et al.,* 2000; Wolterbeek, 2002; Urbat *et al.,* 2004). In a case study on Geochemical and mineral magnetic characterization of urban sediment particulates, Manchester, UK by Robertson *et al.* (2003), largely ferrimagnetic multi-domain mineral magnetic composition of the particulates were recorded, indicating inputs of anthropogenic origin, primarily particulates derived from automobiles.

Industrial activity such as burning of fossil fuels also produces magnetically enhanced particulates in environment (Blundell *et al.,* 2009; Hansard *et al.,* 2011). Xia *et al.* (2008) showed that the magnetic assemblage in the dustfall, mainly originating by coal burning, is dominated by pseudo-single domain (PSD) magnetite associated with maghaemite and haematite. These particulates consist of coarse-grained multidomain and stable single domain magnetic minerals. The presence of magnetite as the dominant magnetic mineral has been confirmed by numerous analyses in different areas (Moreno *et al.,* 2003; Urbat *et al.,* 2004; Lehndorff *et al.,* 2006; Maher, 2009; Saragnese *et al.,* 2011; Hansard *et al.,* 2011). In a case study on magnetic properties of roadside dust in Seoul, Korea Kim *et al.* (2007) grouped magnetic materials into three types i.e. magnetic spherules possibly emitted from factories and domestic heating systems, aggregates derived from vehicle emission or motor vehicle brake systems, and angular magnetic particles of natural origin. There may be several magnetic minerals associated with particulates (having different magnetic status) derived from terrestrial environment.

2.3 Health impacts of PM pollution

PM is associated with many adverse human health impacts (Jahn *et al.,* 2011; Rohr and Wyzga, 2012; Taner *et al.,* 2013; Hicken *et al.,* 2014; Pascal *et al.,* 2014; Yadav *et al.,* 2014; Rai and Panda, 2014; Rai *et al.,* 2014; Kim *et al.,* 2015; Yang *et al.,* 2015). PM vehicular emissions, notably in the ultrafine fraction, have been specifically associated with endpoints such as oxidative stress and mitochondrial damage (Li *et al.*, 2003), lipid peroxidation (Pereira *et al.*, 2007), up regulation of genes relevant to vascular inflammation (Gong *et al.*, 2007), and early atherosclerosis and oxidative stress (Araujo *et al.*, 2008). Progression of atherosclerosis has also been reported due to exposure of PM pollution (Suwa *et al.*, 2002).

Inhalation exposure studies have shown that short term exposure to diesel exhaust has an acute inflammatory effect on normal human air ways resulting in marked neutrophilia, activation of mast cells and neutrophils and the production of cytokines and chemokine associated with neutrophil accumulation and activation (Salvi *et al.*, 2000; Frampton, 2001; Stenfors *et al.*, 2004). Epidemiologic studies conducted in different parts of the world have demonstrated an important association between ambient levels of motor vehicle traffic emissions and increased symptoms of asthma and rhinitis (Rai, 2013). Additionally, recent human and animal laboratory-based studies have shown that particulate toxic pollutants, and in particular diesel exhaust particles (DEP), can enhance allergic inflammation and induce the development of allergic immune responses (Salvi *et al.*, 2000; Frampton, 2001; Stenfors *et al.*, 2004).

Diesel exhaust-exposed workers have been shown to have an increased risk of lung cancer (Nielsen *et al.*, 1996 a,b; Scheepers *et al.*, 2002). Methods for the assessment of exposures to diesel exhaust were evaluated by comparing underground workers (drivers of diesel-powered excavators) at an oil shale mine in Estonia with surface workers and it was observed that underground miners were also occupationally exposed to benzene and polycyclic aromatic hydrocarbons, as indicated by excretion of urinary metabolites of benzene and pyrene and increased O^6-alkylguanine DNA adducts were detected in the white blood cells of underground workers, suggesting higher exposure to nitroso-compounds (Scheepers *et al.,* 2002). Diesel exhaust consists of a complex mixture of particulates which contain known genotoxicants, one of which is benzene. Muzyka *et al.* (1998) indicated significant differences in 5-aminolevulinic acid (ALA) synthesis and heme formation between the exposed workers to PM containing benzene when compared to the non-exposed individuals.

Chen *et al.* (2004) reported that ambient air pollution had acute and chronic effects on mortality, morbidity, hospital admissions, clinical symptoms, lung function changes, etc. in China. Schoket (1999), in his exhaustive study found that in Silesia, Poland, and Northern Bohemia, Czech Republic, where coal-based industry and domestic heating are the major sources of PAHs, significant differences have been observed in white blood cell DNA adducts and cytogenetic biomarkers between environmentally exposed and rural control populations, and significant seasonal variations of DNA damage have been detected. Further, Schoket (1999) found that in Copenhagen, Athens, Genoa and Cairo, Bus drivers, traffic policemen and local residents have been involved in biomarker studies and differences have been measured in the level of DNA damage of urban and rural populations.

Traffic originating from increased number of vehicles may cause multiple adverse health effects including asthma and allergic diseases, cardiac effects, respiratory symptoms, reduced lung function growth, adverse reproductive outcomes, premature mortality, and lung cancer (White *et al.,* 2005; Samet, 2007).

Various studies showed PM exposure, associated with elevated levels of c-reactive protein, a marker of systemic inflammation that may be important and independent predictor of cardiovascular diseases. For example, a recent study reported associations between CRP and interleukin (IL)-6 with PM in subjects with coronary artery disease (Delfino *et al.,* 2008). inflammatory lung injury, bone marrow and blood cell responses, enhanced human alveolar macrophage production of proinflammatory cytokines, elevated blood plasma viscosity (Ghio *et al.,* 2004), endothelial dysfunction and brachial artery vasoconstriction and triggering of myocardial infarction. Polichetti *et al.* (2009) extensively reviewed the impact of PM on cardiovascular system. Particulate matter is also linked with psychosocial stress and high blood pressure (Hicken *et al.,* 2014).

In literatures, it is well documented that particulate pollution causes adverse health impact particularly in the size range of less than 10μm (Curtis *et al.,* 2006; Lipmann, 2007; Zeger *et al.,* 2008; Mitchell *et al.,* 2010). PM pollutants are associated with adverse effects on respiratory system (Schwartz, 1996; Pope *et al.,* 2002; Knutsen *et al.,* 2004; Knox, 2006; Maher *et al.,* 2008; Hansard *et al.,* 2011). If these particulates of size lower than 10μm causes inflammation and diminished pulmonary function can be unavoidable (Seaton *et al.,* 1995; Knutsen *et al.,* 2004; Maher *et al.,* 2008). Further, PM with aerodynamic diameter smaller than 2.5 μm ($PM_{2.5}$) have even more deleterious health impacts because when inhaled they penetrate deeper than PM_{10} and can reach lungs alveola (Rizzio *et al.,* 1999; Harrison and Yin, 2000; Wichmann and Peters, 2000; Saragnese *et al.,* 2011). Links with lung cancer (*Pope et al.,* 2002) and increased cardiovascular mortality rates (Schwartz, 1996) have also been established. Lung diseases due to PM may be attributed to presence of inflammatory cells in the airways including neutrophils (PMN), eosinophils and monocytes (Mo), and increased numbers of alveolar macrophages (AM) (Becker *et al.,* 2002).

Global records showed PM below size 2.5 μm causes 3% of mortality from cardio-pulmonary disease; 5% of mortality from cancer of the trachea, bronchus and lung; and 10% of mortality from acute respiratory infections in children under five (Cohen *et al.,* 2005; Maher, 2009). It is well established through literatures that air pollution with PM in children results in detectable effects indicated by a number of biomarkers of exposure and early effects (Pedersen *et al.,* 2006). Aforesaid hypothesis was tested through a family pilot study which was conducted in the Czech Republic through fluorescence in situ hybridization (FISH) and it was concluded that micronuclei (MN) is a valuable and sensitive biomarker for early biological effect in children and adults living in two different areas characterised with significant exposure differences in c-PAHs concentrations during winter (Pedersen *et al.*, 2006).

There has been considerable concern on the pulmonary effects of particulates less than 2.5 μm ($PM_{2.5}$) or 10 μm (PM_{10}), as they can reach the alveoli and translocate to the circulation, whereas particles of larger size deposit mainly in the upper airways and can be cleared by the mucociliary system (Oberdorster *et al.,* 2005; Moller *et al.,* 2008). In the recent past, many studies highlighted the role of ambient airborne PM as an important environmental pollutant for many different cardiopulmonary diseases and lung cancer (Valavanidis *et al.,* 2008). Further, it has increasingly being realized that generation of reactive oxygen species (ROS) and oxidative stress is an important toxicological mechanism of particle induced lung cancer (Knaapen *et al.,* 2004; Risom *et al.,* 2005). The fraction of PM contains a number of constituents that may increase the generation of ROS by a variety of reactions such as transition metal catalyses, metabolism, redoxcycling of quinones, and inflammation. PM, thus, can generate oxidative damage to DNA, including guanine oxidation, which is mutagenic (Kasai, 1997; Moller *et al.,* 2008). The oxidative stress mediated by PM and resulting DNA damage may originate from generation of ROS from the surface of particles, soluble compounds such as transition metals or organic compounds, altered function of mitochondria or NADPH-oxidase, and activation of inflammatory cells capable of generating ROS and reactive nitrogen species (Risom *et al.,* 2005). Production of reactive oxygen species (ROS) and the secretion of inflammatory cytokines could interact by inducing cell death by apoptosis (Shukla *et al.,* 2000; Haddad, 2004; Dagher *et al.,* 2006).

In view of the abovementioned deleterious impacts of PM, it is important to investigate the feasible and eco-sustainable control technologies.

2.4 Magnetic biomonitoring approach of particulates for roadside plant leaves

In the light of several health hazard concerns mentioned in previous sections of the review, it is necessary to have a bird's eye view on the existing technologies, their limitations and an overview on biomonitoring potential of plant leaves.

2.4.1 Existing technologies

Dust particles can be removed from the atmosphere by dry, wet or occult deposition (National Expert Group on Transboundary Air Pollution, 2001). Dry deposition is the removal of pollutants by sedimentation under gravity, diffusion processes (i.e., Brownian motion) or by turbulent transfer resulting in impaction and interception. However, existing technologies for abatement of particulates are not cost-effective. Okona-Mensah *et al.* (2005) mentioned the use of Benzo[*a*]pyrene (B[a]P), Dibenzo[*a, h*]anthracene (DBA) and dibenzo[*a, l*]pyrene (DB[*a, l*]P) in control of PAH, however, hand in hand they reviewed the advantages of biomonitoring approach over these chemicals as they are carcinogenic. It is well known that vehicle-derived PM_{10} values decrease not only with increased distance from roads, but also with increased height (e.g. Maher *et al.,* 2008; Mitchell and Maher, 2009; Mitchell *et al.,* 2010). Therefore, conventional monitoring stations are not option for particulate pollution monitoring as they distantly located from residential area and their height is in excess of 3 m (Mitchell *et al.*, 2010).

Although several volatile and semi-volatile organic compounds are also frequently analysed using passive biomonitors (Eriksson *et al.,* 1989; Simonich and Hites, 1994; Davidson *et al.,* 2003; Urbat *et al.,* 2004), however, vegetation-atmosphere partitioning seems to be effective in abatement approaches (Calamari *et al.,* 1991; Yang *et al.,* 1991; Jensen *et al.,* 1992; Franzaring, 1997; Ockenden *et al.,* 1998; Wenzel *et al.,* 2000; Kylin *et al.,* 2002; Davidson *et al.,* 2003; Urbat *et al.,* 2004).

2.4.2 Biomonitoring and biomagnetic monitoring of particulates

Although, there are many conventional (physical and chemical) devices for assessment of air pollution, however, biomonitoring is an efficient tool (Rai *et al.,* 2014). Biological monitors are organisms that provide quantitative information on some aspects of their environment, such as how much of a pollutant is present (Martin and Coughtrey, 1982). 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 ecosystems (Pandey and Agrawal, 1993; Nowak and Rowntree, 1994; Nowak and Dwyer, 2000; Nowak *et al.,* 2002; Randolph, 2004).

Biomonitoring of dust pollution and its biochemical impact has attracted the attention of both national and international scientific communities. Internationally, the quantification and valuation of pertinent ecosystem services have drawn much attention over the last decade

(Nowak, 1994; Taha, 1996, 1997; McPherson *et al.,* 1997, 1998, 1999; Beckett *et al.*, 1998; Nowak *et al.*, 1998, 2000, 2002, 2006; Rosenfeld *et al.*, 1998; Scott *et al.*, 1998; Akbari *et al.,* 2001; Akbari, 2002).

Besides the application of advanced technologies in prevention and amelioration, the option of employing natural mechanisms to effect ecological abatement is occasionally adopted by design but commonly contributes by default. The main advantage of the plant's use as bio-monitor is that they are wide-spread providing a high density of sampling points (Moreno *et al.,* 2003). Moreover, the most economical and reasonable method for biomonitoring heavy metal levels in the atmosphere is using plants (Celik *et al.,* 2005). Among trees, evergreen species are better traps for particles than deciduous ones because of their greater leaf longevity, which can accumulate pollutants throughout the year (Gratani and Varone, 2006, 2007). Further, it might be worth mentioning that conifers also trap better because of larger leaf area.

Therefore, vegetation is an efficient sink for dust originating from diverse sources. Dust particles from the air mainly adhere to the outside of plants. This is in contrast to air polluting gases and very small particles (<0.1 mm) which are largely absorbed via an important part via the stomata into the leaves. The use of different plant materials as biomonitors of anthropogenic contamination is discussed in detail in Markert (1993).

Likewise, in the past decade there has been increased interest, in many parts of the world, in the study of tree leaves as bio accumulators of trace elements/metals present in dust, in the surroundings of industrial facilities (Helmisaari *et al.,* 1995; Nieminen and Helmisaari, 1996; Bussotti *et al.*, 1997; Giertych *et al.*, 1997; Mieieta and Murín, 1998; Rautio *et al.,* 1998a,b,c) and in urban environments (Alfani *et al.,* 1996; Monaci *et al.*, 2000), although few studies have been made of rural and background areas (Loppi *et al.*, 1997; Ukonmaanaho *et al.*, 1998; Ceburnis and Steinnes, 2000). Lehndorff and Schwark (2009) investigated the spatial distribution of three-ring polycyclic aromatic hydrocarbons and their derivatives (PAH-3) in Greater Cologne Conurbation (GCC) using pine needle as passive samplers.

Lichens, bryophytes or mosses and certain conifers were proved to be potent biomonitoring tool of air pollution in recent times (Al- Alawi *et al.,* 2007; Al-Alawi and Mandiwana, 2007; Larsen *et al.,* 2007; Tretiach *et al.,* 2007; Nali *et al.,* 2007; Batarseh *et al.,* 2008). Plants as well as lichens were also used in an integrated way for diagnosis of air quality (Nali *et al.,* 2007). Use of Pine as well as cypress bark was found fruitful in biomonitoring of air pollutants particularly heavy metals (Al-Alawi *et al.,* 2007; Al-Alawi and Mandiwana, 2007; Batarseh *et al.*, 2008).

However, biomagnetic monitoring, using tree leaves as sampling surfaces, can generate high spatial resolution PM10 proxy data (Hansard *et al.*, 2011). Since, atmospheric pollutants also consist of complex mixture of magnetic particles, which are derived from iron impurities in the fuel, biomagnetic monitoring through roadside plant leaves is extremely relevant in present scenario (Hansard *et al.,* 2011). Also, tree leaves are abundant in number and hence are convenient for sampling. Moreover, lichens and mosses may be less abundant in severely polluted urban areas and they are also climate specific unlike roadside tree plant leaves. Therefore, in urban areas higher plants are mostly suitable for monitoring dust pollution as lichens and mosses are often missing (Al-Alawi and Mandiwana, 2007). Moreover, magnetic techniques, using natural surfaces as passive collectors of particulate pollution, are sensitive, rapid, and relatively cheap (Mitchell *et al.*, 2010).

2.5 Global researches on environmental magnetism

With the advent of environmental magnetism, magnetic measurement is becoming an important means in particulate pollution study (Zhang *et al.,* 2007). In environmental magnetism, there is growing interest in using magnetic methods in sediment tracing in the urban environment (Beckwith *et al.,* 1990; Matzka and Maher, 1999; Xie *et al.,* 2001).

In plants and soil samples, minerals capable of acquiring magnetic remanence include mainly the iron oxides (magnetite, maghemite and hematite), oxyhydroxides (goethite) and sulphides (greigite). Magnetic iron sulphides are found only in reducing (anoxic) environments, such as estuarine muds, where organic matter is consumed by bacteria in the absence of oxygen. The strongest naturally occurring magnetic minerals are magnetite and maghemite, while hematite and goethite are magnetically much weaker.

The excellent potential 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 (Hay *et al.*, 1997; Hoffmann *et al.,* 1999; Shu *et al.,* 2000; Xie *et al.*, 2000; Urbat *et al.,* 2004), and vegetation samples including tree bark (Kletetschka *et al.,* 2003) and leaves or needles (Matzka and Maher, 1999; Jordanova *et al.,* 2003; Moreno *et al.,* 2003). In urban particulates, a strong correlation has been observed between magnetic susceptibility as well as remanence and PM_{10} concentrations (e.g. Morris *et al.,* 1995; Muxworthy *et al.,* 2003; Sagnotti *et al.,* 2006; Szönyi *et al.,* 2008; Sagnotti *et al.,* 2009; Hansard *et al.,* 2011), as a proxy for particulate pollution concentrations (Hansard *et al.,* 2011).

Active sampling i.e. through air filters has been used to discriminate particle sources and compare magnetic data with geochemical and meteorological data (Shu *et al.,* 2001;

Muxworthy *et al.,* 2001, 2003; Spassov *et al.,* 2004; McIntosh *et al.,* 2007). Passive methods include the study of soils and street dust (Hay *et al.,* 1997; Hoffmann *et al.,* 1999; Xie *et al.,* 2000; Urbat *et al.,* 2004; Shilton *et al.,* 2005; McIntosh *et al.,* 2007) and natural surfaces such as tree bark, tree leaves and pine needles (e.g. Flanders, 1994; Matzka and Maher, 1999; Moreno *et al.,* 2003; Urbat *et al.,* 2004; McIntosh *et al.,* 2007).

Blaha *et al.* (2008) analysed fly ash samples from a black coal-fired power plant in Germany through the comparison of the bulk sample grain-size (0.5-300 µm) and grain-size spectra from magnetic extracts (1-186.5 µm) and showed that strongly magnetic particles mainly occur in the fine fractions of <63 mm.

Although environmental magnetism parameters have been optimized as qualitative proxy indicators of the distribution of anthropogenic particulates, heavy metals and organic materials, however, Kim *et al.* (2009) proposed a quantitative magnetic proxy which is suitable for the monitoring of spatial and temporal pollution patterns in urban areas. In aforesaid study, performed in south-western Seoul, Kim *et al.* (2009) analysed road dust samples with thermomagnetic data in conjunction with intensive electron microscopy and found predominance of carbon-bearing iron-oxides, indicating that anthropogenic particulates mostly originated from fossil fuel combustions.

Muxworthy *et al.* (2003) advocated that saturation isothermal remanent magnetization (SIRM) was found to be strongly correlated with the PM mass, and not only acts as a proxy for PM monitoring but also is a viable alternative to magnetic susceptibility when the samples are magnetically too weak.

In several researches (Brilhante *et al.,* 1989; Charlesworth and Lees, 1997; Xie *et al.,* 2001), there is report on possible linkages between magnetic properties and heavy metals in street dust. Moreover, in aerosols, magnetite is associated to heavy metals e.g. zinc, cadmium and chromium (Georgeaud *et al.,* 1997) and to mutagenic organic compounds (Morris *et al.,* 1995), also dangerous to human health (Moreno *et al.,* 2003). Significant correlation between sample mutagenicity and magnetic susceptibility for urban dust samples has already been established (Morris *et al.,* 1995). Traditional geochemical methods (e.g. AAS, ICP-MS) are relatively complex, time-consuming and expensive, and are therefore not suitable for performing mapping or monitoring of large-scale heavy metal or sediment pollution (Zhang *et al.,* 2011).

Vehicle-derived pollutants act as major source of pollutants in the landscapes where intensive industries are not present. It has been shown that vehicle derived pollutants simultaneously release deleterious fine-grained particulates and magnetic particles into the atmosphere (Pandey *et al.,* 2005; Maher, 2009). Xie *et al.* (2001) on his investigation on Liverpool street dust suggested that magnetic properties, and mean values of some element concentrations and the organic matter content may be obtained with a small number of samples from a sampling period of one or several days.

Hoffmann *et al.* (1999) did the magnetic mapping of soil surface emanating due to vehicle pollution by measuring profiles of magnetic susceptibility along a German motorway. Further, one more study on magnetic properties dusts was done in the Munich city, which demonstrated high correlation between total PM_{10} dust mass and its magnetic concentration as revealed by having high saturation remanent magnetization {(SIRM) the magnetization retained by a sample after exposure to a large magnetic field, e.g. 300 mT or 1 T} (Matzka, 1997; Matzka and Maher, 1999).

Industrial sources e.g. thermal power plants emit fly ashes which also contribute to higher magnetic values (Schadlich *et al.,* 1995; Pandey *et al.,* 2005; Sharma and Tripathi, 2008; Hansard *et al.,* 2011).

Environmental magnetic proxies provide a rapid means of assessing the degree of industrial heavy metal pollution in air, soils and sediments (Zhang *et al.,* 2011). Roadside dusts act as a common source for the heavy metals and magnetic carriers as revealed by a strong positive inter-correlation between the concentrations of heavy metals (Fe, Mn, Cr, Zn, Pb, and Cu) and magnetic susceptibility (Lu *et al.*, 2008 a,b).

The association/correlation of magnetic properties with heavy metals may be demonstrated in soil samples (Lu *et al.,* 2008 a,b). The magnetic parameters could provide a proxy measure for the level of heavy metal contamination and could be a potential tool for the detection and mapping of contaminated soils. Lu *et al.* (2008a,b) investigated concentrations of copper (Cu) and zinc (Zn) and various magnetic parameters in contaminated urban roadside soils using chemical analysis and magnetic measurements and their results revealed that high magnetic susceptibility may be attributed to anthropogenic soft ferrimagnetic particles. Lu and Bai. (2006) also demonstrated a straight linear correlation between the magnetic mineral concentration-related parameters and the concentrations of Cu, Zn, Cd and Pb. Hu *et al.* (2007) demonstrated significant correlations between heavy metals and several magnetic properties of the topsoils (fromurban and agricultural site) in the Shanghai indicated that the magnetic techniques can be used for monitoring soil pollution.

Alagarsamy, (2009) performed the environmental assessment of heavy metal concentrations and its impact in the coastal environment using magnetic techniques and found strong relationships between Anhysteretic Remanent Magnetization and heavy metals which may be attributed to role of iron oxides checking metal concentrations.

Road dust extracted from snow, collected near a busy urban highway and a low traffic road in a rural environment (southern Finland), was studied using magnetic, geochemical and micromorphological analyses by Bucko *et al.* (2010) and results revealed the a decreasing trend in χ and selected trace elements was observed with increasing distance from the road edge.

Shilton *et al.* (2005) demonstrated significant correlations between the organic matter content of urban street dust and certain mineral magnetic properties, however, this group suggested that since the relationship may vary for different roads, even, within same area, therefore, caution should be taken before making the remark that magnetic parameters offer potential as a proxy for organic content.

McIntosh *et al.* (2007) found that concentration and grain-size trends across the roads act as the source of the magnetic signal where the relationships between IRM_{1T} (magnetic concentration) and the concentration of NO_x and PM_{10} showed that the magnetic signal is specific to traffic-related emissions and not to total particle mass. Saragnese *et al.* (2011) investigated that superparamagnetic particles of nanometric dimension were identified in the PM by magnetic techniques and proposed a model linking total nitrogen oxides with magnetic particles.

In the light of abovementioned discussion, it is quite clear that magnetic parameters may assist in multifaceted environmental geomagnetic studies (e.g. soil, street dust, sediments etc.).

CHAPTER- 3

STUDY AREA AND STUDY SITES

3.1 Description of study area

Mizoram (21˚56'–24˚31'N and 92˚16'–93˚26'E) is one of the eight states under northeast India (Figure 3.1), 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 Indian 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 (Champion and Seth, 1968). This region falls within the Indo-Burma hot spot regions (Rai, 2009). Aizawl district comes under Indo-Burma hotspot region of North East India (Rai, 2009, 2012), having variety of diverse plant species possess varying leaf morphology which can be utilized in sampling of dust deposition and hence, the study of magnetic parameters. The diversity of tropical evergreen plants prevails along the roadsides of Aizawl district, and therefore, it can retain the pollutants throughout the year; offering no seasonal constraint (Rai *et al.*, 2014).

Aizawl (21˚58'–21˚85'N and 90˚30'–90˚60'E), the capital of the Mizoram state is 1132 m above the sea level (asl). The altitude of Aizawl district varies from 800 to 1200 m asl. The climate of the area is typically monsoonic. The annual average rainfall is amounting ca. 2350 mm. This area experiences distinct seasons. The ambient air temperature is normally ranging from 20 to 30˚C in summer and 11 to 21˚C in winter (Laltlanchhuang, 2006; Rai *et al.*, 2014).

The meteorological data may enable to correlate the air pollution including the dust or particulate deposition; therefore average meteorological data (Figure 2) of the study area are also included for the study period. Landscape Geography may also affect the dispersal of particulates, therefore, we recorded latitude and longitude for different sampling sites.

3.2 Study sites

The study was carried out in Aizawl district from four different sampling points.

Site 1. Durtlang (23°46.11'N and 92°44.08'E): Durtlang is a connecting road between Mizoram and Assam and is one of the main and busy roads of this city with very high traffic density. Vehicles are the main source of pollution at this site.

Site 2. Zarkawt (23°44.17'N and 92°43.01'E): Zarkawt is a commercial place of Aizawl. Because of high traffic density the emission of dust particles is usually very high in this area.

Site 3. Ramrikawn (23°44.85'N and 92°40.81'E): Ramrikawn is very densely populated commercial area with markets, bus as well as taxi stand and Food Corporation of India (FCI). FCI provides space for food grain storage for entire 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). Moreover, Ramrikawn is also having a public bus and taxi stand, vehicular movement is rendered high in this area. Stone quarrying activities are also found in this area may lead emission of dust particles. Biomass burning through shifting cultivation is very common in this region (Rai, 2009, 2012); poses an enhanced load of suspended particulate matters in the atmosphere. Keeping in view, the specific Ramrikawn site is included in present investigation.

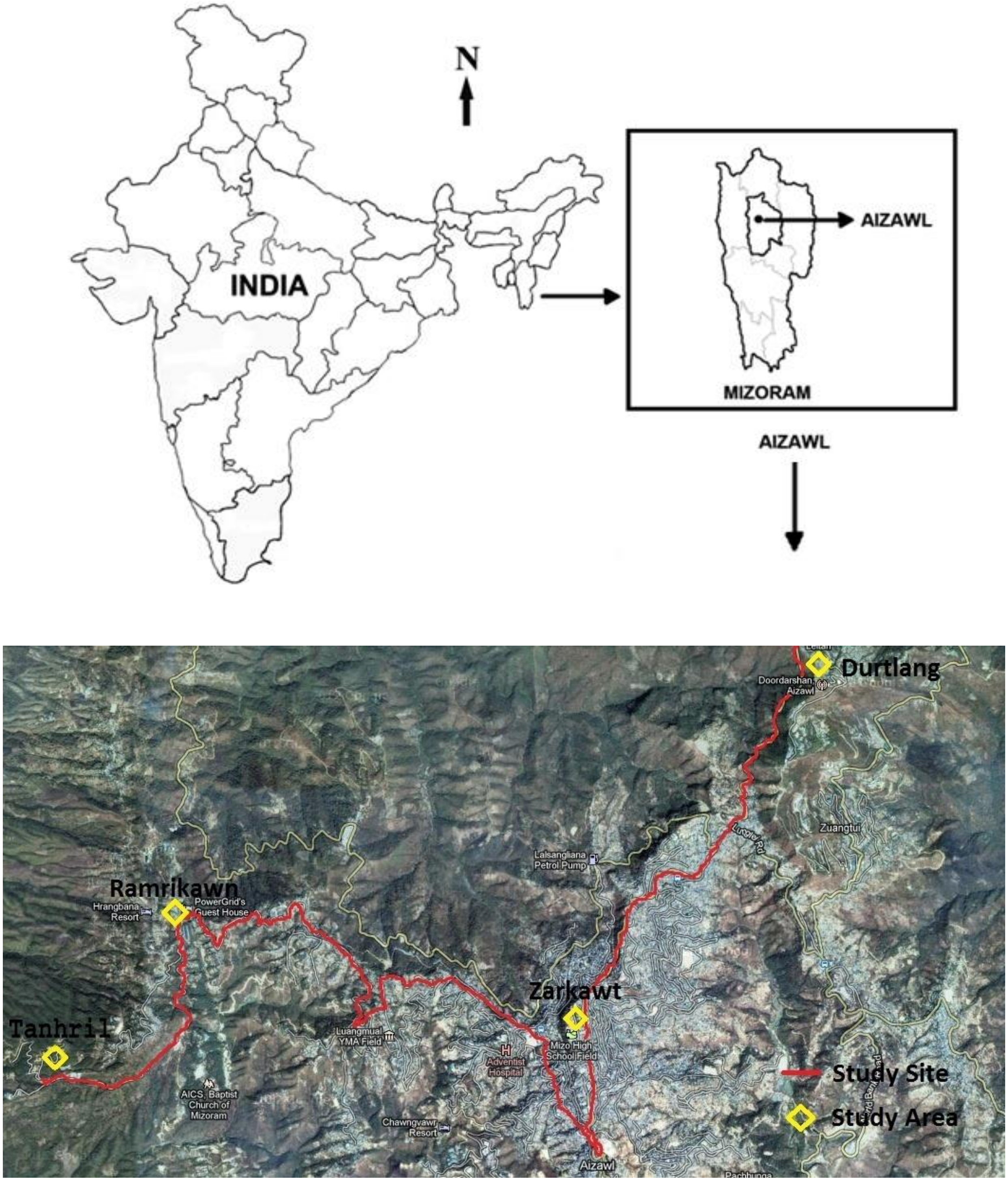

Figure. 3.1 Map of the Study Area, Aizawl, Mizoram, North East India.

Photo plate 3.1: Different sampling points.

Site 4. Tanhril (23°44.24'N and 92°39.64'E): Tanhril is a rural area having low vehicular activity, located in western part of Aizawl district. However, the load of vehicles is very low and less frequent in comparison to other site and therefore included as reference or control site in order to compare the results recorded from other sites.

3.3 Study Area Meteorology

The meteorological data from 2012 to 2014 was procured from Border Roads Task Force (BRTF), Puspak, Aizawl. The study site characteristics may be presented as follows.

3.3.1 Temperature

The average ambient temperature at Aizawl site ranged from 10.9°C to 28.7°C. The maximum and minimum monthly temperature values were 28.6°C (April) and 10.9°C (January) during 2012; 28.7°C (March) and 11.9°C (December) during 2013; 28.8°C (March) and 12.4°C (December) during 2014 (Figure 3.2).

3.3.2 Relative Humidity

The relative humidity range from 33.0% to 97.8%. The maximum and minimum monthly humidity values were 97.2% (September) and 33.3% (February) during 2012; 97.8% (August) and 27.7% (February) during 2013; 98.4% (August) and 26.3% (February) during 2014 (Figure 3.2).

3.3.3 Rainfall

During the year 2012-2014, Aizawl received total annual rainfall of 2213 mm. The maximum and minimum monthly rainfall values were 412.0 mm (August) and 0.70 mm (February) during 2012; 505.5 mm (June) and 007.3 mm (February) during 2013; 507.0 mm (June) and 2.4 mm (February) during 2014 (Figure 3.2).

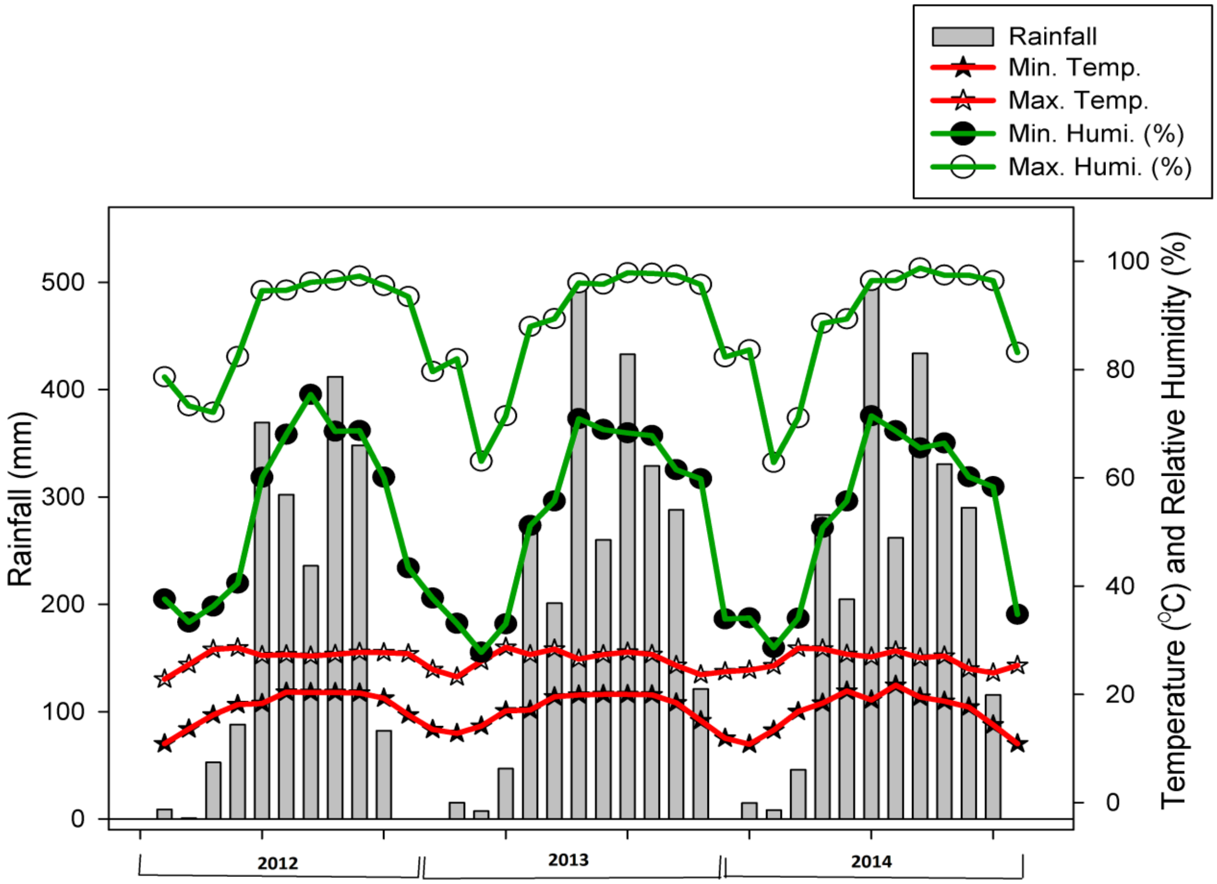

Figure. 3.2 Mean monthly rainfall (mm), maximum and minimum humidity (%) & maximum and minimum temperature (°C) at Aizawl during the study period 2012 to 2014.

3.4 Sources of Pollution

The Aizawl district, capital of Mizoram is heavily entrapped with heavy vehicles load resulting in increased quantity of vehicular emission particularly dust/particulates in urban areas. Rapid urbanization and continuously expanding population has been the major cause of increase in the number of vehicles and hence particulates. On every crossway in Aizawl, there is a heavy traffic fleet of maxi cab and state transport buses, which are the major mode of transport connecting different parts of Aizawl. Particularly during the late morning and evening time, there is heavy traffic all around the Aizawl city. Also, a part of Aizawl district is connected to the National Highway road NH 54 (Pushpak) going to Airport, Silchar, Shillong and finally Guwahati which harbours heavy vehicular fleet. Apart from vehicular dust generation other anthropogenic sources are soil erosion, mining and stone quarrying activities. Since the rocks of Aizawl are very fragile, the weathered rock dust may also get deposited on plant leaves. Particularly, particulates below the size of 10 micron pose serious threat to vegetation and human health. Moreover shifting cultivation is very common. The soot particles from the burning of the remains of the plant material also takes a great role in the pollution of the particular area.

CHAPTER- 4

MATERIAL AND METHODS

4.1 Air quality analysis

Sampling was done using ‘High Volume Sampler’ (Envirotech APM 460) on 24 hour basis for Suspended Particulate Matter (SPM) and Respirable Suspended Particulate Matter (RSPM) during the months of May, 2013 to May, 2015 with a frequency of once in a week at four sampling sites (details given in Figure. 3.1). 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.

High Volume Sampler with a cyclone attachment fractionates the dust into respirable and non-respirable fractions. The suspended particles enter the cyclone where coarse non-respirable suspended particulate matter (NRSPM) is separated from the air stream by centrifugal force. It falls through the cyclone’s conical hopper and gets collected in the pre-weighed cyclonic cup. The fine dust comprising the respirable fraction (RSPM or PM_{10}) of the suspended particulate matter is collected on a pre-weighed Whatman glass microfibre filter paper (GF/A 20.3 x 25.4 cm). The Sampler is fixed at a breathing height of 2 m above the ground level and flow rate is noted after 5 minutes of starting of the sampling. The RSPM collected over the GF filter paper and the NRSPM collected in the cyclonic cup are weighed using an electronic top loading weighing balance. The concentration of the particulate matter is estimated on the net mass collected divided by the volume of air sampled. The amount of non-respirable suspended particulate matter (NRSPM) is added to the amount of RSPM for calculation of SPM.

4.1.1 Concentration of SPM

$$\textbf{SPM (}\boldsymbol{\mu}\textbf{g/m}^{\mathbf{3}}\textbf{) =} \quad \frac{(W_f - W_i) \times 10^6}{V}$$

Where,

W_f = Final weight of filter in gm

W_i = Initial weight of filter in gm

V = Volume of air sample

4.1.2 Concentration of RSPM

$$\textbf{RSPM (}\boldsymbol{\mu}\textbf{g/m}^{\mathbf{3}}\textbf{) =} \quad \frac{(W_f - W_i) \times 10^6}{V}$$

Where,

W_f = Final weight of filter in gm

W_i = Initial weight of filter in gm

V = Volume of air sample

4.2 Magnetic parameters

- For magnetic analysis, sampling was conducted during the months of May, 2013 to May, 2015. Ten socio-economically important and evergreen plant species of common occurrence along the roadside i.e. *Mangifera indica*, *Hibiscus rosa-sinensis*, *Bougainvillea spectabilis*, *Cassia auriculata*, *Lantana camara*, *Artocarpus heterophyllus*, *Psidium guajava*, *Ficus bengalensis*, *Ficus religiosa* and *Bauhinia variegata* were selected for the study. 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 make them powder form. After that packed them into the 10 cc plastic sample pots and 2 gm of each sample were taken for magnetic analysis (Walden,1999).

Table 4.1. Vegetation characteristics of common roadside plant species selected for the study.

Sl. No.	Scientific Name	Common Name	Family	Habit	Nature	Leaf Characteristics	Uses
1.	*Ficus benghalensis* Linn.	Bengal fig, Indian banyan, Indian fig	Moraceae	Tree	Evergreen	The leaves are large, leathery, entire, ovate or elliptic, Coriaceous, Rough on the upper side	Medicinal, fodder, timber, making paper pulp.
2.	*Psidium guajava* Linn.	Apple guava, common guava	Myrtaceae	Small Tree	Evergreen	Aromatic leaves, opposite, entire, broad, hard, concave and directed horizontal	Medicinal, dyeing silk and cotton, for making handicraft and turnery.
3.	*Bougainvillea spectabilis* Willd.	Paper flower	Nyctaginaceae	Shrub	Evergreen or Semi-Evergreen	Simple, alternate, oval in shape, tapering to a point, smooth, slightly folded margin	Ornamental.
4.	*Mangifera indica* Linn.	Mango	Anacardiaceae	Tree	Evergreen	Spirally arranged on branches, linear-oblong, short petiole, large and thick surface.	Edible, medicinal and timber.
5.	*Lantana camara* Linn.	Big sage, tick berry, wild sage.	Verbenaceae	Shrub	Evergreen	Textured surface covered with rough hairs, wavy margin, and short petiole.	Medicinal, ornamental, Furniture making and firewood.
6.	*Hibiscus rosasinensis* Linn.	China rose, Chinese hibiscus, shoe flower.	Malvaceae	Shrub	Evergreen	Toothed leaves, alternately arranged, large, smooth, shiny and long petiole	Ornamental, edible, Medicinal, cosmetics,fibre
7.	*Ficus religiosa* Linn.	Bo tree, Bodhi tree, peepal, sacred fig.	Moraceae	Tree	Deciduous or semi evergreen	Cordate in shape with a distinctive extended drip tip, long petiole, smooth and shiny	Medicinal.
8.	*Cassia auriculata* Linn.	Golden shower tree	Fabaceae	Shrub	Evergreen	Alternate, small leaf area, smooth, flat surface and slender,	Ornamental, Medicinal.
9.	*Artocarpus heterophyllus* Lam.	Jackfruit, jaca, nangka.	Meraceae	Tree	Evergreen	Oblong, oval, or elliptic, glossy, smooth and flat surface.	Edible, timber, fodder, making furniture, latex, medicinal.
10.	*Bauhinia variegata* Linn.	Orchid tree, mountain ebony.	Fabaceae /Leguminosae	Tree	Deciduous	Leaves are Cow's Hoof shaped, broad, hard, weep downward and flat surface	Medicinal, edible, dye making and ornamental.

Bougainvillea spectabilis.

Cassia auriculata.

Photo plate 4.1: Selected plant species for the study.

Mangifera indica.

Artocarpus heterophyllus.

Photo plate 4.2: Selected plant species for the study.

Ficus bengalensis.

Ficus religiosa.

Photo plate 4.3: Selected plant species for the study.

Psidium guajava.

Hibiscus rosa-sinensis.

Photo plate 4.4: Selected plant species for the study.

Lantana camara.

Bauhinia variegata.

Photo plate 4.5: Selected plant species for the study.

The magnetic parameters such as magnetic susceptibility (χ), anhysteretic remanent magnetization (ARM) and saturation isothermal remanent magnetization (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.

4.2.1 Magnetic susceptibility (χ)

The magnetic susceptibility reflects the total composition of the dust deposited on the leaves, with a prevailing contribution from ferromagnetic minerals, which could show higher susceptibility values than paramagnetic and diamagnetic minerals, such as, 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. The sensitivity of this instrument was in the range of $10^{-6}m^3kg^{-1}$.

$\boldsymbol{\chi_{LF}}$ **($10^{-6}m^3kg^{-1}$) =** (value/mass) x 10

4.2.2 Anhysteretic remanent magnetisation (ARM)

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).

ARM ($10^{-5}Am^2kg^{-1}$) =Value/ (mass x 0.4 x 79.6)

4.2.3 Saturation Isothermal remanent magnetisation (SIRM)

SIRM indicates 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 (Power *et al.,* 2009). 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.

4.2.4 S-ratio

The ratio of IRM-300 and SIRM is defined as the S-ratio (King and Channell, 1991). The S-ratio mainly reflects the relative proportion of antiferromagnetic to ferrimagnetic minerals in a sample. A ratio close to 1.0 reflects almost pure magnetite while ratios of <0.8 indicate the presence of some antiferromagnetic minerals, generally goethite or haematite (Thompson, 1986).

4.3 Statistical analysis

All statistical calculation was performed using Statistical Programme for Social Science (SPSS version 11.2).

CHAPTER- 5
RESULTS AND DISCUSSION

5.1 Particulate pollutants

The average seasonal values of two air pollutants (SPM and RSPM) recorded at four study sites throughout two years sampling period is presented in Tables 5.1 and 5.2.

The average concentration of SPM at Ramrikawn, Tanhril, Zarkawt and Durtlang were 263.12 ±0.01, 210.91±0.16, 223.51±0.11 and 220.22±0.24 µg/m^3 in summer; 260.01±0.12, 207.07±0.41, 229.21±0.02 and 224.07±0.01 µg/m^3 in winter and 98.04±0.04, 42.9±0.21, 93.01±0.29 and 87.03±0.32 µg/m^3 in rainy seasons respectively for the year of 2013-14. In 2014-15, the mean values of SPM at Ramrikawn, Tanhril, Zarkawt and Durtlang were 272.15 ±0.11, 217.11±0.06, 230.81±0.21 and 227.72±0.14 µg/m^3 in summer; 277.11±0.08, 214.08±0.19, 236.06±0.08 and 231.52±0.03 µg/m^3 in winter and 93.04±0.12, 49.7±0.06, 98.31±0.07 and 81.09±0.28 µg/m^3 in rainy seasons respectively.

The mean values of RSPM at Ramrikawn, Tanhril, Zarkawt and Durtlang were 228.09 ±0.23, 102.31±0.02, 189.03±0.08 and 183.41±0.03 µg/m^3 in summer; 232.23±0.19, 109.28±0.04, 200.61±0.41 and 190.15±0.11 µg/m^3 in winter and 71.21±0.83, 20.18±0.12, 63.18±0.19 and 56.91±0.05 µg/m^3 in rainy seasons respectively for the year of 2013-14. In 2014-15, average concentration of RSPM at Ramrikawn, Tanhril, Zarkawt and Durtlang were 231.18 ±0.01, 108.82±0.07, 192.08±0.02 and 188.38±0.12 µg/m^3 in summer; 237.07±0.06, 114.51±0.11, 203.21±0.21 and 193.62±0.23 µg/m^3 in winter and 78.17±0.29, 21.12±0.26, 72.05±0.08 and 61.06±0.09 µg/m^3 in rainy seasons respectively.

Table 5.1: The average concentration of two air pollutants (SPM and RSPM) at four 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**

Table 5.2: The average concentration of two air pollutants (SPM and RSPM) at four different study sites during 2014 - 15.

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})	272.15± 0.11	277.11± 0.08	93.04± 0.12	217.11± 0.06	214.08± 0.19	49.7± 0.06	230.81± 0.21	236.06± 0.08	98.31± 0.07	227.72± 0.14	231.52± 0.03	81.09± 0.28	**200**
RSPM (µg m^{-3})	231.18± 0.01	237.07± 0.06	78.17± 0.29	108.82± 0.07	114.51± 0.11	21.12± 0.26	192.08± 0.02	203.21± 0.21	72.05± 0.08	188.38± 0.12	193.62± 0.23	61..06± 0.09	**100**

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

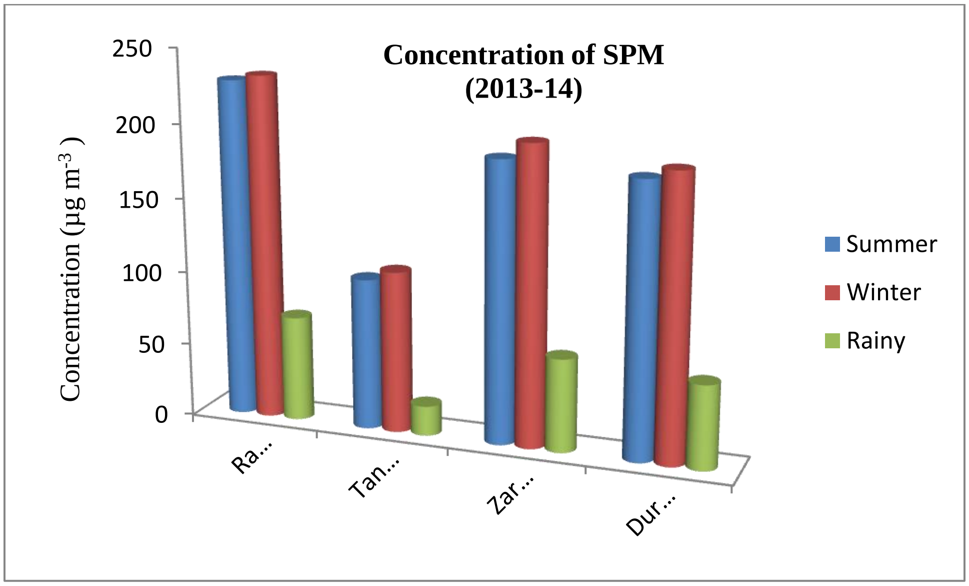

Figure 5.1: Concentration of SPM (µg m^{-3}) at different sites of Aizawl.

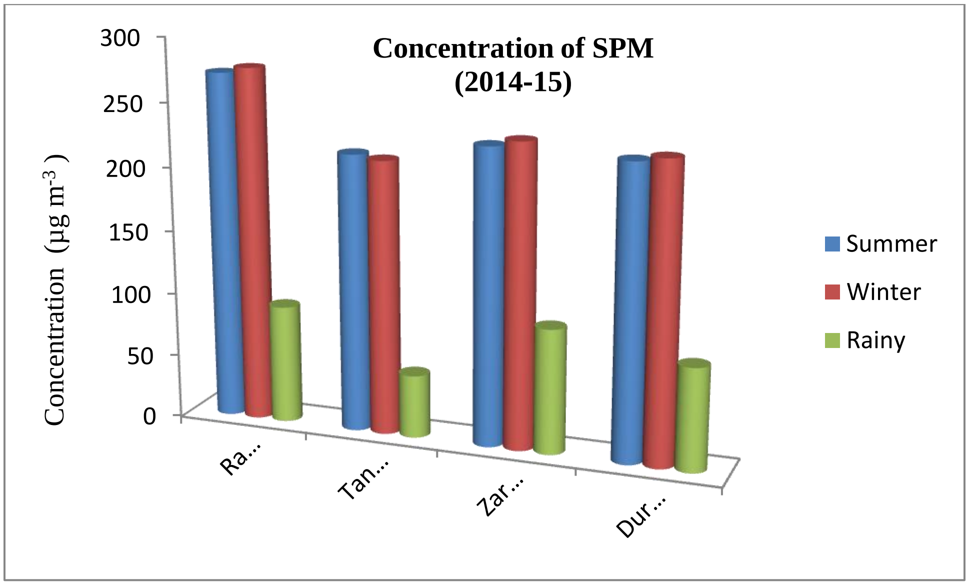

Figure 5.2: Concentration of SPM (µg m^{-3}) at different sites of Aizawl.

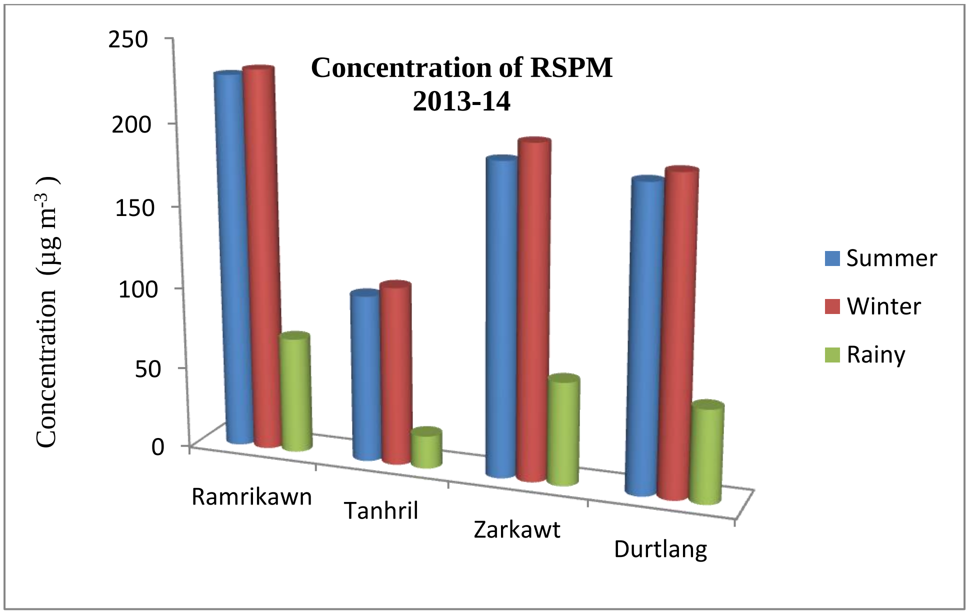

Figure 5.3: Concentration of RSPM (µg m^{-3}) at different sites of Aizawl.

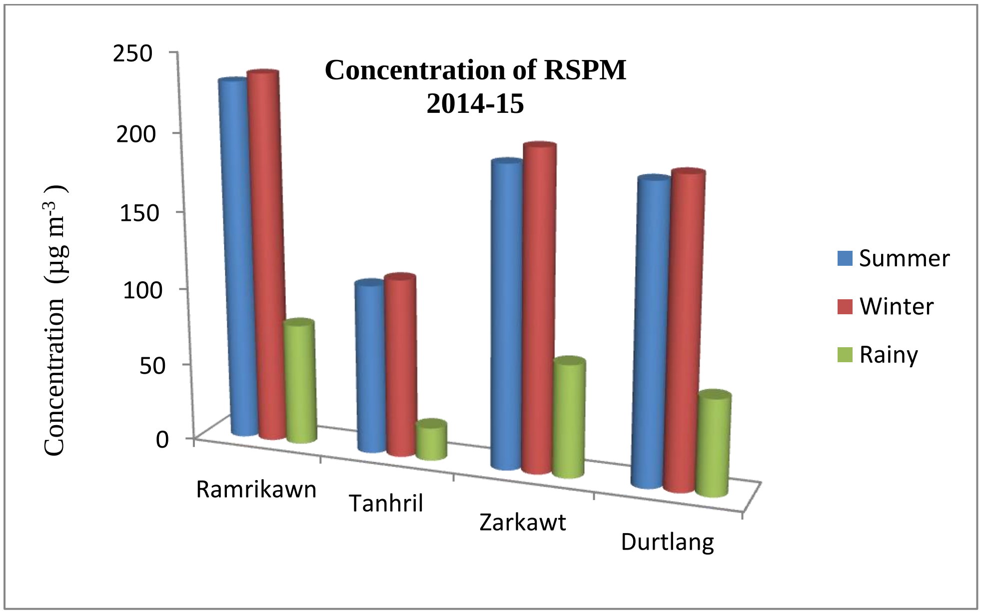

Figure 5.4: Concentration of RSPM (µg m^{-3}) at different sites of Aizawl.

The ambient PM concentrations were recorded highest at Ramrikawn, followed by Zarkawt and Durtlang, while lowest values were recorded at Tanhril site. The quantity of SPM and RSPM at four different the sites were much higher than the prescribed limits of Central Pollution Control Board (CPCB) of India during summer and winter season. 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 (Verma and Singh, 2006). 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 (at the time of study) may be the reason for the augmented concentration of air pollutants at different study sites. During rainy season very negligible PMs were found in plant leaves therefore we were not taking this season for magnetic analysis.

5.2 Magnetic analysis

The average magnetic data collected throughout two years sampling period is presented in Tables 5.3 to 5.10, respectively for all ten tree leaves.

5.2.1 Magnetic susceptibility (χ)

Magnetic susceptibility (χ) values of Ramrikawn site ranged from 20.22±0.07 to 52.28±0.21 (10^{-7} m^3 kg^{-1}) in winter with maximum in *Ficus benghalensis* (52.28±0.21) (10^{-7} m^3 kg^{-1}) and minimum in *Bauhinia variegata* (20.22±0.07) (10^{-7} m^3 kg^{-1}); 15.33±0.37 to 29.11±0.22 (10^{-7} m^3 kg^{-1}) in summer with maximum in *Artocarpus heterophyllus* (29.11±0.22) (10^{-7} m^3 kg^{-1}) and minimum in *Bauhinia variegata* (15.33±0.37) (10^{-7} m^3 kg^{-1}).

The minimum and maximum values of Magnetic susceptibility (χ) in Tanhril site ranged from 11.13±0.02 (10^{-7} m^3 kg^{-1}) (*Cassia auriculata*) to 27.98±1.74 (10^{-7} m^3 kg^{-1}) (*Ficus bengalensis*) and 7.73±0.11 (10^{-7} m^3 kg^{-1}) (*Bauhinia variegata*) to 15.11±0.27 (10^{-7} m^3 kg^{-1}) (*Artocarpus heterophyllus*) during the winter and summer respectively.

Similarly the values of Magnetic susceptibility (χ) in Zarkawt site ranged from 17.27±0.91 (10^{-7} m^3 kg^{-1}) (*Ficus religiosa*) to 45.53±0.19 (10^{-7} m^3 kg^{-1}) (*Mangifera indica*) and 13.23±0.55 (10^{-7} m^3 kg^{-1}) (*Bauhinia variegata*) to 27.97±0.11(10^{-7} m^3 kg^{-1}) (*Mangifera indica*) during the winter and summer respectively.

Magnetic susceptibility (χ) values of Durtlang site ranged from 14.19±0.12 to 37.01±0.12 (10^{-7} m^3 kg^{-1}) in winter with maximum in *Ficus benghalensis* (37.01±0.12) (10^{-7} m^3 kg^{-1}) and minimum in *Cassia auriculata* (14.19±0.12) (10^{-7} m^3 kg^{-1}); 10.11±0.43 to 25.12±0.52 (10^{-7} m^3 kg^{-1}) in summer with maximum in *Ficus benghalensis* (25.12±0.52) (10^{-7} m^3 kg^{-1}) and minimum in *Bauhinia variegata* (10.11±0.43) (10^{-7} m^3 kg^{-1}). Several researches demonstrated that magnetic susceptibility is a useful proxy parameter to monitor the regional distribution of air PM matter pollution or relative changes in an area (e.g., Moreno *et al.*, 2003; Gautam *et al.*, 2005; Sant'Ovaia *et al.*, 2012; Rai *et al.*, 2014).

5.2.2 Anhysteretic remanent magnetisation (ARM)

ARM values of Ramrikawn site ranged from 8.24±0.31 to 48.72±0.92 (10^{-5} Am^2 kg^{-1}) in winter with maximum in *Ficus benghalensis* (48.72±0.92) (10^{-5} Am^2 kg^{-1}) and minimum in *Bauhinia variegata* (8.24±0.31) (10^{-5} Am^2 kg^{-1}); 13.39±0.11 to 26.92±0.77 (10^{-5} Am^2 kg^{-1}) in summer with maximum in *Artocarpus heterophyllus* (26.92±0.77) (10^{-5} Am^2 kg^{-1}) and minimum in *Cassia auriculata* (13.39±0.11) (10^{-5} Am^2 kg^{-1}).

The minimum and maximum values of ARM in Tanhril site ranged from 5.01±0.11(10^{-5}Am^2 kg^{-1}) (*Psidium guajava*) to 23.31±0.51 (10^{-5} Am^2 kg^{-1}) (*Ficus bengalensis*) and 6.23±0.71 (10^{-5} Am^2 kg^{-1}) (*Bauhinia variegata*) to 13.21±0.63 (10^{-5} Am^2 kg^{-1}) (*Artocarpus heterophyllus*) during the winter and summer respectively.

Similarly the values of ARM in Zarkawt site ranges from 8.19±0.41 (10^{-5} Am^2 kg^{-1}) (*Lantana camara*) to 42.33±0.73 (10^{-5} Am^2 kg^{-1}) (*Mangifera indica*) and 10.27±0.49(10^{-5} Am^2 kg^{-1}) (*Cassia auriculata*) to 25.92±0.11 (10^{-5} Am^2 kg^{-1}) (*Mangifera indica*) during the winter and summer respectively.

ARM values of Durtlang site ranged from 4.46±0.23 to 33.28±0.07 (10^{-5} Am^2 kg^{-1}) in winter with maximum in *Mangifera indica* (33.28±0.07) (10^{-5} Am^2 kg^{-1}) and minimum in *Psidium guajava* (4.46±0.23) (10^{-5} Am^2 kg^{-1}); 9.01±0.27 to 23.97±0.07 (10^{-5} Am^2 kg^{-1}) in summer with maximum in *Ficus benghalensis* (23.97±0.07) (10^{-5} Am^2 kg^{-1}) and minimum in *Bauhinia variegata* (9.01±0.27) (10^{-5} Am^2 kg^{-1}).

Table 5.3: Summary of the magnetic data (mean and standard error) for roadside dusts on different selective plant (tree & shrubs) leaves at Ramrikawn area.

Plants	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)	**2014-15 (Winter)**	**2013-14 (Winter)**	**2014-15 (Winter)**	**2013-14 (Winter)**	**2014-15 (Winter)**	**2013-14 (Winter)**	**2014-15 (Winter)**	**2013-14 (Winter)**	**2014-15 (Winter)**	**2013-14 (Winter)**	**2014-15 (Winter)**
Mangifera indica	46.27± 0.71	48.56± 0.22	44.96±0.17	43.77± 0.28	284.96± 0.72	296.21± 0.17	0.97	0.90	6.15	6.09	0.963	0.967
Artocarpus heterophyllus	38.21± 0.42	38.41± 0.17	23.10± 0.31	24.11± 0.17	265.21± 0.61	278.19± 0.19	0.60	0.62	6.94	7.24	0.951	0.959
Ficus bengalensis	49.71± 0.21	52.28± 0.21	43.01± 0.27	48.72± 0.92	314.52± 0.11	298.15± 0.31	0.86	0.93	6.32	5.70	0.961	0.967
Psidium guajava	44.78±0.15	47.11± 0.12	40.74± 0.49	40.23± 0.21	292.62± 0.77	301.27± 0.11	0.90	0.85	6.53	6.39	0.952	0.957
Lantana camara	37.09± 0.81	38.12± 0.91	8.24± 0.31	9.19± 0.44	203.70± 0.52	211.90± 0.71	0.22	0.24	5.49	5.55	0.951	0.958
Bauhinia variegata	20.22± 0.07	21.44± 0.27	18.47± 0.97	17.27± 0.23	262.14± 0.94	273.47± 0.56	0.91	0.80	12.96	12.75	0.941	0.947
Cassia auriculata	21.45± 0.25	21.77± 0.72	20.77± 0.14	19.29± 0.14	242.72± 0.09	273.33± 0.13	0.96	0.88	11.31	12.55	0.947	0.944
Hibiscus rosa-sinensis	25.12± 0.38	26.33± 0.21	23.72± 0.22	24.17± 0.32	266.19± 0.36	276.72± 0.22	0.94	0.91	10.59	10.50	0.931	0.934
Ficus religiosa	23.42± 0.14	24.17± 0.17	22.32± 0.36	23.91± 0.14	277.41± 0.41	291.72± 0.11	0.95	0.98	11.84	12.06	0.941	0.952
Bougainvillea spectabilis	28.42± 0.08	29.22± 0.27	29.32± 0.22	30.01± 0.24	273.41± 0.31	278.22± 0.11	1.03	1.02	9.62	9.52	0.938	0.939

Table 5.4: Summary of the magnetic data (mean and standard error) for roadside dusts on different selective plant (tree & shrubs) leaves at Tanhril area.

Plants	**χ $(10^{-7}\, m^3\, kg^{-1})$**		**ARM $(10^{-5}\, Am^2\, kg^{-1})$**		**SIRM $(10^{-5}\, Am^2\, kg^{-1})$**		**ARM/ χ $(10^2 Am^{-1})$**		**SIRM/ χ $(10^2 Am^{-1})$**		**S-ratio**	
	2013-14 (Winter)	**2014-15 (Winter)**	**2013-14 (Winter)**	**2014-15 (Winter)**	**2013-14 (Winter)**	**2014-15 (Winter)**	**2013-14 (Winter)**	**2014-15 (Winter)**	**2013-14 (Winter)**	**2014-15 (Winter)**	**2013-14 (Winter)**	**2014-15 (Winter)**
Mangifera indica	23.71± 0.11	23.19± 0.72	10.71± 0.24	12.10± 0.13	177.41± 0.41	181.09± 0.02	0.45	0.52	7.48	7.80	0.941	0.952
Artocarpus heterophyllus	24.44± 0.27	24.48± 0.71	20.24± 0.08	19.22± 0.26	206.11± 0.37	218.28± 0.98	0.82	0.78	8.43	8.91	0.919	0.928
Ficus bengalensis	25.19± 0.91	27.98± 0.14	21.76± 0.82	23.31± 0.51	203.96± 0.56	214.52±0.93	0.86	0.83	8.09	7.66	0.901	0.912
Psidium guajava	23.11± 0.21	23.27± 0.23	5.01± 0.11	5.67± 0.27	154.2± 0.17	158.27± 0.42	0.21	0.24	6.66	6.80	0.954	0.958
Lantana camara	19.72± 0.41	19.83± 0.44	7.19± 0.18	8.27± 0.51	140.41± 0.44	148.17± 0.27	0.36	0.41	7.12	7.47	0.954	0.957
Bauhinia variegata	12.14± 0.03	11.94± 0.27	10.23± 0.99	10.37± 0.24	112.42± 0.26	130.44± 0.29	0.84	0.86	9.26	10.92	0.877	0.881
Cassia auriculata	11.13± 0.02	12.67± 0.17	09.18± 0.19	11.27± 0.79	133.76± 0.29	140.51± 0.11	0.82	0.88	12.01	11.08	0.881	0.897
Hibiscus rosa-sinensis	12.13± 0.11	12.44± 0.27	10.18± 0.18	11.21± 0.03	168.76± 0.18	172.12± 0.17	0.83	0.90	13.91	13.83	0.982	0.981
Ficus religiosa	11.41± 0.14	11.92± 0.22	10.74± 0.19	9.27± 0.13	122.47± 0.03	131.24± 0.32	0.94	0.77	10.73	11.01	0.931	0.929
Bougainvillea spectabilis	11.14± 0.09	11.29± 0.14	9.38± 0.11	11.22± 0.73	150.44± 0.15	156.21± 0.22	0.84	0.99	13.50	13.83	0.873	0.877

Table 5.5: Summary of the magnetic data (mean and standard error) for roadside dusts on different selective plant (tree & shrubs) leaves at Zarkawt area.

Plants	**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)	**2014-15 (Winter)**	**2013-14 (Winter)**	**2014-15 (Winter)**	**2013-14 (Winter)**	**2014-15 (Winter)**	**2013-14 (Winter)**	**2014-15 (Winter)**	**2013-14 (Winter)**	**2014-15 (Winter)**	**2013-14 (Winter)**	**2014-15 (Winter)**
Mangifera indica	43.08± 0.21	45.53± 0.19	40.27± 0.01	42.33± 0.73	271.21± 0.09	268.19± 0.92	0.93	0.92	6.29	5.89	0.960	0.958
Artocarpus heterophyllus	39.19± 0.42	40.23± 0.27	12.76± 0.29	13.27± 0.17	266.11± 0.61	268.19± 0.27	0.32	0.32	6.79	6.66	0.953	0.951
Ficus bengalensis	43.19± 0.17	44.28± 0.76	40.71± 0.42	38.91± 0.53	281.03± 0.52	289.09± 0.05	0.94	0.87	6.50	6.52	0.960	0.962
Psidium guajava	34.62± 0.29	36.19± 0.72	9.53± 0.38	12.13± 0.91	273.41± 0.63	295.12± 0.17	0.27	0.33	7.89	8.15	0.953	0.961
Lantana camara	33.87± 0.54	33.96± 0.17	8.19± 0.41	12.24±0.14	201.42± 0.26	219.21±0.03	0.24	0.36	5.94	6.45	0.952	0.961
Bauhinia variegata	17.42± 0.92	18.19± 0.12	16.43± 0.03	16.33±0.14	248.72±0.6	246.11± 0.72	0.94	0.89	14.27	13.52	0.934	0.931
Cassia auriculata	21.14± 0.11	22.77± 0.72	17.69± 0.22	18.97± 0.12	232.09± 0.12	250.17± 0.91	0.83	0.83	10.97	10.98	0.912	0.921
Hibiscus rosa-sinensis	26.14± 0.18	26.77± 0.03	24.69± 0.08	25.17± 0.21	256.09± 0.29	263.12± 0.14	0.94	0.94	9.79	9.82	0.972	0.978
Ficus religiosa	17.27±0.91	19.24± 0.31	16.23±0.31	18.04±0.91	203.91± 0.13	219.03± 0.74	0.93	0.93	11.80	11.38	0.940	0.942
Bougainvillea spectabilis	22.07± 0.39	22.11± 0.27	20.12± 0.21	21.71± 0.17	238.72± 0.28	267.11± 0.03	0.91	0.98	10.81	12.08	0.901	0.912

Table 5.6: Summary of the magnetic data (mean and standard error) for roadside dusts on different selective plant (tree & shrubs) leaves at Durtlang area.

Plants	**χ (10^{-7} m^{3} kg^{-1})**		**ARM (10^{-5} Am^{2} kg^{-1})**		**SIRM (10^{-5} Am^{2} kg^{-1})**		**ARM/ χ (10^{2}Am^{-1})**		**SIRM/ χ (10^{2}Am^{-1})**		**S-ratio**	
	2013-14 (Winter)	**2014-15 (Winter)**	**2013-14 (Winter)**	**2014-15 (Winter)**	**2013-14 (Winter)**	**2014-15 (Winter)**	**2013-14 (Winter)**	**2014-15 (Winter)**	**2013-14 (Winter)**	**2014-15 (Winter)**	**2013-14 (Winter)**	**2014-15 (Winter)**
Mangifera indica	34.27± 0.24	36.27± 0.27	31.17± 0.62	33.28± 0.07	242.45± 0.21	249.24± 0.87	0.90	0.91	7.07	6.87	0.933	0.924
Artocarpus heterophyllus	29.01± 0.38	31.92± 0.12	5.09± 0.73	7.27± 0.11	153.83± 0.34	162.17± 0.13	0.17	0.22	5.30	5.08	0.961	0.960
Ficus bengalensis	36.77± 0.09	37.01± 0.12	31.42± 0.51	29.56± 0.91	270.21±0.64	274.39± 0.49	0.85	0.79	7.34	7.41	0.943	0.940
Psidium guajava	26.81± 0.25	27.11± 0.45	4.46± 0.23	8.16± 0.42	153.11± 0.27	171.42± 0.18	0.16	0.30	5.71	6.32	0.962	0.968
Lantana camara	28.59± 0.39	29.11± 0.12	4.48± 0.29	7.21± 0.16	153.21± 0.31	167.81± 0.33	0.15	0.24	5.35	5.76	0.963	0.972
Bauhinia variegata	17.23± 0.13	17.49± 0.27	15.97± 0.14	16.27± 0.49	171.01± 0.24	178.72± 0.29	0.92	0.93	9.92	10.21	0.907	0.919
Cassia auriculata	14.19± 0.12	14.78± 0.27	12.91± 0.44	11.02± 0.74	149.11± 0.14	137.39± 0.67	0.90	0.74	10.50	9.29	0.938	0.941
Hibiscus rosa-sinensis	16.12± 0.23	16.18± 0.17	14.47± 0.38	15.17± 0.22	192.77± 0.11	201.23± 0.27	0.89	0.93	11.95	12.43	0.931	0.938
Ficus religiosa	14.19± 0.32	15.93± 0.23	12.23± 0.17	13.27±0.72	167.57± 0.31	180.24± 0.11	0.86	0.83	11.80	11.31	0.895	0.899
Bougainvillea spectabilis	17.19± 0.07	18.21± 0.19	15.23± 0.04	15.77± 0.91	201.57± 0.21	220.12± 0.17	0.88	0.86	11.72	12.08	0.925	0.931

Table 5.7: Summary of the magnetic data (mean and standard error) for roadside dusts on different selective plant (tree & shrubs) leaves at Ramrikawn area.

Plants	**χ (10^{-7} m^3 kg^{-1})**		**ARM (10^{-5} Am^2 kg^{-1})**		**SIRM (10^{-5} Am^2 kg^{-1})**		**ARM/ χ ($10^2 Am^{-1}$)**		**SIRM/ χ ($10^2 Am^{-1}$)**		**S-ratio**	
	2013-14 (Summer)	**2014-15 (Summer)**	**2013-14 (Summer)**	**2014-15 (Summer)**	**2013-14 (Summer)**	**2014-15 (Summer)**	**2013-14 (Summer)**	**2014-15 (Summer)**	**2013-14 (Summer)**	**2014-15 (Summer)**	**2013-14 (Summer)**	**2014-15 (Summer)**
Mangifera indica	27.27± 0.96	26.11± 0.81	26.01± 0.51	24.17± 0.27	301.71±0.11	293.22±0.23	0.95	0.92	11.06	11.23	0.951	0.942
Artocarpus heterophyllus	28.36± 0.74	29.11± 0.22	26.52± 0.19	26.92± 0.77	331.09±0.66	321.76±0.27	0.93	0.92	11.67	11.05	0.947	0.942
Ficus bengalensis	24.42± 0.31	27.19±0.11	23.72± 0.22	25.11± 0.72	281.43±0.18	293.15±0.41	0.97	0.92	11.52	10.78	0.931	0.942
Psidium guajava	26.12± 0.41	28.47± 0.71	24.09± 0.23	25.41± 0.27	290.53±0.27	286.14±0.22	0.92	0.89	11.12	10.05	0.942	0.944
Lantana camara	23.21± 0.08	25.37± 0.11	22.01± 0.17	23.77± 0.22	271.51±0.29	287.17±0.11	0.94	0.93	11.69	11.31	0.944	0.946
Bauhinia variegata	15.33± 0.37	17.81± 0.56	14.35± 0.11	15.25± 0.28	177.14±0.09	168.29±0.47	0.93	0.85	11.55	9.44	0.901	0.908
Cassia auriculata	15.43± 0.26	16.29± 29	13.39± 0.11	14.29± 0.03	180.11±0.03	184.27±0.19	0.86	0.87	11.67	11.31	0.901	0.912
Hibiscus rosa-sinensis	19.77± 0.03	21.29± 0.04	17.56± 0.57	20.14± 0.27	191.11±0.07	188.27±0.16	0.88	0.94	9.66	8.84	0.943	0.948
Ficus religiosa	18.74± 0.01	17.19± 0.57	16.52± 0.71	15.44± 0.24	165.11±0.08	171.47±0.25	0.88	0.89	8.81	9.97	0.931	0.933
Bougainvillea spectabilis	21.47± 0.56	22.10± 0.17	18.54± 0.29	20.27± 0.33	170.77±0.52	168.57± 0.77	0.86	0.91	7.95	7.62	0.941	0.944

Table 5.8: Summary of the magnetic data (mean and standard error) for roadside dusts on different selective plant (tree & shrubs) leaves at Tanhril area.

Plants	**χ (10^{-7} $m^3 kg^{-1}$)**		**ARM (10^{-5} $Am^2 kg^{-1}$)**		**SIRM (10^{-5} $Am^2 kg^{-1}$)**		**ARM/ χ ($10^2 Am^{-1}$)**		**SIRM/ χ ($10^2 Am^{-1}$)**		**S-ratio**	
	2013-14 (Summer)	**2014-15 (Summer)**	**2013-14 (Summer)**	**2014-15 (Summer)**	**2013-14 (Summer)**	**2014-15 (Summer)**	**2013-14 (Summer)**	**2014-15 (Summer)**	**2013-14 (Summer)**	**2014-15 (Summer)**	**2013-14 (Summer)**	**2014-15 (Summer)**
Mangifera indica	12.33± 0.11	14.39± 0.24	10.38± 0.11	12.41± 0.27	141.33±0.21	161.19±0.39	0.84	0.86	11.46	11.20	0.867	0.891
Artocarpus heterophyllus	15.07± 0.71	15.11± 0.27	13.11± 0.29	13.21± 0.63	152.17± 0.91	148.42±0.17	0.86	0.87	10.09	9.82	0.917	0.911
Ficus bengalensis	12.41± 0.76	11.09± 0.44	11.27± 0.44	10.02± 0.71	189.56±0.72	196.03±0.31	0.90	0.90	15.27	17.67	0.871	0.887
Psidium guajava	14.77± 0.09	11.17± 0.91	13.21± 0.11	10.11±0.14	201.11± 0.77	180.44± 0.19	0.89	0.90	13.61	16.15	0.901	0.913
Lantana camara	11.81± 0.07	12.01± 0.24	10.81± 0.17	11.17± 0.54	132.77±0.05	138.14±0.95	0.91	0.93	11.24	11.50	0.867	0.877
Bauhinia variegata	7.73± 0.11	9.39± 0.06	6.23± 0.71	7.74± 0.44	119.27±0.21	110.01±0.03	0.80	0.82	15.42	11.71	0.863	0.861
Cassia auriculata	9.11± 0.44	11.19± 0.25	7.14± 0.33	10.51± 0.71	106.72±0.31	117.44±0.97	0.78	0.93	11.71	10.49	0.887	0.884
Hibiscus rosa-sinensis	11.08± 0.14	13.81± 0.14	10.11± 0.25	11.27± 0.83	108.23±0.55	112.11±0.31	0.91	0.81	9.76	8.11	0.801	0.813
Ficus religiosa	8.11± 0.56	10.11± 0.87	6.29± 0.07	8.17± 0.55	109.23±0.56	106.23±0.07	0.77	0.80	13.46	10.50	0.831	0.838
Bougainvillea spectabilis	11.48± 0.16	12.18± 0.22	10.03± 0.22	11.19± 0.13	119.55± 0.11	134.31±0.11	0.87	0.91	10.41	11.02	0.861	0.877

Table 5.9: Summary of the magnetic data (mean and standard error) for roadside dusts on different selective plant (tree & shrubs) leaves at Zarkawt area.

Plants	**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 (Summer)	**2014-15 (Summer)**	**2013-14 (Summer)**	**2014-15 (Summer)**	**2013-14 (Summer)**	**2014-15 (Summer)**	**2013-14 (Summer)**	**2014-15 (Summer)**	**2013-14 (Summer)**	**2014-15 (Summer)**	**2013-14 (Summer)**	**2014-15 (Summer)**
Mangifera indica	26.77± 0.09	27.97± 0.11	24.47± 0.26	25.92± 0.11	291.11±0.26	298.41±0.77	0.91	0.92	10.87	10.66	0.941	0.947
Artocarpus heterophyllus	24.20± 0.72	25.26± 0.92	22.94± 0.56	24.19± 0.12	277.56±0.17	268.24±0.56	0.94	0.95	11.46	10.61	0.961	0.967
Ficus bengalensis	22.11± 0.51	24.41± 0.93	19.12± 0.81	20.97± 0.33	248.11±0.12	259.12±0.74	0.86	0.85	11.22	10.61	0.921	0.931
Psidium guajava	26.11± 0.09	26.38± 0.14	24.27± 0.23	24.38± 0.11	301.14±0.23	316.13±0.19	0.92	0.92	11.53	11.98	0.932	0.939
Lantana camara	20.75± 0.18	23.27± 0.17	20.05± 0.08	21.01± 0.21	244.31±0.12	247.11±0.14	0.96	0.90	11.77	10.61	0.931	0.944
Bauhinia variegata	13.23± 0.71	13.27± 0.23	11.27± 0.08	11.21± 0.14	170.26±0.01	183.24±0.26	0.85	0.84	12.86	13.80	0.891	0.893
Cassia auriculata	13.23± 0.55	13.48± 0.24	10.27± 0.49	10.38± 0.17	168.23± 0.56	171.28±0.07	0.77	0.77	12.71	12.70	0.887	0.884
Hibiscus rosa-sinensis	17.48± 0.13	18.19± 0.49	15.17± 0.19	16.14± 0.47	183.18±0.44	180.13±0.41	0.86	0.88	10.47	9.90	0.938	0.933
Ficus religiosa	16.27± 0.17	18.56± 0.18	13.49± 0.13	16.27± 0.56	124.48±0.14	129.23±0.78	0.82	0.87	7.65	6.96	0.930	0.933
Bougainvillea spectabilis	18.31± 0.91	17.44± 0.29	15.42± 0.79	16.72± 0.57	168.11± 0.65	159.23±0.12	0.84	0.95	9.18	9.13	0.938	0.934

Table 5.10: Summary of the magnetic data (mean and standard error) for roadside dusts on different selective plant (tree & shrubs) leaves at Durtlang area.

Plants	χ $(10^{-7}\ m^3\ kg^{-1})$		ARM $(10^{-5}\ Am^2\ kg^{-1})$		SIRM $(10^{-5}\ Am^2\ kg^{-1})$		ARM/ χ $(10^2 Am^{-1})$		SIRM/ χ $(10^2 Am^{-1})$		S-ratio	
	2013-14 (Summer)	**2014-15 (Summer)**	**2013-14 (Summer)**	**2014-15 (Summer)**	**2013-14 (Summer)**	**2014-15 (Summer)**	**2013-14 (Summer)**	**2014-15 (Summer)**	**2013-14 (Summer)**	**2014-15 (Summer)**	**2013-14 (Summer)**	**2014-15 (Summer)**
Mangifera indica	23.19± 0.74	24.77± 0.04	20.92± 0.07	21.73± 0.02	227.29±0.61	241.11±0.23	0.90	0.87	9.80	9.73	0.932	0.938
Artocarpus heterophyllus	20.11± 0.14	23.19± 0.45	18.52± 0.29	21.22± 0.02	197.44± 0.21	192.11±0.16	0.90	0.91	9.67	8.28	0.924	0.919
Ficus bengalensis	23.17± 0.19	25.12± 0.52	21.22± 0.11	23.97± 0.07	290.47±0.26	286.12±0.14	0.91	0.95	12.53	11.39	0.917	0.921
Psidium guajava	15.12± 0.31	17.92± 0.77	14.22± 0.44	16.31± 0.17	188.24±0.35	201.19±0.17	0.94	0.91	12.44	11.22	0.912	0.922
Lantana camara	14.03± 0.11	15.97± 0.41	12.56± 0.41	13.97± 0.47	153.42±0.71	167.14±0.17	0.89	0.87	10.93	10.46	0.891	0.901
Bauhinia variegata	10.11± 0.43	12.17± 0.29	9.01±0.27	10.24± 0.06	128.17± 0.52	121.11±0.07	0.89	0.84	12.67	9.95	0.889	0.884
Cassia auriculata	12.42± 0.72	14.41± 0.17	10.42± 0.99	12.12±0.07	103.21±0.03	112.01±0.19	0.83	0.84	8.30	7.77	0.897	0.892
Hibiscus rosa-sinensis	13.32± 0.72	13.92± 0.07	11.48± 0.56	12.79± 0.92	110.02± 0.11	118.23±0.49	0.86	0.91	8.25	8.49	0.891	0.897
Ficus religiosa	11.72± 0.24	13.18± 0.17	10.48± 0.14	11.29± 0.43	114.11±0.31	110.44±0.49	0.89	0.85	9.73	8.37	0.842	0.850
Bougainvillea spectabilis	13.14± 0.77	13.77± 0.72	11.07± 0.14	11.19± 0.79	168.23± 0.18	161.44±0.17	0.84	0.81	12.80	11.72	0.917	0.921

5.2.3 Saturation Isothermal remanent magnetisation (SIRM)

SIRM values of Ramrikawn site ranged from 203.70±0.52 to 314.52±0.11(10^{-5} Am^2 kg^{-1}) in winter with maximum in *Ficus benghalensis* (314.52±0.11) (10^{-5} Am^2 kg^{-1}) and minimum in *Lantana camara* (203.70±0.52) (10^{-5} Am^2 kg^{-1}); 165.11±0.08 to 331.09±0.66 (10^{-5} Am^2 kg^{-1}) in summer with maximum in *Artocarpus heterophyllus* (331.09±0.66) (10^{-5} Am^2 kg^{-1}) and minimum in *Ficus religiosa* (165.11±0.08) (10^{-5} Am^2 kg^{-1}).

The minimum and maximum values of SIRM in Tanhril site ranged from 112.42±0.26 (10^{-5} Am^2 kg^{-1}) (*Bauhinia variegata*) to 218.28±0.98 (10^{-5} Am^2 kg^{-1}) (*Artocarpus heterophyllus*) and 106.23±0.07(10^{-5} Am^2 kg^{-1}) (*Ficus religiosa*) to 201.11±0.77(10^{-5} Am^2 kg^{-1}) (*Psidium guajava*) during the winter and summer respectively.

Similarly the values of SIRM in Zarkawt site ranges from 201.42±0.26(10^{-5} Am^2 kg^{-1}) (*Lantana camara*) to 295.12±0.17(10^{-5} Am^2 kg^{-1}) (*Psidium guajava*) and 124.48±0.14(10^{-5} Am^2 kg^{-1}) (*Ficus religiosa*) to 316.13±0.19 (10^{-5} Am^2 kg^{-1}) (*Psidium guajava*) during the winter and summer respectively.

SIRM values of Durtlang site ranged from 137.39±0.67 to 274.39±0.49 (10^{-5} Am^2 kg^{-1}) in winter with maximum in *Ficus benghalensis* (274.39±0.49) (10^{-5} Am^2 kg^{-1}) and minimum in *Cassia auriculata* (137.39±0.67) (10^{-5} Am^2 kg^{-1}); 103.21±0.03 to 290.47±0.26 (10^{-5} Am^2 kg^{-1}) in summer with maximum in *Ficus benghalensis* (290.47±0.26) (10^{-5} Am^2 kg^{-1})and minimum in *Cassia auriculata* (103.21±0.03) (10^{-5} Am^2 kg^{-1}).

The values of ARM/ χ and SIRM/ χ can reflect the grain size of magnetic minerals (Thompson and Oldfield, 1986; 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 5.3 to 5.10). ARM/ χ values are ranged from 0.15 to 1.03 (10^2Am^{-1}) and SIRM/ χ values are ranged from 5.08 to

17.67 ($10^2 Am^{-1}$) 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 leaf samples are ranging from 0.801 to 0.982 (Tables 5.3 to 5.10), which indicates that these leaf samples are dominated by 'soft' magnetic minerals with a low coercive force, associated partly with 'hard' magnetic minerals with a relatively high coercive force (Robinson, 1986).

Table 5.11: Correlation between magnetic measurements of *Mangifera indica* with SPM and RSPM at four different study sites.

Magnetic Parameter	**SPM** (R^2)				**RSPM** (R^2)			
	2013-14		**2014-15**		**2013-14**		**2014-15**	
	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
χ	0.787	0.435	0.695	0.279	0.920	0.924	0.932	0.815
ARM	0.759	0.502	0.595	0.315	0.971	0.950	0.943	0.820
SIRM	0.751	0.531	0.765	0.440	0.970	0.895	0.993	0.850

Table 5.12: Correlation between magnetic measurements of *Artocarpus heterophyllus* with SPM and RSPM at four different study sites.

Magnetic Parameter	**SPM** (R^2)				**RSPM** (R^2)			
	2013-14		**2014-15**		**2013-14**		**2014-15**	
	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
χ	0.611	0.777	0.497	0.69	0.738	0.905	0.807	0.986
ARM	0.117	0.734	0.267	0.629	0.006	0.910	0.003	0.967
SIRM	0.323	0.770	0.349	0.782	0.179	0.806	0.171	0.799

Table 5.13: Correlation between magnetic measurements of *Ficus bengalensis* with SPM and RSPM at four different study sites.

Magnetic Parameter	**SPM** (R^2)				**RSPM** (R^2)			
	2013-14		**2014-15**		**2013-14**		**2014-15**	
	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
χ	0.876	0.424	0.876	0.445	0.954	0.933	0.907	0.943
ARM	0.761	0.569	0.899	0.449	0.9	0.955	0.817	0.918
SIRM	0.857	0.329	0.618	0.470	0.995	0.774	0.970	0.899

Table 5.14: Correlation between magnetic measurements of *Psidium guajava* with SPM and RSPM at four different study sites.

Magnetic Parameter	**SPM** (R^2)				**RSPM** (R^2)			
	2013-14		**2014-15**		**2013-14**		**2014-15**	
	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
χ	0.941	0.487	0.917	0.613	0.738	0.536	0.744	0.833
ARM	0.864	0.483	0.950	0.565	0.452	0.570	0.549	0.815
SIRM	0.660	0.388	0.589	0.322	0.568	0.403	0.616	0.510

Table 5.15: Correlation between magnetic measurements of *Lantana camara* with SPM and RSPM at four different study sites.

Magnetic Parameter	**SPM** (R^2)				**RSPM** (R^2)			
	2013-14		**2014-15**		**2013-14**		**2014-15**	
	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
χ	0.815	0.688	0.783	0.648	0.955	0.733	0.964	0.782
ARM	0.160	0.646	0.027	0.698	0.032	0.688	0.093	0.747
SIRM	0.665	0.663	0.512	0.738	0.695	0.689	0.696	0.739

Table 5.16: Correlation between magnetic measurements of *Bauhinia variegata* with SPM and RSPM.

Magnetic Parameter	**SPM** (R^2)				**RSPM** (R^2)			
	2013-14		**2014-15**		**2013-14**		**2014-15**	
	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
χ	0.858	0.751	0.828	0.943	0.990	0.848	0.992	0.856
ARM	0.778	0.836	0.554	0.942	0.998	0.887	0.950	0.859
SIRM	0.745	0.598	0.764	0.337	0.853	0.666	0.854	0.518

Table 5.17: Correlation between magnetic measurements of *Cassia auriculata* with SPM and RSPM at four different study sites.

Magnetic Parameter	**SPM** (R^2)				**RSPM** (R^2)			
	2013-14		**2014-15**		**2013-14**		**2014-15**	
	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
χ	0.683	0.757	0.507	0.778	0.761	0.981	0.651	0.928
ARM	0.872	0.837	0.551	0.808	0.859	0.950	0.531	0.531
SIRM	0.691	0.588	0.644	0.600	0.670	0.527	0.567	0.499

Table 5.18: Correlation between magnetic measurements of *Hibiscus rosa-sinensis* with SPM and RSPM at four different study sites.

Magnetic Parameter	**SPM** (R^2)				**RSPM** (R^2)			
	2013-14		**2014-15**		**2013-14**		**2014-15**	
	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
χ	0.602	0.738	0.570	0.802	0.719	0.800	0.711	0.609
ARM	0.609	0.779	0.539	0.882	0.729	0.752	0.713	0.746
SIRM	0.729	0.555	0.703	0.576	0.754	0.559	0.788	0.593

Table 5.19: Correlation between magnetic measurements of *Ficus religiosa* with SPM and RSPM at four different study sites.

Magnetic Parameter	**SPM** (R^2)				**RSPM** (R^2)			
	2013-14		**2014-15**		**2013-14**		**2014-15**	
	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
χ	0.977	0.711	0.923	0.366	0.775	0.855	0.877	0.677
ARM	0.942	0.758	0.915	0.419	0.692	0.921	0.838	0.722
SIRM	0.979	0.986	0.949	0.957	0.829	0.619	0.856	0.629

Table 5.20: Correlation between magnetic measurements of *Bougainvillea spectabilis* with SPM and RSPM at four different study sites.

Magnetic Parameter	**SPM** (R^2)				**RSPM** (R^2)			
	2013-14		**2014-15**		**2013-14**		**2014-15**	
	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
χ	0.941	0.772	0.919	0.892	0.886	0.736	0.915	0.737
ARM	0.975	0.803	0.933	0.779	0.834	0.706	0.811	0.595
SIRM	0.892	0.332	0.671	0.549	0.925	0.890	0.923	0.977

Ramrikawn site showed slightly higher magnetic values comparing to the other sites. On the other hand, Ramrikawn and Zarkawt experienced relatively higher deposition of magnetic grains, originating from PM. χ, ARM and SIRM values are found to be higher for *Ficus bengalensis, Mangifera indica, Artocarpus heterophyllus, Psidium guajava* and *Lantana camara* when compared to other plants. The spatial trends of these three magnetic parameters display similar trends having Ramrikawn with maximum value and Tanhril area with minimum value. The correlation coefficients indicated significant relationship between the concentration of PM and magnetic measurement for ten plant leaves (Tables 5.11 to 5.20.). 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 (magnetic susceptibility, 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 5.3 to 5.10) demonstrated that the accumulation of PM on tree leaves varies at different study sites. The results suggested 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 FCI, 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). Zhang *et al.* (2001) and 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; Rai, 2013). *Ficus bengalensis, Mangifera indica, Artocarpus heterophyllus, Psidium guajava* and *Lantana* *camara* leaves were more rough when compared to *Bauhinia variegata, Cassia auriculata* , *Hibiscus rosa-sinensis, Ficus religiosa and Bougainvillea spectabilis* which may be attributed to its high magnetic concentrations.

Sitewise, plants from Ramrikawn, Zarkawt and Durtlang showed high pollutant magnetic concentration due to tall buildings which may tend to concentrate the pollutants through the low dispersal of pollutants. Also, the presence of trees in street canyons may prevent the dispersal of pollutants (Sternberg *et al.,* 2010; Speak *et al.,* 2012; Hofman *et al.,* 2013). At Tanhril site dispersal of particulates may take place due to lack of high buildings and multilane condition. Further, at Ramrikawn site there exist narrow as well as poor roads with heavy traffic, street dust load and tall buildings.

CHAPTER - 6

SUMMARY AND CONCLUSIONS

Biomonitoring of atmospheric particulate matter using magnetic properties of tree leaves is a useful approach to delineate primary anthropogenic airborne particulate pollution, which leads to the deterioration of ambient air quality and causes adverse effects to human health. From the present study, we can conclude that; The total amount of Suspended Particulate Matter (SPM) and Respirable Suspended Particulate Matter (RSPM) were found much higher at different sites than the prescribed limits of Central Pollution Control Board (CPCB) of India during summer and winter season. The ambient PM concentrations were recorded highest at Ramrikawn, followed by Zarkawt and Durtlang, while lowest values were recorded at Tanhril site. Magnetic properties of tree leaves change significantly in different sampling sites. Magnetic concentration data suggest that the deposition of PM on tree leaves varies due to different traffic behavior between sites and due to other activities like soil erosion, mining and stone quarrying etc. Among ten plant species *Ficus bengalensis, Mangifera indica, Artocarpus heterophyllus, Psidium guajava* and *Lantana camara* were found as good PM accumulator. Trees with high PM collecting potential can solve the problems of air particulate pollution to a great extent. The magnetic properties of tree leaves in Aizawl city also revealed that the magnetic fraction of dust is dominated by multidomain magnetite-like ferromagnetic particles. The magnetic parameters of these plants showed significant positive correlation with ambient PM thus, may act as proxy of ambient PM. Biomagnetic monitoring of PM through plant leaves provides a rapid and economic technique for monitoring atmospheric PM pollution, thus paves the way to the innovation of an eco-sustainable environmental monitoring and hence possible management.

The major findings of the present study can be summarized as follows:

1. The total amount of Suspended Particulate Matter (SPM) and Respirable Suspended Particulate Matter (RSPM) were found much higher at different sites than the prescribed limits of CPCB of India during summer and winter season.
2. The values of particulate pollutants were lowest in rainy season. Which may be attributed to large precipitations while summer and winter seasons were characterized by nearly same concentrations at all study sites.
3. The ambient PM concentrations were recorded highest at Ramrikawn, followed by Zarkawt and Durtlang, while lowest values were recorded for Tanhril site.
4. Magnetic properties of tree leaves changed significantly at different study sites.
5. Magnetic data suggest that the deposition of PM on tree leaves varies due to different traffic behavior between different sites.
6. The ARM/ χ and SIRM/ χ values were found to be low at all studied sites.
7. Low values of ARM/ χ and SIRM/ χ indicate relatively large grain size of magnetic particles present in leaf samples.
8. S-ratio of leaf samples were ranging from 0.801 to 0.982, which indicates that these leaf samples are dominated by multidomain magnetite-like ferromagnetic particles.

9. PM deposition capacity was found to be higher for *Ficus bengalensis, Mangifera indica, Artocarpus heterophyllus*, *Psidium guajava* and *Lantana camara* comparing to other plants.

10. The magnetic parameters of these plants showed significant positive correlation with ambient PM thus, may act as proxy of ambient PM pollution.

The present study is a strong first step and warrants further efforts which may paves the way to screen the feasibility of this plants in context of their potentially to be planted in other urban areas with varying pollution load. The plant species constituting Green Belt of effective dust capturing plant species should be developed around residential areas/industrial areas, as the tree can act as efficient biological filters, removing significant amounts of particulate pollution from urban atmospheres. This is a cost effective technology for controlling particulate and gaseous emission generated due to vehicular movement, domestic emission and even industrial emission. Present study is, perhaps, a novel contribution in the area of bio-magnetic monitoring studied with several magnetic parameters. Results indicated that the bio-magnetic monitoring is applied for environmental geomagnetism which act as proxy for ambient PM pollution and further employed as an eco-sustainable tool for environmental management in urban and peri-urban regions.

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