MONITORING OF PARTICULATE MATTERS AND ITS IMPACTS ON HUMAN HEALTH AND ENVIRONMENT IN AIZAWL, MIZORAM

A THESIS SUBMITTED IN PARTIAL
FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF DOCTOR OF
PHILOSOPHY

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MZU REGISTRATION: 100 OF 2011
PHD REGISTRATION: MZU/PH.D. 634 OF 02.05.2014

DEPARTMENT OF ENVIRONMENTAL SCIENCE
SCHOOL OF EARTH SCIENCE AND NATURAL RESOURCE
MANAGEMENT
APRIL, 2021

MONITORING OF PARTICULATE MATTERS AND ITS IMPACTS ON HUMAN HEALTH AND ENVIRONMENT IN AIZAWL, MIZORAM

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CERTIFICATE

This is to certify that Mr. Davy Lalruatliana has submitted the thesis entitled **"Monitoring of particulate matters and its impacts on human health and environment in Aizawl, Mizoram"** under my supervision, for the award of Degree of Doctor of Philosophy in the Department of Environmental Science, Mizoram University, Aizawl. The work is authentic, content of the thesis is the original work of the Research Scholar, and the nature and the presentation of the work are the first of its kind in Mizoram.

It is further certified that no portion(s) or part(s) of the content of the thesis has been submitted for any degree in Mizoram University or any other University or Institute.

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Declaration

I, Davy Lalruatliana hereby declare that the subject matter of this thesis is the record of work done by me, that the contents of this thesis did not form basis of the award of any previous degree to me or to the best of my knowledge to anybody else, and that the thesis has not been submitted by me for any research degree in any other University/Institute.

This is being submitted to the Mizoram University for the degree of Doctor of Philosophy in Environmental Science.

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ACKNOWLEDGEMENT

First and foremost, I offer my sincere gratitude to my supervisor Prof. Lalnuntluanga, Department of Environmental Science, Mizoram University, Aizawl, Mizoram for the continuous support of my research, for his patience, motivation, enthusiasm, and knowledge.

Besides my supervisor, my sincere thanks to all the faculty and staff members of Department of Environmental Science for their assistance and guidance and also for giving me a platform to complete my Ph.D.

My sincere thanks go to the Mizoram Pollution Control Board, Govt. of Mizoram for providing me the required data of air pollutants. I also thank the State Meteorological Centre, Directorate of Science & Technology for providing me data of meteorological parameters.

I sincerely thank Mr. C. Vanlalengkima, Scientist, MIRSAC who prepared all the maps required for the completion of my thesis.

My sincere thanks go to Mr. C. Lalbiakthanga, Joint Director, Directorate of Transport, Govt. of Mizoram for providing me data of vehicles registered in Aizawl District.

I am deeply grateful to my family, especially my wife Dr. S. T. Lalzarzovi for the assistance, motivation and constant support throughout my period of study.

Last but not the least, I thank the Almighty God for granting me health, wisdom and strength to undertake and complete this research.

Place : Aizawl
Date : 28th April, 2021 (DAVY LALRUATLIANA)

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CHAPTER – 1
INTRODUCTION

1.1 Introduction to air pollution

Air is vital for the survival of human beings. Clean air is considered to be a basic requirement of human health and well-being. However, due to the increased reliance on fossil fuels and increasing human consumption patterns driven by population growth, air quality shows a trend of decline. Nine out of ten people breathe polluted air every day (World Health Organization WHO, 2019). It is one of many environmental issues confronting the world today (Bickerstaff & Walker, 2001).

Air pollution is the introduction of chemicals, particulates, biological materials, or other harmful materials into the Earth's atmosphere, possibly causing diseases, death to humans, damage to other living organisms such as food crops, or the natural or built environment. Khopkar (2004) defines air pollution as "substances that on local and regional scales directly harm animals, plants, people and their artifacts". Under the Air Act 1981, air pollution is defined as "any solid, liquid or gaseous substance (including noise) present in the atmosphere in such concentration as may be or tend to be injurious to human beings or other living creatures or plants or property or environment".

The main constituents of unpolluted air by volume are nitrogen with 78 %, oxygen with 21 % and trace amounts of inert gases. Of the inert gases, the most abundant is argon with 0.93 % followed by carbon dioxide with 0.03 %. Besides these gases, methane, hydrogen, nitrous oxides, water vapour, particulate materials and organic vapour are also present. The trace constituents present fluctuate in their concentrations due to natural cycles where there is a dynamic exchange of material between the atmosphere, the land and the water phases. On a global scale, natural transfer processes can involve the movement of vast amounts of primary materials annually but sustainable ecosystems show little overall change in composition. The introduction into the environment of potentially harmful substances, whether gases, gas and liquid vapours or solid particulates may occur through both natural and anthropogenic processes. Anthropogenic emissions of pollutant may be lesser than those from natural sources but their concentration around the point of discharge may produce levels which can have serious consequences for human, animal and plant health in the locality (Kirby, 1995).

In 2019, air pollution is considered by the World Health Organization as the greatest environmental risk to health. Low and middle-income countries are more vulnerable as around 90 % of the deaths caused by air pollution are in low- and middle-income countries, with high volumes of emissions from industry, transport and agriculture, as well as dirty cookstoves and fuels in homes (WHO, 2019). Exposure to air pollution, both ambient and household, increases a person's risk of contracting a disease such as lung cancer, stroke, heart disease, and chronic bronchitis. Short-term exposure to air pollutants have been linked to COPD (Chronic Obstructive Pulmonary Disease), cough, shortness of breath, wheezing, asthma, respiratory disease, and high rates of hospitalization (a measurement of morbidity) while long-term exposure have been associated with chronic asthma, pulmonary insufficiency, cardiovascular diseases, and cardiovascular mortality (Manisalidis et al., 2020). Air pollution is responsible for 5 million premature deaths each year contributing to 9 % of death globally (Ritchie, 2017). According to the latest estimate, 1 in every 10 total deaths in 2013 were attributable to air pollution. Air pollution has posed a significant health risk since the early 1990s, the earliest period for which global estimates of exposure and health effects are available. In 1990, as in 2013, air pollution was the fourth leading fatal health risk worldwide, resulting in 4.8 million premature deaths (World Bank and Institute for Health Metrics and Evaluation, 2016).

Air pollution affects people living in both urban and rural areas. Urban air pollution is now a major concern throughout the world (Gulia et al., 2015). There is an increasing deterioration of air quality in the cities of both developing and developed countries which has affected the surrounding environment and human health. This can be attributed to increase in urban population, uncontrolled traffic growth and emission, urban sprawl and reduction in urban forests (Kim et al., 2015; Pascal et al., 2014; Raaschou-Nielsen et al., 2013). Among these causes, the main culprit is the road transport sector. It is reported that over 70-80 % of air pollution in mega cities in developing nations is attributed to vehicular emissions caused by a large number of older vehicles coupled with poor vehicle maintenance, inadequate road infrastructure and low fuel quality (Gulia et al., 2015). But air pollution is also a problem outside cities. More than 2.8 billion people around the world continue to depend on burning solid fuels such as wood, charcoal, coal, and dung in their homes for cooking and heating (Chafe et al., 2014). Many of these people live in rural areas where they lack access to modern forms of energy such as electricity. Consequently, the health risk posed by air pollution is the greatest in developing countries.

Air pollution is not just a health risk; it is also an economic burden. By causing illness and premature death, pollution reduces quality of life. By causing a loss of productive labor, pollution also reduces output and incomes in these countries. The annual quality of life or welfare costs of air pollution in low- and middle-income countries are in the trillions of dollars, and lost income is in the hundreds of billions of dollars. The enormity of the costs stems from the widespread nature of exposure to air pollution (World Bank and Institute for Health Metrics and Evaluation. 2016).

1.2 Air pollution - A historical perspective

Air pollution may be traced back to the discovery of fire when man started using firewood for cooking and other purposes. The birth of air pollution study came before the industrial revolution when it was recognized that the atmosphere could contain constituents that were obnoxious to health and comfort (Heidorn, 1978). London was the first city to have air pollution problems as early as 1228 due to the burning of bituminous coal called sea coal by brewers and smiths. Protests were led by the clerics and nobility which resulted in the first smoke abatement law enacted in London in 1273 prohibiting use of coal as "prejudicial to health." (Brimblecombe, 1978). King Edward I also prohibited the use of coal in 1307 which had little effect.

During the Industrial revolution in the late 18th and early19th century, air pollution became recognized as a problem with the widespread use of coal. Health effects were increasingly observed on population residing near industrial centers in urban areas as a result of the smoke and smog. Air pollution intensified spreading from Europe to North America (Heidorn, 1978). A series of severe air pollution episodes were observed in industrial countries around the world. Some of the most notable ones are the large scale smog reported in 1930 in Meuse Valley in Belgium, a small industrial town which led to the deaths of 60-80 people with a large part of the population showing acute respiratory symptoms (Anderson, 2009); 20 people were asphyxiated in Donora, Pennsylvanian in 1948 due to air pollution caused by industries and several thousand people were reported sick (Battan, 1966); and in 1952, in what came to be known as the Great Smog of London, 4000+ deaths were reported over the course of several days due to high sulphur dioxide and suspended particulates mixed with air condensation (EPA, 1971). This led to the introduction of the Clean Air Act in the United Kingdom in 1956 (Highwood & Kinnersley, 2006). The first global guidelines for air pollution (particulates, SO_2, NO_2 and O3) were implemented by the WHO in 1987. In India, launching of the economic plans have resulted in rapid industrialization where priority was given to the development of heavy and essential industries This has led to rapid rise in air pollution especially in urban pockets. (Dwivedi & Kishore, 1982). As a result, The Air (Prevention and Control of Pollution) Act was passed in 1981 to regulate air pollution and was amended in 1987 and The Air (Prevention and Control of Pollution) Rules came out in 1982 which defines the procedures of the meetings of the Boards and the powers entrusted to them.

1.3 Air pollutants

Air pollutants are substances causing air pollution. They cause damage to target or receptors. The target may be man, animals, plants, buildings or other materials. As clean air in the troposphere moves across the earth's surface, it collects the products of both natural events (dust storms and volcanic eruptions) and human activities (emissions from cars and smokestacks). These potential pollutants are the primary pollutants and the secondary pollutants (Anjaneyulu, 2004).

Primary air pollutants are those emitted into the atmosphere as a result of some specific processes and remain for a long time in the chemical form in which they are emitted. Some important primary pollutants are - particulate matters, sulphur oxides ($S0_2$), carbon monoxide (CO), hydrocarbons (HC), hydrogen sulphide (H_2S) and ammonia (NH_3) (Purohit & Agrawal, 2006; Stern, 2006; Trivedy & Goel, 2003; Liu & Liptak, 2000).

Secondary pollutants are formed in the atmosphere as a result of some reaction, which may be photochemical or non-photochemical and may take place between two pollutants, or between a single pollutant and natural constituents of the atmosphere.

Some important secondary pollutants are - nitrogen oxides (NO_X), peroxy acetyl nitrate (PAN), ozone, photochemical smog and acid rain (Agarwal, 2002 & 2005).

Air pollutants are emitted from a range of sources both man-made and natural. The main natural sources for pollutants are volcanoes, biological decay, lightning strikes, dust storms, forest and grassland fires, emission of volatile organic compounds from plants, sea sprays and radioactive decay of Radon. Man-made sources of air pollutants include combustion of fossil fuel to generate electricity, in transport, industry and households, industrial process and solvent use, agriculture, waste treatment, land mining, earth moving activities, quarrying, construction and repair work, deforestation and nuclear explosions. In rural areas, indoor air pollution caused by open fires for cooking and heating may be a serious problem. However, in urban areas, the main source of pollution is vehicular pollution.

According to state of matter, air pollutants are classified as gaseous air pollutants and particulate air pollutants. Gaseous air pollutants exist in a gaseous stage at normal temperature and pressure such as carbon dioxide, nitrogen dioxide, sulphur oxides. Particulate air pollutants are suspended droplets, solid particles or mixture of the two.

Exposure to air pollutants can affect human health in various ways, leading to increased mortality and morbidity (WHO, 2005). A wide range of pollutants such as nitrous oxides, Carbon monoxide, sulphur dioxides, ozone, photochemical oxidant, particulate matter (PM), heavy metals, volatile organic compounds (VOCs) and hydrocarbons are present in ambient air and are associated with significant excess mortality or morbidity. From these various air pollutants, the Environment Protection Agency in 1971 had identified six pollutants which required national ambient air quality standard. Of these pollutants, Particulate matter is one of the most important pollutants responsible for air pollution. It has been extensively studied worldwide due to its potential impact on health, visibility and climate in recent years (Wan et al., 2015; Zhang et al., 2014). $PM_{2.5}$ is the air pollutant that has been most closely studied and is most commonly used as proxy indicator of exposure to air pollution more generally (WHO, 2005).

The 2005 World Health Organization's "WHO Air quality guidelines" offer global guidance on thresholds and limits for 4 key air pollutants that pose health risks

- particulate matter (PM), ozone (O_3), nitrogen dioxide (NO_2) and sulfur dioxide (SO_2) (Table 1). Many countries have their own Ambient Air Quality Standards prescribed for their territories. In India the current National Ambient Air Quality Standards were notified on 18 November 2009 by the Central Pollution Control Board. (Table 2). Further, a new National Air Quality Index (AQI) has been launched in October 2014 to disseminate information on air quality in an easily understandable form for the general public. The measurement of air quality is based on eight pollutants, namely, Particulate Matter (size less than 10 µm) or (PM_{10}), Particulate Matter (size less than 2.5 µm) or ($PM_{2.5}$), Nitrogen Dioxide (NO_2), Sulphur Dioxide (SO_2), Carbon Monoxide (CO), Ozone (O_3), Ammonia (NH_3), and Lead (Pb) for which short-term (up to 24-hourly averaging period) National Ambient Air Quality Standards are prescribed and the worst reading in these pollutants represents the AQI for that city. (CPCB, 2014) Indian Standards are slightly less stringent as compared to WHO guidelines.

1.4 Particulate Matter (PM)

Particulate matter is defined as material suspended in the air in the form of minute solid particles or liquid droplets, usually considered as an atmospheric pollutant with significant impact on human health (Martinelli et al., 2013). Particulate matter is also a major driver of climate change. It modifies the earth radiation budget, cloud formation and act as a reaction centre for air pollutants in the upper atmosphere and changes atmospheric visibility, biogeochemical cycles and meteorology in the lower atmosphere (Mukherjee & Agrawal, 2017).

Particulate matter (PM) is a complex mixture of solid and liquid particles and the size, chemical composition, and other physical and biological properties of particles vary with location and time. This variability is caused by differences in pollutant sources which may be natural or anthropogenic. Concentrations and toxicity of particulate matter depend on their composition, shape and size of particles, presence of other pollutants and prevailing meteorological factors (Arruti et al., 2012; Clements et al., 2013; Rashki et al., 2011). The physical and chemical characteristics of particulate matter may vary depending on location and time. Common chemical constituents of PM include sulfates, nitrates, ammonium, other inorganic ions such as ions of sodium, potassium, calcium, magnesium and chloride, organic and elemental carbon, crustal material, particle-bound water, metals (including cadmium, copper, nickel, vanadium and zinc) and polycyclic aromatic hydrocarbons (PAH). In addition, biological components such as allergens and microbial compounds are found in PM. The most health-damaging particles are those with a diameter of 10 µm or less, which can penetrate and lodge deep inside the lungs. Both short- and long-term exposure to air pollutants have been associated with health impact and particulate pollution in particular is the 13th leading cause of mortality worldwide (WHO, 2016).

The size, chemical composition, and other physical and biological properties of particles vary with location and time. Some particulates occur naturally, originating from volcanoes, dust-storms or wind-erosion, forest and grassland fires, living vegetation, and sea spray. Human activities, such as the burning of fossil fuels in vehicles, construction works, agricultural practices, power plants and various industrial processes also generate significant amounts of particulates. In addition, reactive species in the atmosphere combine to generate secondary particles, such as sulfates, that may constitute a significant fraction of total PM. Ambient PM levels in any particular location are also affected by local ambient mixtures of gaseous pollutants, meteorology, geography, and seasonal patterns (Adams et al., 2015). The sources and composition of larger particles generally differ from those of smaller particles: coarse PM (particles 2.5–10 µm in diameter) consists in large part of insoluble crust- derived minerals, biological material (such as pollen, endotoxins, fungi, and bacteria), and sea salts. By contrast, $PM_{2.5}$—which includes the ultrafine fraction—is derived mainly from combustion-related sources. (Adams et al., 2015). According to a review conducted by Karagulian et al. (2015) which looked at 419 source apportionment records from studies conducted in cities of 51 countries to calculate regional averages of sources of ambient particulate matter, globally 25 % of urban ambient air pollution from $PM_{2.5}$ is contributed by traffic, 15 % by industrial activities, 20 % by domestic fuel burning, 22 % from unspecified sources of human origin, and 18 % from natural dust and salt.

1.4.1 Classification of particulate matters

Although it can be categorized in a number of ways, PM has traditionally been classified by size identified by aerodynamic diameter. Aerodynamic diameter is diameter of a sphere that behaves aerodynamically like the actual particle. Particulate matter has a size range of larger than a single small molecule (about 0.002 µm in diameter) and smaller than about 500 µm. In general, the smaller the particle, the stronger its potential impact on human health because it can be more easily inhaled. Based on their size, particulate matters may be classified as -

a) **PM_{10} (Coarse particles):** Inhalable particles less than 10 micrometers (µm) in diameter used as a nominal surrogate for particles between 2.5 and 10µm in diameter; found near roadways and dusty industries. PM_{10} typically deposit to the earth within minutes to hours and within tens of kilometers from the emission source (Hinds, 1999) These particles can suspend and float in the atmosphere over a long period of time and are often naturally occurring and derived primarily from soil and other crustal materials (Liu et al., 2016)

b) **$PM_{2.5}$ (Fine particles):** Inhalable particles less than 2.5µm in diameter; generally found in smoke and haze, emitted from natural sources like forest fires and industrial combustion sources, or formed when gases react in the air. $PM_{2.5}$ has a high residence time (some weeks) and can travel long distances (Hinds, 1999). $PM_{2.5}$ are derived mainly from primary pollution. It is emitted by the combustion of gases such as nitrogen oxides, sulfur dioxide and carbon monoxide in the process of transportation, manufacturing and power generation. It may also be derived from secondary pollution when the primary pollutants react with components in the atmosphere such as common components of fine particles like sulfate and nitrate particles are generated by conversions from primary sulfur and nitrogen oxide emissions. Besides these, soil dust, sea salts, pollen, spore and smoking. are also sources of fine particles. Compared to coarse particle PM_{10}, $PM_{2.5}$ is characterized by smaller diameter, larger area, stronger activity, easier carrier of harmful substance like heavy metal and microbe, more time suspending in the atmosphere, and longer distance to be delivered, therefore, $PM_{2.5}$ has more significant effect on human health and atmosphere quality (Liu et al., 2016). Ultrafine particles ($PM_{0.1}$) are a subset of inhalable $PM_{2.5}$ particles less than 0.1µm in diameter. They are not specifically regulated but have a strong link to combustion and therefore are garnering special attention.

c) **Suspended particulate matter (SPM):** These are bigger size of particulate matters with size ranging upto 100 µm. They are least harmful since they are bigger in size and cannot be inhaled.

Particulate matters can also be classified by its source as primary particles directly emitted from a natural or human source and secondary particles produced when chemicals from natural and human sources react in the atmosphere often energized by sunlight.

1.5 Effects of Particulate Matters

1.5.1 Effect on Human health: According to the Global Burden of Disease Report, 2017, long-term exposure to ambient $PM_{2.5}$ contributed to 2.9 million deaths and to a loss of 83 million disability-adjusted life-years making $PM_{2.5}$ exposure responsible for 5.2 % of all global deaths and 3.3 % of all global disability-adjusted life-years (Health Effects Institute, 2019). As PM can be suspended over long time and travel over long distances in the atmosphere, it can cause a wide range of diseases that lead to a significant reduction of human life. Short term or chronic exposure to PM with possible attachment of different types of viruses and bacteria can have a significant negative impact on human health as the aerosols may be transported deeply into the lungs to reach alveoli and penetrate multilayers barriers of the respiratory system (Zoran et al., 2020). The range of health effects is broad, but are predominantly to the respiratory and cardiovascular systems (WHO, 2005). Several properties govern the toxicity of particulate matters namely the overall mass concentration, particle size, particle surface properties and shape, chemical composition and concentration of trace metals, speciation and mobility of potential toxic elements. Particle mass concentration provides a first estimation of the magnitude of atmospheric pollution and was used already in many epidemiological studies beginning in the 1970s and 1980s as well as in policy making for the implementation of threshold values on national and international levels such as WHO, EU and USEPA. Apart from mass concentration, the size of particles has been directly linked to their potential for causing health problems (Dockery et al., 1993; Oberdorster et al., 1995; Schwartz et al., 1996; Wichmann & Peters, 2000) Small particles of concern include “inhalable coarse particles” with a diameter of 2.5 to 10 µm and “fine particles” smaller than 2.5 µm in diameter. (Kim et al., 2015). Their small size allows them to get deep into the lungs and from there they can reach or trigger inflammation in the lung, blood vessels or the heart, and perhaps other organs. The health effects of particulate matters are well documented in numerous epidemiological and toxicology studies. It is a recognized threat to public health on the global scale not only in highly polluted environments but also in less contaminated environment by prolong exposure with PM concentrations only slightly above background levels (WHO, 2014). Particulate pollution is mostly associated with respiratory ailment and cardiovascular diseases. This includes irritation of the breathing tracts, coughing, and difficulty breathing, reduced lung function, aggravated asthma, chronic bronchitis irregular heartbeat and non-fatal heart attacks. Besides these, it has also been associated with low birth weight, fetal growth characteristics and preterm birth, DNA damage and mutagenic activity, congenital heart defects, ischemic heart disease, inflammatory responses, infant mortality oxidative stress and atherosclerosis (Mukherjee & Agrawal, 2017). In addition, growing scientific evidence suggests that air pollution may contribute to the development of asthma in children and neurological or cognitive disorders such as Alzheimers disease (Health Effect Institute, 2019).

There is good evidence of the effects of short-term exposure to PM_{10} on respiratory health, but for mortality, and especially as a consequence of long-term exposure, $PM_{2.5}$ is a stronger risk factor than the coarse part of PM_{10} (WHO, 2013). A 10 $\mu g/m^3$ increase in PM_{10} level is estimated to increase daily mortality by 0.2–0.6 % (Samoli et al., 2008). A 10 $\mu g/m^3$ increase of $PM_{2.5}$ is estimated to increase the long-term risk of cardiopulmonary mortality by 6–13 % per (Pope et al., 2002; Beelen et al., 2008, Krewski et al., 2009).

Research has also found that certain populations are more vulnerable to these health effects, such as people with pre-existing heart or lung diseases, children, and older adults (Harrison & Yin, 2000). For example, exposure to PM affects lung development in children, including reversible deficits in lung function as well as chronically reduced lung growth rate and a deficit in long-term lung function.

It is estimated that approximately 3 % of cardiopulmonary and 5 % of lung cancer deaths are attributable to PM globally. According to Lim et al. (2012) $PM_{2.5}$ pollution in 2010 accounted for 3.1 million deaths and around 3.1 % of global disability-adjusted life years. The life expectancy of a population is drastically reduced by 8.6 months on average due to PM exposure.

1.5.2 Effect on Environment: Particulate matters have a direct influence on climate due to the scattering and absorption of solar radiation and also an indirect influence due to their role as cloud condensation nuclei and by affecting cloud properties (Seinfeld & Pandis, 1997). It affects meteorological processes and atmospheric chemistry and has been linked to climate change (Von Schneidemesser et al., 2015). However, the impacts of particulate matters on the climate are not completely understood as of now. The most common effects of PM on the environment is reduction of atmospheric visibility (haze) as particulate matters are important component of smog (Singh et al., 2016). Visibility impairment is generally accompanied by airborne particulate matter (PM), especially fine particles with aerodynamic diameters of 2.5μm and less ($PM_{2.5}$), due to their light-scattering and absorption capabilities (Lin et al., 2012). Particulate matters can be carried over long distances and deposited on ground or water. Deposition of PM on leaf surface may cause abrasion and radiative heating, and may reduce the photosynthetically active photon flux reaching the photosynthetic tissues. Acidic and alkaline materials may cause leaf surface injury while other materials may be taken up across the cuticle. PM deposited directly to the soil can influence nutrient cycling, especially that of nitrogen, through its effects on the rhizosphere bacteria and fungi. Alkaline cation and aluminum availability are dependent upon the pH of the soil that may be altered dramatically by deposition of various classes of PM. A regional effect of PM on ecosystems is linked to climate change. Increased PM may reduce radiation interception by plant canopies and may reduce precipitation through a variety of physical effects (Grantz et al., 2003). When it is deposited in water bodies, it may lead to increased acidity of lakes and streams and nutrient balance changes in coastal waters and river basins.

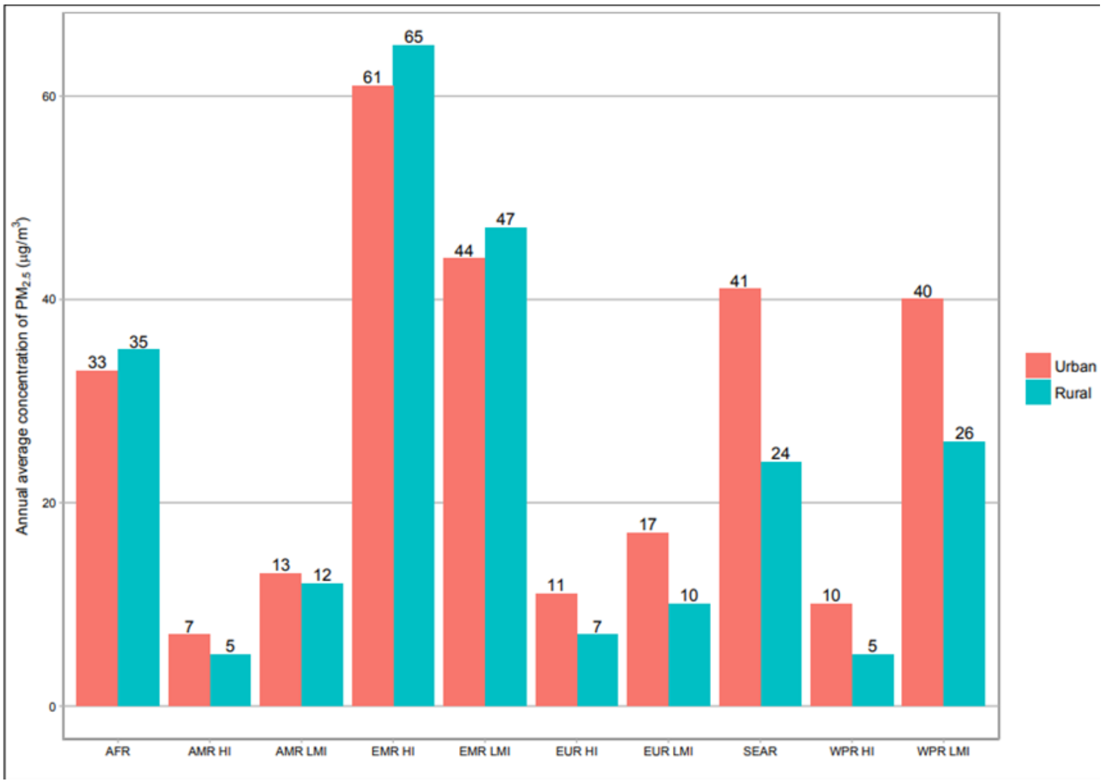
1.6 Current status of Particulate Matter Pollution

Particulate Matter pollution has become one of the world's most menacing environmental problems. It comes from vehicle emissions, coal-burning power plants, industrial emissions, and many other human and natural sources. The traffic–generated emissions are accounting more than 50 % of the total PM emissions in the urban areas (Wróbel et al., 2000). $PM_{2.5}$ is considered a key indicator of ambient, or outdoor, air quality. While exposures to larger airborne particles can also be harmful, studies have shown that exposure to high average concentrations of $PM_{2.5}$ over the course of several years is the most consistent and robust predictor of mortality from cardiovascular, respiratory, and other types of diseases. Around the world, ambient levels of $PM_{2.5}$ continue to exceed the Air Quality Guideline established by the WHO. In 2017, 92 % of the world's population lived in areas that exceeded the WHO guideline for $PM_{2.5}$ (Health Effects Institute, 2019). The annual average concentrations of fine particulate matter air pollution $PM_{2.5}$ by region in urban and rural areas and PM_{10} by region are given in Figure 1.1 and 1.2. Globally, in 2017, the top ten countries with the highest mean exposure to $PM_{2.5}$ pollution include Nepal (more than double the world average) and India in South Asia; Niger, Cameroon, Nigeria, and Chad in Sub-Saharan Africa; and Qatar, Saudi Arabia, Egypt, and Bahrain in the Middle East and North Africa region. The PM levels in developing countries are much higher in comparison to developed countries (Kim et al., 2015). Strong regulation, quality of roads, maintenance of automobiles and planed urban development led to improve the PM levels in developed countries. (Mukherjee & Agrawal, 2017).

According to the State of Global Air 2019 report, air pollution was the 5th highest mortality risk factor in 2017 globally. An estimated 4.2 million premature deaths globally in 2016 are linked to ambient air pollution, mainly from heart disease, stroke, chronic obstructive pulmonary disease, lung cancer, and acute respiratory infectios in children. PM is the most widely used indicator to assess the health effects from exposure to ambient air pollution. Worldwide, ambient air pollution is estimated to cause about 16 % of the lung cancer deaths, 25 % of chronic obstructive pulmonary disease (COPD) deaths, about 17 % of ischaemic heart disease and stroke, and about 26 % of respiratory infection deaths.

Indian cities are among the most polluted cities in the world according to recent studies. Ambient and indoor PM concentrations are much higher in India than in developed countries (Pant et al., 2016). PM_{10} concentrations in India often exceed the national air quality standards, and in 2010, 140 out of 176 cities were found to exceed the $PM_{2.5}$ National Ambient Air Quality Standard (NAAQS) standard values (Gargava & Rajagopalan 2015). Nearly 100,000 premature deaths are linked to air pollution exposure (Public Health Foundation of India 2014) in the country and in Delhi alone between 7,350 and 16,200 premature deaths have been attributed to PM exposure (Guttikunda et al., 2014).

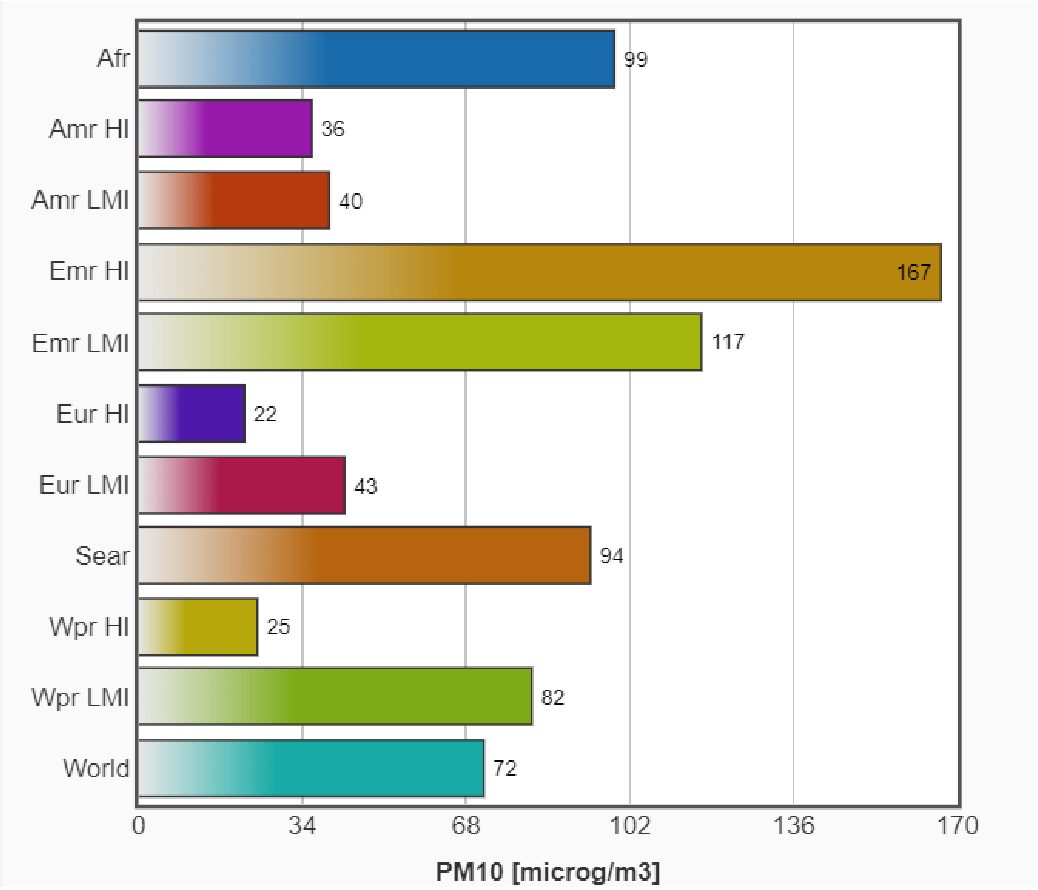
Figure 1.1. Annual average concentrations of $PM_{2.5}$ in µg/m^3, by region – urban and rural areas, 2016.



AFR: Africa; AMR: America; EMR: Eastern Mediterranean; EUR: Europe; SEAR: South-East Asia; WPR: Western Pacific; LMIC: Low- and middle-income countries; HIC: High-income countries.

(Source: World Health Organisation: Exposure to ambient air pollution from particulate matter for 2016)

Figure 1.2. Annual average concentrations of PM_{10} in µg/m^3, by region, 2016.



AFR: Africa; AMR: America; EMR: Eastern Mediterranean; EUR: Europe; SEAR: South-East Asia; WPR: Western Pacific; LMIC: Low- and middle-income countries; HIC: High-income countries.

(Source: World Health Organisation: Global Ambient Air Quality Database (update 2018)

1.7 Scope and Objective of the Study

The health effects and environment effects of particulate matters are well documented. WHO (2005) has declared that there is no evidence of a safe level of exposure or a threshold below which no adverse health effects occur as even at relatively low concentrations, the burden of air pollution on health is significant. Therefore, it is important that there exist in place an effective management of air quality which falls within the Air quality guideline proposed by their country or World Health organization so as to reduce health risks to a minimum. Monitoring provides information regarding the status of present air quality. It provides data to determine if a problem exist or to assess the scale of the problem. It helps in evaluating whether the existing policies and legislations and pollution abatement processes are effective. Monitoring of Particulate Matters is therefore essential to assess population exposure and to assist local authorities in establishing plans for improving air quality.

There have been some advances in monitoring of air pollution in India in recent years with the launch of programs like SAFAR (System of Air Quality Weather Forecasting and Research). However, it should be noted that the data collected by these monitoring networks are not available in the public domain. Moreover, there is no standardized operating protocol and as such, the quality of data remains a concern (Pant et al., 2016). Therefore, monitoring of air pollutants in a standardized manner to get reliable data is the need of the hour as air pollution is a global environmental burden and pose a major threat to the health of human beings.

Air pollution within Mizoram especially that of the capital city, Aizawl has been increasing due to increasing population and rapid urbanization. The main source of particulate pollution within the state consists of both anthropogenic and natural sources. Natural sources are forest fires and wind-blown dust while anthropogenic sources are burning of forest for shifting cultivation, vehicles, biomass combustion and burning of waste. Besides these, household air pollution can also be an important contributor to ambient $PM_{2.5}$ particularly in rural areas where wood/biomass and dung are used for cooking as well as heating (Chafe et al., 2014). Monitoring and assessment of PM_{10} has been carried out since (2005) by The Mizoram Pollution Control Board

(MPCB) under the state government. However, no study has been done in the state to monitor the level of $PM_{2.5}$. There has been no previous study in the state regarding the effects that PM have on the health of the people and on the environment. As such, there is a knowledge gap in the levels of PM pollution in Mizoram and the effect it has on health and environment. This gap has to be filled to identify if a problem exists and if so, which needs to assess the scale of the problem. This research aims to fill that gap to give us a better understanding of the state of particulate matter pollution within Aizawl city and the effects it may have on health and environment.

Objectives: The objectives of the research work are as follows:

1.) To assess particulate matters: $PM_{2.5}$, PM_{10} and suspended particulate matters (SPM)

2.) To study human health related problems caused by particulate matters.

3.) To study environmental problems caused by particulate matters.

Table 1.1 WHO Air Quality Guidelines, 2005

Pollutants	**Time Weighted Average**	**Standard limits as per WHO guidelines (µg/m3)**
Particulate matter (PM) – 2.5	Annual mean	10
	24 hours mean	25
Particulate matter (PM) – 10	Annual mean	20
	24 hours mean	50
Ozone (O3)	8 hour mean	100
Nitrogen dioxide (NO2)	Annual mean	40
	1 hour mean	200
Sulphur dioxide (SO2)	24 hours mean	20
	10 minute mean	500

Table 1.2: National Ambient Air Quality Standards

Pollutant	**Time Weighted Average**	**Concentration in Ambient Air**	
		Industrial, Residential, Rural and Other Areas	**Ecologically Sensitive Area (notified by Central Government)**
Sulphur Dioxide (SO_2), µg/m^3	Annual* 24 hours**	50 80	20 80
Nitrogen Dioxide (NO_2), µg/m^3	Annual* 24 hours**	40 80	30 80
Particulate Matter (size less than 10 µm) or PM_{10} µg/m^3	Annual* 24 hours**	60 100	60 100
Particulate Matter (size less than 2.5 µm) or $PM_{2.5}$ µg/m^3	Annual* 24 hours**	40 60	40 60
Ozone (O_3) µg/m^3	8 hours* 1 hour**	100 180	100 180
Lead (Pb) µg/m^3	Annual* 24 hours**	0.50 1.0	0.50 1.0
Carbon Monoxide (CO) mg/m^3	8 hours* 1 hour**	02 04	02 04
Ammonia (NH_3) µg/m^3	Annual* 24 hours**	100 400	100 400
Benzene (C_6H_6) µg/m^3	Annual*	5	5
Benzo(a)Pyrene (BaP)-particulate phase only, ng/m^3	Annual*	1	1

<table>
<tr><td>Arsenic(As), ng/m^3</td><td>Annual*</td><td>6</td><td>60</td></tr>
<tr><td>Nickel (Ni), ng/m^3</td><td>Annual*</td><td>20</td><td>20</td></tr>
<tr><td colspan="4">* Annual arithmetic mean of minimum 104 measurements in a year at a particular site taken twice a week 24 hourly at uniform intervals.
** 24 hourly or 8 hourly or 1 hourly monitored values, as applicable, shall be complied with 98 % of the time, they may exceed the limits but not on two consecutive days of monitoring.
Source: National Ambient Air Quality Standards, Central Pollution Control Board Notification in the Gazette of India, Extraordinary, New Delhi, 18th November, 2009</td></tr>
</table>

CHAPTER -2

REVIEW OF LITERATURE

2.1 An overview

Air pollution which has become emerged as one of the most threatening environmental problem of our time has a very long history. The earliest mention of air pollution in literature may be traced back to 900 BC when King Tukult I of Egypt comments on the odor from asphalt mining in the town of Hit, 160 km west of Babylon (Heidorn, 1978).

In the pre-industrial era, air pollution affecting the health was primarily indoor air pollution due to cooking and heating with open fires with no proper ventilation. Evidence for this is seen in the scientific study of samples of mummified lung tissues from Egypt, Peru, Britain and elsewhere which shows signs anthracosis (blackening of the lungs), from long exposure to the acrid smoke of domestic fires (Tapp et al., 1975; Tapp, 1979, Montgomerie,2013). Outdoor air pollution only became a major issue with the rise of cities (Mosley, 2014). In 400 BC, Hippocrates associates the city with air pollution in his treatise, “Airs, Waters and Places”. Seneca, a philosopher and statesman complained of the air pollution in Rome in A.D. 61 (Griffiths, 1977).

While domestic smoke was confined to urban centres, emissions from smelting and mining metals which started in Anatolia and Mesopotamia around 5000BC has a more far-reaching environmental impact. The leading sources of metallic pollutants were lead and copper production. Production of lead increased sharply during the Greco-Roman period (Mosley, 2014). Strabo, a Greek geographer, philosopher, and historian in his book “Geography” notes industrial air pollution in Tyre in A.D 1 (Griffiths, 1977) describing how emissions from smelter furnaces were discharged into the air and small sized particles were transported by wind to pollute large regions of the northern hemisphere. W ritings on various types of pollution including air, water, solid waste were found between 9th and 13th centuries by Persian scientists (Gari, 2002).

The first serious work on air pollution, “Fumifugium or the Inconvenience of Aer and Smoke of London. Dissapated: Together with Some Remedies Humbly Proposed” was published by John Evelyn (1661). John Graunt (1662) was the first to hypothesize on the link between air pollution and health problems in London in his book “Natural and Political Observations upon the Bills of Mortality, a statistical examination of the health of an urban population”. Robert Boyle (1682) was aware of anthropogenic influence on atmospheric composition and suggests methods for analyzing trace components in the air.

After the Industrial revolution, air pollution became a more serious problem with the spread of heavy industries. Great Britain was among the first to recognize the problems of air pollution and appointed a number of committees with some resulting, though ineffectual, legislation (Heidorn, 1978). A series of pollution episodes began to occur all over industrialized nations leading to the passage of new legislations in regard to air pollution. Some of the earlier, notable works on air pollution were The Measurement of Atmospheric Pollution (Owens, 1918); The smoke problem of great cities (Shaw & Owens, 1925), the first comprehensive work on urban air pollution problems; Study of pollution in an industrial center, Manchester, England, Atmospheric pollution of American cities for the years 1931-1933 (Ives et al., 1936).

Air pollution has undergone extreme changes in the last 50 years. Before World War II, the important air pollutants in urban areas were sulphur dioxide combined with soot from the use of fossil fuels in heat and power production. Use of cleaner fuels, higher stacks and flue gas cleaning partly solved this problem (Fenger, 2009). In most cities air quality has improved over the past decades. In Europe, emissions of the main old air pollutants such as sulphur dioxide (SO_2) and lead (Pb) together with other hazardous pollutants including persistent organic pollutants (POPs) and heavy metals, have declined significantly in recent decade (Ferrante et al., 2012). However, due to the growing traffic, pollutants such as nitrogen oxides and volatile organic compounds have become a menace. Recently, interest has centered on particulate matters (PM), tropospheric (ground-level) ozone (O_3) and polycyclic aromatic hydrocarbons (PAHs) as the new problematic pollutants due to the impact they have on health (Ferrante et al., 2012). Particulate matter has now been identified as one of the most critical environmental risks globally (Brauer et al., 2016).

Several terms are used to describe particular matter mainly due to its complexity and the importance of particle size in determining exposure and human dose. Terms such as “suspended particulate matter”, “total suspended particulates”, “black smoke” are derived from sampling and analytic methods. Some terms are derived from the site of deposition in the respiratory tract such as “inhalable particles”, which pass beyond the upper airways (nose and mouth), and “thoracic particles”, which deposit within the lower respiratory tract. Other terms, such as “PM_{10}”, have both physiological and sampling connotations (WHO, 2000).

Air-quality standards for PM were first established in 1971 by the United States Environment Protection Agency (EPA) as the National Ambient Air Quality Objective (NAAQO) for Total Suspended Particles (TSP) under the Clean Air Act. The effects that PM had on health and environment were still poorly comprehended at that time. Particulate matter was considered only as a nuisance pollutant. PM as an important component of smog was also unrecognized where it was considered to consist of mainly ground-level ozone. It was only later that the serious health effects of inhaling fine particles began to be recognized with many scientific studies linking fine PM to premature mortality and a range of morbidity effects. In the mid-1980's, studies of the deposition and clearance of particles in the respiratory system, along with studies of atmospheric physics and chemistry, suggested that smaller particles might be a larger part of the health threat, and that control strategies should focus on smaller particles (Dockery, 2009). In 1987, EPA changed the indicator to focus on "inhalable particles", which are particles equal to or smaller than 10 μm aerodynamic diameter and replaced total suspended particles standards with $PM_{10.}$ In the 1990s, evidence developed to indicate that even smaller particles of those less than 2.5 μm were able to penetrate into the alveolar gas-exchange regions of the lungs, and may be specifically related to health effects (Dockery, 2009). In 1997, EPA promulgates additional $PM_{2.5}$ standards that specifically addressed particles smaller than 2.5 microns. This classification based on size for setting of standards is also followed in India.

Air quality standard in India was first adopted in 1982 with two revisions in 1994 and 2009. Initially, particulate matters were divided into two types with separate standards - TSP (total suspended particles) and RSPM (respirable suspended particulate matter, i.e., with aerodynamic diameter less than 10 μm; now typically referred to as PM_{10}). When the standards were revised in 2009, a separate standard for $PM_{2.5}$ was promulgated. The standards for $PM_{2.5}$, both 24 h (60 $\mu g/m^3$) and annual (40

$\mu g/m^3$), are higher than the WHO Air Quality Guidelines as well as standards in the USA and Europe.

2.2 Effects on Health

The World Health Organization estimates that around 7 million people die every year from exposure to fine particles in polluted air that lead to diseases such as stroke, heart disease, lung cancer, chronic obstructive pulmonary diseases and respiratory infections, including pneumonia. Using the Global Exposure Mortality Model (GEMM) obtained from the $PM_{2.5}$ concentration–response in 41 cohorts from 16 countries, involving 20,000 cases and 2.5 million deaths, Burnett et al. (2018) attributed 8.9 million annual deaths to the exposure to ambient air $PM_{2.5}$, more than those attributed by the WHO and the GBD using the Integrated Exposure Response (IER) function. The effects that air pollution have on health are well documented in several reviews and report by the World Health Organization (2000, 2005; 2006, 2007) and the Health Effects Institute (2000, 2003, 2004, 2007, 2010, 2018).

There have been many health effect studies of Particulate matter around the world starting from the 1970s. Numerous reviews and critiques of the particulate air pollution and health literature have also been published. The various studies include effect of PM on mortality- all-natural cause and cause-specific such as cardiovascular mortality, short term studies that address acute effects and long-term studies that address chronic effects. Short-term studies are usually carried out as time-series studies or case crossover studies and they study the association between the short-term changes in air pollution exposure and daily death counts (Brook et al., 2010; Pope & Dockery, 2006). Most of the health evidence on particulate matter has been derived from studies of human populations in urban areas, showing adverse health outcomes such as hospital admissions for cardiovascular and respiratory disease, urgent care visits, asthma attacks, acute bronchitis and restrictions in activity (Martinelli et al., 2013)

2.2.1 Mortality – A large body of epidemiologic literature has found an association of increased fine particulate air pollution ($PM_{2.5}$) with acute and chronic mortality (Laden et al., 2006). Both short term and long-term studies are used to study the mortality caused by particulate matters. The most relevant short term, time series studies were the "National Morbidity, Mortality and Air Pollution Study" (NMMAPS) carried out from 1987- 1994 which included 20 cities initially and expanded to 90 cities in the United States, "Air Pollution and Health Effects—a European Approach" (APHEA and APHEA2) projects in Europe, the APHENA (Air Pollution and Health: a European and North American Approach) which analysed data from APHEA, NMMAPS and 12 Canadian cities in a combined approach. All these studies show a positive association between Particulate matter and mortality (Analitis et al., 2006; Katsouyanni et al., 1995; Katsouyanni et al., 1996; Katsouyanni et al., 1997; Katsouyanni et al., 2001; Samet et al., 2000; Samoli et al., 2008). Besides these studies, there have been numerous published research articles reporting results on analyses of short-term exposure to particulate air pollution and mortality. Most of these studies are single-city daily time series mortality studies (Pope & Dokery, 2006). This has led to many reviews and meta-analyses. Levy et al. (2000) from their meta-analysis of 21 studies concluded that elevated concentrations of PM_{10} were associated with increased mortality counts. Atkinson et al. (2014) from their review and meta-analysis of 110 peer-reviewed time series studies found that 10 $\mu g/m^3$ increment in $PM_{2.5}$ was associated with a 1.04 % (95 % CI 0.52 % to 1.56 %) increase in the risk of death. Orellano et al. (2020) from their meta-analysis 196 articles found evidence of a positive association between short-term exposure to PM_{10} and $PM_{2.5}$ and cardiovascular, respiratory and cerebrovascular mortality. Pascal et al. (2014) from study of nine French cities reported short-term associations between PM_{10} and mortality in nine French cities and reported that 10 $\mu g/m^3$ increase in daily PM_{10} levels was associated with a 0.2 % [-0.5; 0.9] increase in non-accidental mortality. These effects were realized even at concentrations within the EU annual regulation, and close to the WHO guideline values.

Long-term studies compare mortality across populations that vary in their long-term exposure to air pollution usually using a cohort design (Rückerl et al., 2011). The

Harvard Six Cities Study (Dockery et al., 1993; Laden et al., 2006) followed 8,111 patients for 16–18 years and found 29 % (95 % CI, 8–47 %) increase in the adjusted mortality rate for the most polluted of the cities compared to the least polluted. The American Cancer Society (ACS) Study (Pope et al., 1995) followed 552,000 patients in 151 metropolitan areas and found a 17 % (95 % CI, 9–26 %) increase in all-cause mortality and a 31 % (95 % CI, 17– 46 %) increase in cardiopulmonary mortality when comparing the most and least polluted cities. Other important cohort studies in this subject were the follow-up study of American Cancer Society (ACS) study (Pope et al., 2002; Pope et al., 2004), the Women's Health Initiative Study (Hoek et al., 2002), extended follow-up of the Harvard Six Cities study (Laden et al., 2006) and the European ESCAPE (Europe Study of Cohorts for Air Pollution Effects*)* study (Beelen et al., 2014). Zhang et al., (2014) from a 12-year cohort study in four cities in northern China reported that a 10 $\mu g/m^3$ increase in PM_{10} was associated with the relative risk ratios for all-cause mortality 1.24 (95 % CI 1.22–1.27 %), cerebrovascular disease mortality 1.23 (95 % CI 1.18–1.28 %), cardiovascular disease mortality 1.23 (95 % CI 1.19–1.26 %) and heart failure disease mortality 1.11 (95 % CI 1.05–1.17 %) suggesting significant association between long-term exposure to PM_{10} and cardiovascular mortality. Findings from these cohort studies are remarkably consistent and have shown an increase in long-term mortality from exposure to particulate matter, particularly $PM_{2.5}$ (Anderson 2012; Rückerl et al., 2011; Kim et al., 2015)

Reduced $PM_{2.5}$ concentrations have also been associated with reduced mortality risk (Laden et al., 2006). Health impact assessment study in the city of Rotterdam, Netherland, showed that decrease in PM_{10} levels from 1985 to 2008 resulted in a gain in life of an average 13 months per person (Keuken et al., 2011).

2.2.2 Cardiovascular Diseases – The American Heart Association in 2004 published a Scientific Statement that concluded that “studies have demonstrated a consistent increase risk for cardiovascular events in relation to both short- and long-term exposure to present-day concentrations of ambient particulate matter. Studies indicate that the highest attributable risk of adverse health effects of PM is upon the cardiovascular system (Rückerl et al., 2011). For any increase in mortality caused by PM, two thirds of the effect was accounted for by the cardiovascular diseases (Brook et al., 2010). A joint statement from the European Respiratory Society (ERS) and the American Thoracic Society (ATS) identified the cardiovascular system as the main target of air pollution, due, in particular, to $PM_{2.5}$ (Thurston et al., 2017). Chronic and acute exposure to elevated $PM_{2.5}$ levels has been linked with cardiovascular mortality as well as several clinical manifestations of cardiovascular diseases (CVD), including myocardial infarction, stroke, heart failure, arrhythmias, and venous thromboembolism, ischemic heart disease and cerebrovascular disease. It also exacerbates existing heart conditions and appears to have a role in disease development (Martinelli et al., 2013; Hamanaka & Mutlu, 2018).

Initial and extended analyses of the Harvard Six Cities and American Cancer Society cohorts consistently observed $PM_{2.5}$ associations with cardiovascular mortality (Pope & Dockery, 2006). The National Morbidity, Mortality and Air Pollution Study (NMMAPS) estimated a 0.68 % increase in cardiopulmonary mortality for each 10 $\mu g/m^3$ rise in PM_{10} (Samet et al., 2000); the Air Pollution and Health European Approach (APHEA-2) estimated a 0.76 % increase in cardiovascular deaths for each 10 $\mu g/m^3$ rise in PM_{10} (Analitis et al., 2006) ; Air Pollution and Health European and North American Approach (APHENA) estimated a 0.2-0.6 % higher total mortality increase in cardiovascular deaths for each 10 $\mu g/m^3$ rise in $PM_{10.}$ The extended 16-year follow up of the ACS study demonstrated that for each 10 $\mu g/m^3$ rise in the mean annual $PM_{2.5}$ concentration, there was a 6 % increased risk of cardiopulmonary deaths (Pope et al., 2002). More recently, a study from Hong Kong estimated that a 10-$\mu g/m^3$ rise in $PM_{2.5}$ increases the cardiovascular mortality by 1.22 (95 % CI, 1.08-1.39 %) (Wong et al., 2015)

There have been numerous long- and short-term studies which has associated $PM_{2.5}$ exposure with risk of myocardial infarction (Cesaroni et al., 2014; Madrigano et al., 2013; Nawrot et al., 2011; von Klot et al., 2005; Poloniecki et al., 1997), fatal and non-fatal ischemic heart disease (Burnett et al., 2014; Pope et al., 2004; Miller et al., 2007; Cesaroni et al., 2014), heart failure (Shah et al., 2013; Pope et al., 2004; Wellenius et al., 2005; Atkinson et al., 2013). Studies have also associated $PM_{2.5}$ exposure and cerebrovascular disease significantly (Miller et al., 2007; Stafoggia et al., 2014). Dominici et al., (2006) reviewed an air quality data for 204 US urban counties and showed that a 10-μg/m^3 increase in ambient $PM_{2.5}$ increased the risk of hospitalization for cerebrovascular events by 0.8 % (95 % CI, 0.3–1.3 %)

Long-term exposure to ambient PM air pollution have also been associated with increased blood pressure and higher prevalence of hypertension in children and adolescents (Zhang et al., 2019), in adults ≥18y old (Zhang et al., 2018a) and in a cohort of older Americans (57+ years) (Honda et al., 2018). This has been confirmed in a meta-analysis by Yang et al., (2018a) and Cai et al., (2016)

2.2.3. Respiratory Diseases – Studies have confirmed that exposure to particulate matters leads to increased pulmonary inflammation and respiratory symptoms aggravation due to oxidative stress and direct toxic injury (Pope et al., 2002). PM has been shown to increase respiratory mortality and respiratory diseases such as asthma, lung function decline, reduced lung function growth in children, lung cancer, chronic obstructive pulmonary disease (COPD) and temporary loss of lung function in normal people. There are also milder respiratory problems associated with inhaling $PM_{2.5}$ which include shortness of breath (dyspnea), chest discomfort and pain, and coughing and wheezing (Samoli et al., 2013).

Long term cohort studies such as the Six Cities study (Dockery et al., 1993), 20 cities study (Samet el al., 2000) and ACS CPS 2 (Pope et al., 1995) showed association between PM exposure and cardiopulmonary mortality but gave a joint impact of respiratory mortality and cardiovascular mortality. A follow-up study using data from the 20 Cities Study revealed a 0.87 % (95 % CI, 0.38–1.36 %) increased respiratory mortality for short-term increases in PM_{10} by 10 μg/m^3 (Zeka et al., 2005) while a study of larger cohort of 112 US cities revealed a 1.68 % (95 % CI, 1.04–2.33 %) increase in respiratory mortality for every 10-μg/m^3 increase in $PM_{2.5}$ (Zanobetti et al., 2009). Susceptible groups with pre-existing lung or heart disease, as well as elderly people and children, are particularly vulnerable (WHO, 2013).

The respiratory effect of particulate pollution is mostly studied in children as their lungs are immature and therefore more vulnerable to harmful effects (Heinrich & Slama, 2007). Gauderman et al. (2004) reported that children growing up in the most polluted areas were left with substantial deficits in lung function at age 18. Chronic exposure of PM levels greater than 200 μg/m^3 can lead to adult COPD, increased rates of lung infection, and impaired lung function (Grigg, 2009). In adults, large cohort studies by the Swiss Study on Air Pollution and Lung Diseases in Adults (SAPALDIA), and the German study on the Influence of Air Pollution on Lung Function, Inflammation, and Aging (SALIA) show a reduced lung function with increase in PM concentrations and vice versa (Downs et at., 2007; Schikowski et al., 2014)

In 2013, the WHO International Agency for Research on Cancer (IARC) announced that PM is carcinogenic. Earlier studies (Pope et al., 2002; Dockery et al., 1993) have linked PM with lung cancer mortality. Raaschou-Nielsen et al. (2013) found a statistically significant association with risk for lung cancer and $PM_{10.}$ Meta-analysis has confirmed that increased atmospheric PM concentrations are associated with lung cancer development (Huang et al., 2017; Hamra et al., 2014). Increased PM has been linked to increased onset of asthma (Gowers et al., 2012; Guarnieri and Balmas, 2014). Recent literature had also shown that the rate of hospitalization of patients suffering from asthma, COPD and pneumonia increased with increasing exposure to PM (Zanobetti et al., 2009; Medina-Ramon et al., 2006; Arena et al., 2006; Peng et al., 2009; Gan et al., 2013; Li et al., 2016; Sunyer & Basagaña, 2001)

Zoran et al. (2020) studied the impact of PM on Covid-19 outbreaks in Milan, Italy and found a strong influence of daily averaged ground levels of particulate matter concentrations, positively associated with average surface air temperature and inversely related to air relative humidity on COVID-19 cases outbreak in Milan.

2.2.4 Reproductive Disorders, Perinatal Disorders – The World Health Organisation (WHO) in 2005 from their review of air pollution and children's health and development concluded that "overall, there is evidence implicating air pollution in adverse effects on pregnancy outcomes" (WHO, 2005). Various epidemiologic studies have found associations between maternal exposure to particulate matter and adverse birth outcomes which includes low birth weights, infant mortality, preterm births, small for gestational age birth (SGA) and birth defects.

Low birth weight (LBW) is defined by the World Health Organization (WHO) as a birth weight less than 2500 grams. Birth weights are important indicators of the health of newborns and infants that may influence the health status in adulthood

(Sinclair et al., 2007). Fleischer et al. (2014) in their analysis of 22 countries from the year 2004-2008 under the World Health Organization Global Survey on Maternal and Perinatal Health have concluded that exposure to $PM_{2.5}$ was associated with low birth weight [odds ratio (OR) = 1.22; 95% CI: 1.07, 1.39 %] for fourth quartile of $PM_{2.5}$ (> 20.2 μg/m^3) compared with the first quartile (< 6.3 μg/m^3). Stieb et al. (2012) from meta-analysis of sixty-two studies reported that pooled odds ratios for low birth weight for $PM_{2.5}$ was 1.05 (0.99-1.12) per 10 μg/m^3 and for PM_{10}, it was 1.10 (1.05-1.15) per 20 μg/m^3 PM_{10} based on entire pregnancy exposure. From the European cohort study ESCAPE, Pedersen et al. (2013) reported that a 5 μg/m^3 increase in concentration of $PM_{2.5}$ during pregnancy was associated with an increased risk of low birthweight at term (adjusted odds ratio [OR] 1·18, 95 % CI 1·06-1·33 %) and for PM_{10} (OR for 10 μg/m ^{3} increase 1·16, 95 % CI 1·00–1·35 %) as well. They also found that the population attributable risk estimated for a reduction in $PM_{2·5}$ concentration to 10 μg/m ^{3} during pregnancy corresponded to a decrease of 22 % (95 %, CI 8–33 %) in cases of low birthweight at term.

Infant mortality refers to the number of children dying before their first birthdays per 1,000 live births in a region. Several studies and reviews have been conducted that shows that PM exposure is most strongly and consistently associated with post-neonatal respiratory mortality (Pope & Dockery, 2006). Combining data on a million births with local-level estimates of aerosol particulate matter, Heft-Neal et al. (2020) found that an increase of 10 μg/m^3 in local annual mean $PM_{2.5}$ concentrations causes a 24 % increase in infant mortality (95 % confidence interval: 10–35 %).

Preterm Births (PTB) are defined as infants born before 37 weeks of gestation Srám et al. (2005) found a small association between total suspended particles (TSP) and PM_{10} and the risk of premature births. A cohort study in Netherlands among 7772 pregnant women showed that PM_{10} exposure in the third and fourth quartiles were positively associated with preterm birth (van den Hooven et al., 2012). Schifano et al. (2013) from birth cohort study in Rome found delayed and prolonged effect of PM_{10} exposure on preterm-birth risk in birth cohort. However, results from more studies are still inconclusive. While Fleischer et al. (2014) have found no association, other studies such as Shah et al. (2011) has reported that exposure to fine particulate matter (PM) of ≤2.5 μM was associated with, PTB and SGA births, and exposure to coarse

PM of ≤10 μM was associated with SGA births. Laurent et al. (2016) in their study of Preterm Birth and Air Pollution in California from 2000-2008 have also found that exposures to PM were associated with an increase in PTB. Qian et al. (2016) from their studies in China studies suggested that increased $PM_{2.5}$, PM_{10}, CO, and O_3 exposures over the full pregnancy were associated with small increases in the odds of PTB. Rich et al. (2009) found that every 4 $\mu g/m^3$ increase in $PM_{2.5}$ exposure during the first and the third trimester increases the risk for SGA by 4.5 % (95 % CI: 0.5-8.7 %) and 4.1 % (95 % CI: 0.3-8.0 %), respectively.

The association between birth defects mostly in the form of cleft lip with or without cleft palate and various forms of congenital heart defects and PM pollution have been studied. In Atlanta, Strickland et al. (2009) studied exposure to PM_{10} during 3-7 weeks of gestation and found a small increased risk for one of 12 specific cardiac abnormalities. Meta-analysis by Vrijheid et al. (2011) linked PM_{10} exposure to an increased risk of atrial septal defects (OR per 10 $\mu g/m^3$=1.14, 95 % CI: 1.01-1.28 %) but found no statistically significant increase in risk of other cardiac anomalies or oral clefts. Ren et al. (2018) reported that increased exposure to $PM_{2.5}$ in the periconception period is associated with some modest risk increases for congenital malformations. Liu et al., (2019) reported that an increase of 10 $\mu g/m^3$ in $PM_{2.5}$ exposure over the entire pregnancy was significantly associated with increased risk of congenital anomalies, with hazard ratio (HR) of 1.35 [95 % confidence interval (95 % CI): 1.16, 1.58] in China. Marshall et al. (2010) found no evidence of an association between oral cleft defects and levels of $PM_{2.5}$. A birth cohort study in Tel Aviv reported that increased exposure to PM_{10} during 3–8 weeks of pregnancy is significantly associated with an increased risk for multiple congenital heart defects (Agay-Shay et al., 2013).

Review and meta-analysis of recent literature had revealed that although the evidence is compelling that PM pollution has a detrimental effect on infant mortality and fetal development, results are less consistent for other reproductive outcomes like preterm birth and birth defects. Even for fetal development, there is difficulty in drawing robust conclusions due to the heterogeneity in results of various studies (Shah et al., 2011).

2.2.5 Neurological Disorders – The effect that PM pollution may affect the brain has been recently discovered (Peters et al., 2006). A large body of literature shows association between PM and the occurrence of stroke, particularly ischemic stroke. Studies investigating the short-term exposure to PM have suggested a significant effect of PM exposure and the risk of stroke (Tian et al., 2019; Lin et al., 2017; Shah et al., 2015; Matsuo et al., 2016; Yu et al., 2014; Yang et al., 2014; Wang et al., 2014; O'Donnell et al., 2011). Zhang et al. (2018b) examined the short-term effects of PM on ischemic stroke mortality and hemorrhagic stroke mortality in Beijing, China and reported that 10 μg/m^3 increase of $PM_{2.5}$ was associated with the increase of mortality, 0.23 % (95 % CI, 0.04-0.42 %) for ischemic stroke and 0.37 % (95 % CI, 0.07-0.67 %) for hemorrhagic stroke. They also associated PM_{10} with ischemic stroke. A meta-analysis of long-term exposure to PM by Scheers et al. (2015) involving 20 studies, more than 10 million people, and more than 200,000 stroke events reported that the association between long-term particulate matter exposure and stroke event was positive in North America and Europe. Yuan et al. (2019) from meta-analysis of cohort studies also concluded that long-term exposure to $PM_{2.5}$ is an important risk factor for stroke.

Association between air pollution and neurodegenerative diseases were first studies in wild dogs in Mexico living in highly polluted environment. Brain lesions of inflammatory origin were detected in these dogs (Calderón-Garciduenas et al., 2002; Calderón-Garciduenas et al., 2003). Inflammation in the central nervous system (CNS) plays a critical role in neurodegenerative diseases such as Alzheimer's disease (AD) and Parkinson's disease (PD), the two most prevalent neurodegenerative diseases (Hirtz et al., 2007). Silbajoris et al. (2011) also demonstrated that PM_{10} in ambient air can induce inflammatory responses. Recently, quite a few studies have examined the association of PM exposure with neurodegenerative disorders and long-term cognitive disorders (Ailshire & Clarke, 2015; Chen & Schwartz, 2009; Chen et al., 2015; Costa et al., 2017; Dimakakou et al., 2018; Peters et al., 2019; Power et al., 2016; Ranft et al., 2009; Tonne et al., 2014; Weuve et al., 2012, Wilker et al., 2015) and neurological hospital admissions (Kioumourtzoglou et al., 2016). Chen et al. (2008) found a positive association between $PM_{2.5}$ and dementia incidence. Tsai et al. (2019) analyzed the results of four cohort studies conducted in Canada, Taiwan, the UK, and the US during

2015-2018 among more than 12 million elderly subjects aged ≥50 years and have confirmed that exposure to $PM_{2.5}$ was positively associated with a higher risk for dementia/ Alzheimer's disease (AD). Yu et al. (2020) suggests that exposure to $PM_{2.5}$ might increase the risk of cognitive impairment.

2.2.6 Effect on Biological Mechanisms: $PM_{2.5}$ exposure has been linked to systematic inflammation, oxidative stress and alteration of the electrical processes of the heart (Brook et al., 2010). Künzli et al. (2005 & 2010) have associated long-term exposure of $PM_{2.5}$ with preclinical markers of atherosclerosis and with progression of this pathology of high relevance to cardiovascular diseases. This is also confirmed by a series of studies from Germany (Hoffmann et al., 2006 & 2007).

2.3 Effect on environment

2.3.1 Impairment of Visibility – Visibility impairment has been primarily attributed to the scattering and absorption of visible light by suspended particles (Chan et al., 1999). One of the most common cause of visibility impairment is the presence of atmospheric haze. Haze is an atmospheric phenomenon where dust, smoke and other dry PM composed of various components obscure the clarity of the sky (Liu et al., 2016). Pollutional haze is not to be confused with fog. Fog which has 90 % water content may also impair visibility and affect traffic conditions but has little negative health effects when air is unpolluted. When air is polluted with dry particles like $PM_{2.5}$ and PM_{10} and gases like ozone, nitric oxide, nitrogen dioxide and sulfur dioxide, pollutional haze may occur if the relative humidity is less than 80 %. The basic components of pollutional haze are gases (e.g., ozone, sulfur dioxide, nitric oxide, nitrogen dioxide, carbon monoxide, carbon dioxide), volatile organic compounds (e.g., Benzene), and PM (e.g., metals, nitrates, sulfates, organic carbon, microbial components, pollen) (Osornio-Vargas et al., 2011, Chen et al., 2008). Out of these components, fine particles, generally characterized as $PM_{2.5}$, are believed to be primarily responsible for the scattering of visible light and a cause of the degradation of visibility (Sloane et al., 1991; Kim et al., 2001; Ghim et al., 2005). Zhao et al. (2013) studied the relation between visibility and PM for two years in urban area of Northeast China and concluded that fine particles are the most important factor in the deterioration of visibility. The 2009 PM ISA concluded that “a causal relationship exists between PM and visibility impairment” based on strong and consistent evidence that PM is the overwhelming source of visibility impairment in both urban and remote areas (U.S. EPA, 2009).

2.3.2 Effect on soil, water and ecosystems – Particulate matter can be carried over long distances by wind and may be deposited on soil or water or vegetation. This atmospheric deposition usually happens by three methods- wet deposition by means of snow and rain, dry depositions and occult depositions by means of fog, mist or cloud-water. Particulate matter deposition comprises a heterogeneous mixture of particles differing in origin, size, and chemical composition. Exposure to a given concentration of particulate matter may, depending on the mix of deposited particles, lead to a variety of toxic responses and ecosystem effects. Effects of particulate matters on ecological receptors can be both chemical and physical (U.S. EPA, 2009, 2004). The adverse ecological effect of particulate matters has been attributed more to particle composition than to particle size (Grantz et al., 2003). However, there are also some effects of particle size such as changes to flux of solar radiation and soiling of leaves by large coarse particles in areas near industrial facilities and unpaved roads. (U.S. EPA, 2009)

PM-associated components include Nitrogen (N) and Sulphur (S) and their transformation products, trace metals, organics, base cations, and salts. The deposition of particulate matter containing N and S onto the landscape puts ecosystems at risk, through ecosystem acidification and alteration of nutrient balances. Acidification is caused by both wet deposition via precipitation and dry deposition of gases and particles of N and S from the atmosphere. (Greaver et al., 2012)

Acidification of surface water due to PM deposition alters the surface water chemistry and may result in the loss of acid-sensitive biota; the greater the acidification, the more species are lost (Driscoll et al., 2001). Although both N and S deposition can cause aquatic acidification, S deposition is generally the primary cause of chronic acidification, with secondary contributions from N deposition These changes in water chemistry associated with acidification include alterations in the concentrations of sulfate ,nitrate , inorganic Al, and calcium ions (Ca2+); surface-water pH; the sum of base cations; acid-neutralizing capacity (ANC); and base cation surplus (Lawrence et al., 2008). Reduction in acid-neutralizing capacity can lead to higher Al concentrations causing toxicity to sensitive species of phytoplankton, zooplankton, macroinvertebrates and fish (Rago & Wiener 1986; Driscoll et al., 2001). Adverse biological effects may be seen at pH levels < 6.0–6.5 and inorganic Al concentrations > 30–50 μg L–1 (Baker et al., 1990).

In terrestrial ecosystems, effects of acidification due to sulphur and nitrogen deposition included change in plant physiology, plant growth and terrestrial biodiversity. The physiological changes observed were slower growth and increased mortality of sensitive plant species as seen from studies of tree species such as sugar maple (Bilodeau-Gauthier et al., 2011; Sullivan et al., 2013) and red spruce (Schaberg et al., 2011; Boyce et al., 2013). This is attributed mostly to Al toxicity and decreased ability of plant roots to take up base cations (Ca).

In addition to acidification, N deposition can alter the nutrient balance of entire ecosystems, causing a cascade of effects (Greaver et al., 2012). In freshwater and estuarine ecosystems, PM deposition containing Nitrogen may cause enrichment/eutrophication. Aquatic eutrophication results in increased productivity of algae and aquatic plants, altered nutrient ratios, and sometimes decreased oxygen levels and may alter aquatic species assemblage (Elser et al., 2009; Bricker et al., 2007). S depositions may lead to internal eutrophication as was observed in mesocosms of samples collected from Lake Moshui, China (Yu et al., 2012).

In terrestrial ecosystems, N may simultaneously act as a nutrient and as a strong acid anion in some ecosystems, causing a range of effects that maybe considered both positive and negative (Compton et al., 2011). The addition of nitrogen to terrestrial ecosystems through PM depositions can affect the uptake and emission of methane and nitrous oxides leading to increased emissions. It has been found to decrease methane uptake in coniferous and deciduous forest and increase methane production in wetlands (Liu & Greaver 2009) while increasing the biogenic emission of nitrous oxide in coniferous forests, deciduous forests, grasslands, and wetlands. Nitrogen deposition can increase primary productivity, thereby altering the biogeochemical cycling of C and potentially altering ecosystem C budgets. Nitrogen deposition has been shown to increase C sequestration in some forest ecosystems (Liu & Greaver

2009; Thomas et al., 2010; Butterbach-Bahl et al., 2011). Various studies have confirmed that S deposition can stimulate microbes to produce methylate mercury (Hg), a process that introduces Hg, a highly neurotoxic substance into the food chain and leads to its bio-accumulation (Goñi-Urriza et al., 2015; Bae et al., 2014; Frohne et al., 2011; Yu et al., 2012; Tsui et al., 2008)

PM may affect vegetation due to the deposition on vegetation surface leading to altered photosynthesis, transpiration and reduced growth (U.S. EPA, 2020). PM emitted from industrial sources contain trace metals and once deposited to biological surfaces may be taken up by biota, accumulate in tissues and elicit toxic effects (Gall et al., 2015). These responses are highly variable across organisms. In plants, metal uptake is generally via soil to root transfer (McBride et al., 2013), although recent studies provide evidence for foliar transfer of metals following atmospheric deposition (Schreck et al., 2014; Burkhardt et al., 2012; Schreck et al., 2012). Once uptake occurs, plant physiological responses may include decreased gas exchange, altered metabolism and photosynthesis, altered pigment and mineral content, and altered enzyme activity (Naidoo & Chirkoot, 2004). There is some evidence that metals reduce frost hardiness and impair nutrition (Taulavuori et al., 2005; Kim et al., 2004).

PM may contain organic compounds such as persistent organic pollutants (POPs), pesticides, semi-volatile organic compounds (VOCs), PAHs, and flame retardants emitted mostly by vehicular traffics in metropolitan areas (U.S. EPA, 2009). Some of these compounds are carcinogenic and considered as priority pollutants. Studies have confirmed that there is airborne transfer to polar regions and at other remote locations such as remote national parks and biomagnification of organics through the food web indicated contaminants were present at multiple trophic levels. (Pritz et al., 2014; Landers et al., 2010).

Several studies show PM chemical constituent effects on soil physical properties and nutrient cycling. The upper soil layers where deposited particles accumulate are typically active sites of litter decomposition and plant root uptake. PM deposition containing heavy metals may have a negative effect on soil nutritional value and may also affect soil texture and density (Ulrichs et al., 2008). Since soil is heterogenous, the effect of PM deposition, accumulation in soil and the subsequent bioavailability of PM components depend on a number of soil characteristics. For example, heavy metal accumulation in soil was found to be influenced by pH of soil, Fe and aluminum oxide content, amount of clay and organic material, and cation exchange capacity (Hernandez et al., 2003). Bioavailability depends on metal speciation, soil pH, and degree of binding to dissolved organic matter (Sauvé, 2001)

Toxicity of heavy metals like Zn, Cd, and Cu to soil microflora have been found to reduce decomposition processes in soils and interfere with nutrient cycling (U.S. EPA, 2009). In the study of soils contaminated by atmospheric emissions from an active mining and smelting complex, soil microbial biomass had been found to be negatively correlated with metal concentrations (Shukurov et al., 2014). Pandey & Pandey (2009) demonstrated the role of atmospheric deposition of particulate heavy metals in inhibiting C cycling. In this study, a cropping system was exposed to atmospheric deposition while a similar cropping system was designed to exclude it by using a greenhouse. Total organic carbon and water-soluble organic carbon increased in the exposed plots and decreased in the greenhouse plots; slow decomposition in soils polluted with heavy metals could have caused the increased levels of total organic carbon and water-soluble organic carbon observed in the open plots. Studies also show a decrease in enzyme activity and varying sensitivity of enzymes to PM metal pollution. Soil dehydrogenase activity was diminished in polluted soils compared to control soils (Bojarczuk & Kieliszewska-Rokicka, 2010). High soil dehydrogenase activity indicates a living microbial community.

PM can affect physical properties of soils, such as bulk density, porosity, and water holding capacity. Changes in these properties can decrease plant growth and yield (U.S.EPA, 2020). In a study of experimental cropping system, one open to deposition and another closed to deposition, Pandey & Pandey (2009) found that the bulk density of soil was elevated in the open one while porosity and water holding capacity were diminished over the same time period. The opposite was the case for the experimental cropping system closed to deposition. The authors suggested that the influx of deposition of particulate matter during the study period caused a rise in bulk density, and the elevated bulk density caused the decrease in porosity and water holding capacity (Pandey and Pandey, 2009).

2.4 Global scenario of Particulate Matters

After industrialization to the present time, PM has become one of the major air pollutants in urban, suburban and even in rural and remote regions of the world (Mukherjee & Agrawal, 2017). According to the State of Global Air, 2020 report, over 90 % of the world's population experienced annual average $PM_{2.5}$ concentrations that exceeded the WHO Air Quality Guideline of 10 µg/m^3 in 2019. Continent wise, the highest annual average exposures were seen in Asia, Africa, and the Middle East. The 10 countries with the highest exposures worldwide are in these regions though given uncertainty in the estimates, the rankings are not absolute. The 10 countries with the lowest exposures (i.e., population-weighted annual average concentrations less than 8 µg/m^3) are Australia, Brunei Darussalam, Canada, Estonia, Finland, Iceland, New Zealand, Norway, Sweden, and the United States (Health Effect Institute, 2020).

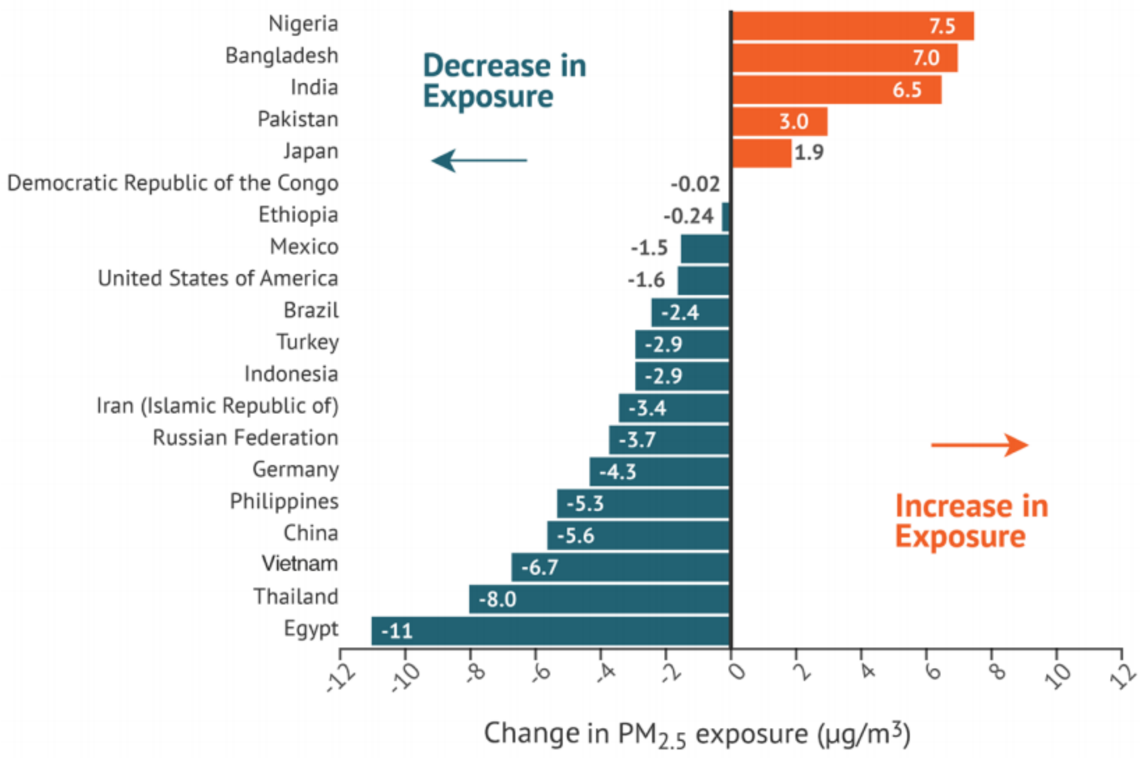
Table 2.1: Top 10 countries with the highest population-weighted annual average $PM_{2.5}$ exposures in 2019

Country	**$PM_{2.5}$ concentration µg/m^3**	**95% uncertainty intervals**
India	83.2	76.1 to 90.7
Nepal	83.1	62.9 to 107
Niger	80.1	42.2 to 145
Qatar	76.0	59.2 to 96.6
Nigeria	70.4	45.2 to 105
Egypt	67.9	47.8 to 92.8
Mauritania	66.8	37.6 to 108
Cameroon	64.5	43.8 to 92.6
Bangladesh	63.4	55.1 to 73.8
Pakistan	62.6	49.9 to 77.5

According to the State of Global air report, 2020, The average global $PM_{2.5}$ exposures was found to decline a little from 2010 to 2019. The regions seeing improvement include Southeast Asia, East Asia, and Oceania, led by China, Vietnam, and Thailand. Regions with no improvement or increased exposure include North Africa, the Middle East, and sub-Saharan Africa.

The decline in average $PM_{2.5}$ exposures have also been reported by Health Effect Institute (2020) from their study of twenty most populous countries of the world representing 70 % of the world's population from 2010 – 2019. 14 countries experience declines in annual average $PM_{2.5}$ exposures, ranging from a slight decrease of 2.9 µg/m^3 (from 22.3 to 19.4 µg/m^3) in Indonesia to a substantial decline of 10.6 µg/m^3 (from 78.5 to 67.9 µg/m3) in Egypt over the past decade. Germany and the United States experienced modest reductions since 2010. Japan saw a modest increase in $PM_{2.5}$ levels (11.5 to 13.5 µg/m^3). At the other end of the spectrum, Nigeria experienced an increase of 7.5 µg/m^3 in the level of $PM_{2.5}$, from 62.9 µg/m^3 (95 % uncertainty interval [UI]: 41.1 to 92.4) in 2010 to 70.4 µg/m^3 (95 % UI: 45.4 to 105.2) in 2019. Countries with some of the highest exposures in the world like India, Pakistan, and Bangladesh continue to see increases (Health Effect Institute,2020).

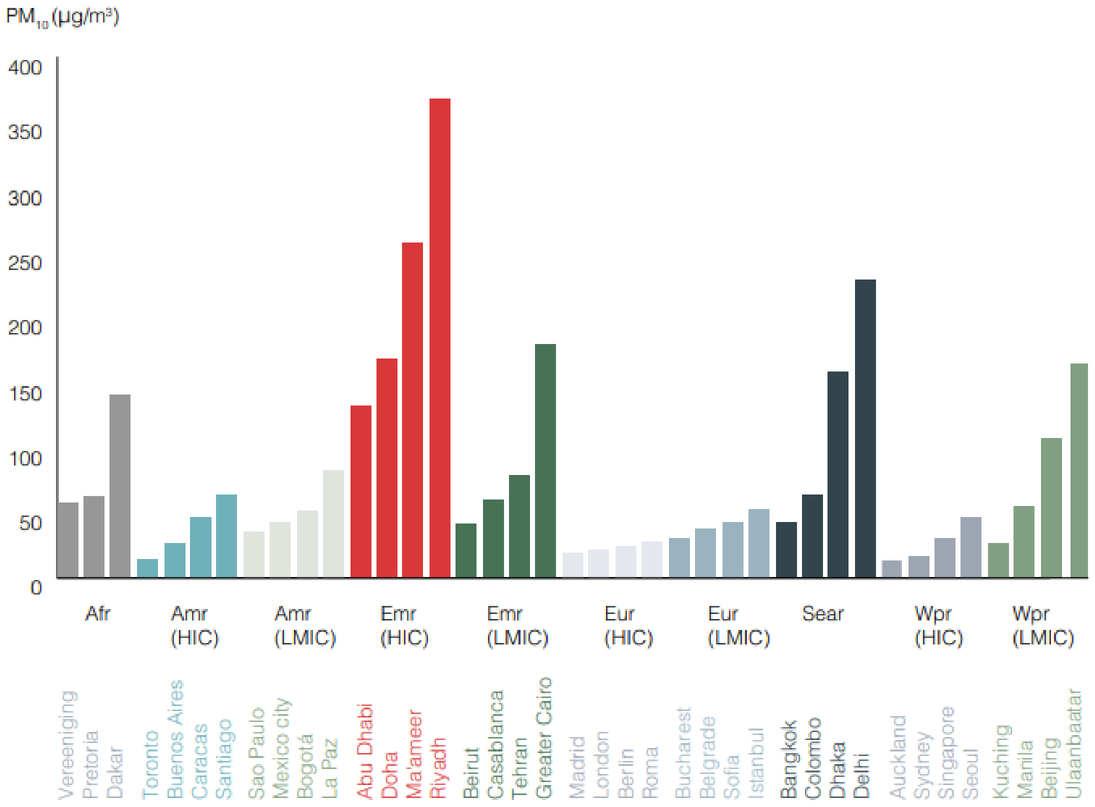
Figure 2.1: Change in population-weighted annual average $PM_{2.5}$ exposure in the 20 most populous countries (2010–2019) .



Reduction in global PM_{10} levels in the last two decades have also been reported by Pandey et al. (2006) contributed mostly by developed countries. The greatest reduction was seen in the Russian Federation with reduction of 59.6 % followed by Greece (53.7 %), Ukraine (53.6 %), Japan (52.2 %) and USA (51.4 %) In Asia, China showed 32.5 % reduction and India showed 18 % reduction. However, there are countries in Asia and Africa with increase in PM_{10} level in last two decades such as Bangladesh (31.4 %), Kenya (26.3%), Nepal (24.6 %), Senegal (14.1 %) and Cambodia (13.3 %) (Pandey et al., 2006).

According to World Health Organisation (2016), the Eastern Mediterranean region has the highest level of PM_{10} during the period 2011-2015. In their assessment of the level of PM_{10} in mega-cities with more than 14 million habitants, Delhi was found to have the highest level.

Figure 2.2: PM_{10} levels for selected cities by region, for the last available year in the period 2011-2015



PM_{10}: Particulate matter of 10 microns or less; Afr: Africa; Amr: Americas; Emr: Eastern Mediterranean; Eur: Europe; Sear: South-East Asia; Wpr: Western Pacific; LMIC: low- and middle-income countries; HIC: high-income countries.

Yang et al. (2018b) compared the concentration of particulate matters in China, India and United States from 2014 to 2017 and found that the average daily concentrations of $PM_{2.5}$ and PM_{10} was lowest level in the U.S ranging from 2.79–21.64 $\mu g/m^3$ and 7.94–61.06 $\mu g/m^3$, followed by China ranging from 6.03–126.03 $\mu g/m^3$ and 15.58–217.04 $\mu g/m^3$, and highest in India ranging from 15.16–536.5 $\mu g/m^3$ and 44.66–646.3 $\mu g/m^3$, respectively.

Karagulian et al. (2015) collected 529 records from source apportionment studies of PM in 51 cities around the world using receptor models published between 1990 and 2014. For $PM_{2.5}$, the leading contributor in urban region was found to be traffic (25 %), industrial activities including power generation contributed 15 %, 20 % domestic fuel burning contributed 20 %, unspecified sources of human origin contributed 22 % while and 18 % was from natural dust and sea salt. However, the contribution by different sources vary according to regions. Traffic was found to be the main contributor of $PM_{2.5}$ in India (37 %), South Eastern Asia (36 %), Southwestern Europe (35 %), Southern Asia (34 %), Brazil (33 %), and the Rest of the Americas (30 %). Industrial activities had the highest contributions from human activities in Japan (34 %), Middle East and Southern Asia (27 %), Turkey (30 %), Brazil (19 %), Central Europe (17 %), and South Eastern Asia (18 %). Domestic fuel burning was the main contributor in Africa (34 %), and in Central and Eastern Europe (32 %) although based on very few records in this region). Domestic fuel burning was also important in the Rest of the Americas (25 %), Northwestern Europe (22 %), the Southern China region (21 %), South Eastern Asia (19 %), and India (16 %). For PM_{10}, 25 % was contributed by traffic, 18 % by industrial activities including power generation, 15 % from domestic fuel burning, 20 % from unspecified sources of human origin, and 22 % from natural dust and sea salt.

Kumar et al. (2021) in their study of ten global cities found that African and Asian cities showed higher average concentrations of PM compared to Latin-American and Middle-Eastern cities. They also found that the dominant sources of

$PM_{2.5}$ and PM_{10} pollution in each city vary, and include vehicular emissions, dust resuspension from unpaved roads, biomass burning and industrial and urban activities.

2.5 National scenario of Particulate Matters

The World Air Quality Report 2019 (IQAir Air Visual, 2020), a global compilation of $PM_{2.5}$ particulate pollution data has ranked India as the 5th most polluted country in 2019 with average $PM_{2.5}$ concentration of 58.1 µg/m³. It has placed twenty-one of the India cities among the top worlds 30 cities with the worst air pollution. Ghaziabad, a satellite city of the capital New Delhi in northern Uttar Pradesh state, is ranked as the world's most polluted city, with an average $PM_{2.5}$ concentration measurement of 110.2 µg/m³. In 2018, the World Health Organization has also place 9 cities of India among the top 10 most polluted cities from monitoring of PM annual mean concentration all over the world from 2008 to 2017. Kanpur had the highest concentration of PM in 2016 where the concentration of $PM_{2.5}$ was 173µg/m³ and PM_{10} was 319 µg/m³. This is followed by cities like Faridabad ($PM_{2.5}$ -172 µg/m³ and PM_{10} - 216 µg/m³) Gaya ($PM_{2.5}$ -149µg/m³ and PM_{10} -275µg/m³), Varanasi ($PM_{2.5}$ - 146µg/m³ and PM_{10} - 260µg/m³), Patna ($PM_{2.5}$ -144µg/m³ and PM_{10} - 266µg/m³), Delhi ($PM_{2.5}$ -143 µg/m³ and PM_{10} -292µg/m³), Lucknow ($PM_{2.5}$ -138µg/m³ and PM_{10} - 255µg/m³), Agra ($PM_{2.5}$ -131µg/m³ and PM_{10} - 194µg/m³) and Gurgaon ($PM_{2.5}$ - 120µg/m³ and PM_{10} - 124µg/m³) .

The Government of India launched the National Ambient Air Monitoring Programme (NAMP) in 1984 which monitors the air quality throughout the country. The ambient air quality monitoring network has 793 operating stations in 344 cities/towns in 29 states and 6 Union Territories of the country. Monitoring is carried out for 24 hours (4-hourly sampling for gaseous pollutants and 8-hourly sampling for particulate matter) with a frequency of twice a week, to have 104 observations in a year. The monitoring is being carried out by Central Pollution Control Board; State Pollution Control Boards; Pollution Control Committees; National Environmental Engineering Research Institute (NEERI), Nagpur. Under NAMP three criteria pollutants which includes PM_{10} were identified for regular monitoring at all locations. Other notified parameters like $PM_{2.5}$ are being monitored at selected locations. The analysis of air quality data of 42 cities during 2017 have shown that with respect to

PM_{10}, 41 cities (98 %) do not comply with the National Ambient Air Quality Standard (NAAQS) which is 60.0 µg/m^3. With respect to $PM_{2.5}$, out of 18 cities monitored, 10 cities (56 %) exceed the NAAQS (40.0 µg/m^3) (CPCB, 2019)

From analysis of PM_{10} concentration data from the national regulator monitoring network for 12 years (2004–2015) from 27 states and 5 Union territories at 630 unique monitoring locations, Pant et al. (2019) reported that 0.23 % of all PM_{10} measurements (11 out of 4789) were found to meet the annual average WHO Air Quality Guideline (20 µg/m^3), while 19 % of the locations were in compliance with the Indian air quality standards for PM_{10} (60 µg/m^3). Besides this, the study also reported that most of the monitoring stations in the country are located in urban areas and peri-urban areas and there may be lack of data from rural areas as the coverage is sparse. PM_{10} concentrations were the highest in northern India — Uttar Pradesh, Delhi, Jharkhand, Punjab and Rajasthan.

According to the Global Burden of Disease Report 2017, the annual population-weighted mean exposure to ambient particulate matter $PM_{2.5}$ in India was 89.9 µg/m^3 (95 % uncertainty interval [UI] 67·0–112·0) in 2017. Most of the states and 76.8 % of the population of India were exposed to annual population-weighted mean $PM_{2.5}$ greater than the limit recommended by the National Ambient Air Quality Standards in India. Delhi had the highest annual population-weighted mean $PM_{2.5}$, followed by Uttar Pradesh, Bihar, and Haryana in north India, all with mean values greater than 125 µg/m^3. 1.24 million deaths in India in 2017, which were 12.5 % of the total deaths, were attributable to air pollution, including 0.67 million from ambient particulate matter pollution and 0.48 million from household air pollution. India contributed 18.1 % of the global population but had 26.2 % of the global air pollution. The ambient particulate matter pollution Disability-Adjusted Life Year (DALY) rate was highest in the north Indian states of Uttar Pradesh, Haryana, Delhi, Punjab, and Rajasthan (India State-Level Disease Burden Initiative Air Pollution Collaborators, 2019)

There have been numerous studies in particulate pollution in India. The majority of it is concentrated in the capital, Delhi as it is among the most polluted city in world (WHO, 2016). All the studies have reported critical levels of PM exceeding WHO standards as well as the National Ambient Air Quality Standards (Hama et al.,2020; Kaushik et al., 2018). Tiwari et al., (2015) reported that the mean mass concentrations of $PM_{2.5}$, $PM_{10–2.5}$ and PM_{10} were 118.3 ± 81.7, 113.6 ± 70.4 and 232.1 ± 131.1 μg/m^3 respectively in three different sites across Delhi. Tyagi et al. (2014) in their study of Industrial, residential, and commercial areas in Delhi from 2009- 2011 reported SPM values of 646 μg/m^3 and RSPM values of 330 μg/m^3 at Sahibabad Industrial area, SPM of 190 μg/m^3 and RSPM of 90 μg/m^3 in Raj Nagar residential area, SPM of 543 μg/m^3 and RSPM of 282 μg/m^3 in Begum Bridge. Sharma et al. (2012) from their study of Delhi and Chandigarh from Dec 2010–March 2011 reported PM_{10} values of 192.88–288.8 μg/m^3 in Delhi and 132.5–186.9 μg/m^3 in Chandigarh. Kaushik et al. (2011) reported 687.71 μg/m^3 of TSP and 268.6 μg/m^3 of PM_{10} in the industrial area, 495 μg/m^3 of TSP and 202.1 μg/m^3 of PM_{10} in the residential area and 514.6μg/m^3 of TSP and 256.9μg/m^3 of PM_{10} in the commercial area of Delhi. Apte et al. (2011) reported an averaged concentration of 190 μg/m^3 $PM_{2.5}$ in Delhi. Prakash & Bassin (2010) reported RSPM values (24 hourly average) of 62–664 μg/m^3, 48–619 μg/m^3 and 28–483 μg/m^3 for industrial, commercial and residential areas of Delhi respectively. Tiwari et al. (2013) reported annual mean level of $PM_{2.5}$ of 122 μg/m^3 in Delhi. Dutta and Jinsart (2020) analysed the pollution data for Guwahati from 2016-2019 and found that in the winter season, the ambient PM_{10} concentrations exceeded 100 μg/m^3.

Numerous studies have reported a seasonal variation in the levels of PM in Delhi with the highest levels in winter and lowest levels in monsoon. Sharma et al. (2014) reported PM_{10} level of 241.4 ± 50.5 μg/m^3 during winter and PM_{10} level of 140.1 ± 43.9 μg/m^3 during monsoon. Tiwari et al. (2015) reported an average 24-h PM_{10} concentration in summer of 283.8 μg/m^3 with a maximum concentration of 592.1 μg/m^3, while in winter, the value was 303.9 μg/m^3 with a maximum concentration of 700.2 μg/m^3. Guttikunda (2009) from his analysis of monitoring data of air pollutants from September’06 to March’09 in Delhi confirms that seasonal peaks coin-cides with lower mixing heights of the winter months and that the measured PM pollution in the winter is double the level measured during the rest of the seasons. Pandey et al. (2011) reported the PM_{10} concentration (μg/m^3) in Lucknow city at 4 locations in three different seasons ranged between 148.6–210.8 (avg. 187.2 ± 17.1) during summer, 111.8–187.6 (avg. 155.7 ± 22.7) during monsoon and 199.3–308.8 (avg. 269.3 ± 42.9) during winter while $PM_{2.5}$ ranged between 32.4–67.2 (avg. 45.6 ± 10.9), 25.6–68.9 (avg. 39.8 ± 4.6) and 99.3–299.3 (avg. 212.4 ± 55.0) during respective seasons. This phenomenon has also been observed in other cities of India such as Hyderabad (Gummeneni et al., 2011), Kolkata (Chatterjee et al., 2012), Chennai (Srimuruganandam & Nagendra, 2011, Agra (Massey et al., 2012). Ambade (2016) studied the seasonal variations of PM_{10} levels in urban and rural area and reported higher values during winter season (167 and 153 $\mu g/m^3$) and lowest values during monsoon season (34 and 32 $\mu g/m^3$) at both sites.

Northern parts of India have shown higher levels of PM compared to the southern and northeastern parts. Gargava & Rajagopalan (2015) from their study of PM_{10} levels in six major cities from 2007–2010 found higher PM_{10} concentrations in North Indian cities compared to the South. Mean PM_{10} concentrations during the entire study period at residential, industrial and kerb sites were 98, 137 and 164 $\mu g/m^3$for Bangalore, 123, 142 and 170 $\mu g/m^3$ for Chennai, 419, 519 and 576 $\mu g/m^3$ for Delhi, 213, 385 and 275 $\mu g/m^3$ for Kanpur, 207, 196 and 205 $\mu g/m^3$ for Mumbai and 132, 136 and 195 $\mu g/m^3$ for Pune, respectively. Sharma et al. (2016) from their study of three cities showed the same result. Pant et al. (2019) from analysis of PM_{10} monitoring data from 2004 to 2015 throughout the country have also reported higher concentrations of PM_{10} in northern part of the country. This may be attributed to high traffic, unplanned urban development, poor maintenance of road and vehicles, meteorological and topographical conditions in the Northern cities and higher vegetation cover, lower emissions, and planned urbanization in Southern cities (Mukherjee & Agrawal, 2017). In Chennai, Gajghate et al. (2012) reported the annual average PM_{10} levels in the Industrial, commercial, and residential locations varying from 32 to 48 $\mu g/m^3$. Jha et al. (2011) reported SPM ranged between 35 and 174 $\mu g/m^3$ from 2007–2008 in Port Blair.

In Western parts of India, Joseph et al. (2012) reported an average $PM_{2.5}$ mass concentrations at control, kerb, residential and industrial sites at 69 ± 20, 84 ± 31, 89 ± 33 and 95 ± 36 $\mu g/m^3$ respectively for 2007-2008 in Mumbai and Kothai et al. (2011) reported the average mass concentration of $PM_{2.5–10}$ and $PM_{2.5}$ as 70 $\mu g/m^3$ and 41 $\mu g/m^3$ respectively for 2008 in Mumbai. In Rajasthan, Kumar et al. (2011) reported that SPM varied between 79.81 and 854.33 $\mu g/m^3$ and RSPM ranged 46.64–340.85

μg/m^3 during 2009–2010 in Jaipur; Kapoor et al. (2013) reported that for Urban, industrial and forest areas SPM ranged between 118.39 (rainy season) to 528.56 (summer season) μg/m^3 during 2010 to 2012 in Udaipur; Yadav et al. (2014) reported that PM$_{2.5}$ varied between 8–111 μg/m^3 and PM$_{10}$ varied between 28–350 μg/m^3 during 2010 to 2011.

In Central India, various studies have reported high values of PM. Barman et al. (2010) reported 24-h average concentration in May 2006 for SPM is 382.3 μg/m^3 and RSPM is 171.5 μg/m^3 in urban areas of Lucknow; Singh et al. (2010) reported the 24-h average of PM$_{10}$ in summer, winter, and rainy seasons at Taj Mahal, Agra varied between 115–233, 155–321, and 33–178 μg/m^3 respectively. In Nagpur, Anjikar et al. (2015) reported that the annual concentration of SPM was 270 μg/m^3 and of RSPM was 150 μg/m^3. In Kanpur city, Kumar et al. (2014) reported that PM levels were generally higher at vehicular intersections and construction sites and recorded the highest concentration of PM$_{10}$ (1110 μg/m^3) and PM$_{2.5}$ (124 μg/m^3) in Kalyanpur. Panicker et al. (2015) reported that PM$_{10}$ levels vary from 48 to 149 μg/m^3 in Jabalpur.

The most populated city in East India, Kolkata had high level of PM$_{10}$ mass concentrations ranging from 68.2 to 280.6 μg/m^3 at a residential site and 62.4 to 401.2 μg/m^3 at an industrial site. (Karar & Gupta 2006). Dubey et al. (2012) reported mean annual PM$_{10}$ at mining and non-mining areas in Jharkhand as 258.64 and 134 29 μg/m^3, respectively.

In North-east India, Barman (2013) reported that the annual average RSPM concentration in Residential and commercial areas of Assam during 2007-2009 varied from 86.67–112.97, 94.74–149.57, 111.32–139.74 μg/m^3 in Guwahati. Gohain & Kalita (2016) studied the SPM and RSPM levels in six stations in industrial, commercial, and residential areas of Guwahati and reported that SPM ranged from 282- 491 μg/m^3, 85–206 μg/m^3 and 74–146 μg/m^3 and RSPM from 153 -236 μg/m^3, 33–107 μg/m^3, and 44–89 μg/m^3 respectively. Lamare & Chaturvedi (2014) also recorded high values of RSPM, NRSPM, and TSPM in Meghalaya varying from 81.24 - 261.43 μg/m^3; 73.17–265.54 μg/m^3, and 212.49–467.94 μg/m^3 respectively.

Various source apportionment of particulate matters has been carried out in the country. A major source for PM$_{10}$ in India is dust (Pande et al., 2018, Pant et al.,2016) while household emissions are responsible for the largest share of PM$_{2.5}$ exposure in

India according to several studies (Conibear et al., 2018; Butt et al., 2015; Lelieveld et al., 2015). The four main activities under this are biomass burned for residential cooking, space- and water heating, and kerosene used for lighting.

Most of the studies in PM pollution in India are carried out in big cities and there is a poor representation of smaller cities and towns and rural areas. A detailed PM_{10} source apportionment study conducted in six Indian cities during 2007–2010 by Gargava & Rajagopalan (2015) reported that road dust and vehicles are the two major sources accounting for ~30 to 70 % and ~15 to 20 % of PM_{10} emissions, respectively. Venkataraman et al. (2017) reported that about 60 % of India's mean population-weighted $PM_{2.5}$ concentrations come from anthropogenic source sectors, while the remainder are from "other" sources, windblown dust and extra-regional sources and the leading contributors are residential biomass combustion, power plant and industrial coal combustion and anthropogenic dust (including coal fly ash, fugitive road dust and waste burning) while transportation, brick production and distributed diesel were other contributors to $PM_{2.5}$. Other dominant sources of PM including fossil fuel and biomass burning, and waste burning are also reported by various studies (Pant & Harrison 2012; Guttikunda et al., 2014; Wiedinmyer et al., 2014; Sadavarte & Venkataraman 2014).

A study of the source apportionment of PM concentrations in Delhi-National Capital Region (NCR) based on two approaches - Receptor and Dispersion modelling reported that industries (28 %), road dust (13 %), residential (20 %), and agricultural burning (17 %) are the main contributors to PM_{10} emissions in NCR and industries (24 %), residential (25 %), agricultural burning (19 %), and transport (13 %) are the major contributors for $PM_{2.5.}$ whereas in Delhi, the share of the transport sector is significant (39 %) in $PM_{2.5}$ emissions and 19 % in PM_{10} emissions. (Sharma et al., 2018). A sector wise contribution to PM pollution study in Delhi by Guttikunda et al. (2014) reported transport sector (17 %) as the biggest source of $PM_{2.5}$ followed by power plants (16 %) and brick kilns (15 %) and for PM_{10}, road dust (22 %) is the biggest source followed by power plants (15 %) and transport (13 %). Sharma et al. (2014) from their Positive Matrix Factorization (PMF) analysis reported that the largest contributor to PM_{10} in Delhi were secondary aerosols (21.7 %), soil dust (20.7 %), fossil fuel combustion (17.4 %), vehicle emissions (16.8 %), and biomass burning (13.4 %). Sahu et al. (2011) reported that the biggest source of PM_{10} is road dust resuspension (55 %) and mixed sources for $PM_{2.5}$. Balachandran et al. (2000) also reported three major sources namely vehicular emissions, industrial emission, and soil resuspension. Beside these sectors, other sources of PM in Delhi are open refuse burning, domestic biofuel like kerosene secondary aerosols, and construction activities (Khillare et al., 2004; Mönkönnen et al., 2004)

Gummeneni et al. (2011) from their study in Hyderabad reported that the main source for PM_{10} was resuspended dust (40 %), followed by vehicular pollution (22 %), combustion (12 %), industrial (9 %) and refuse burning (7 %); while in $PM_{2.5}$ vehicular pollution (31 %) dominated over resuspended dust (26 %), combustion (9 %), industrial (7 %) and refuse burning (6 %).

In Kolkata, Chatterjee et al. (2012) through principal component analysis (PCA) of $PM_{2.5}$ reported that the main sources were vehicular emission (38.0 %), biomass burning (27.0 %), dust aerosols (18.0 %), and secondary anthropogenic components (11 %). Gupta et al. (2007) studied source apportionment using chemical mass balance model in Kolkata in residential and industrial site and reported that the most dominant source throughout the study period at residential site was coal combustion (42 %), while vehicular emission (47 %) dominates at industrial site to PM_{10}. Paving road, field burning and wood combustion contributed 21 %, 7 % and 1 % at residential site, while coal combustion, metal industry and soil dust contributed 34 %, 1 % and 1 % at industrial site, respectively, to PM_{10} during the study period. The contributors to Total Suspended Particles (TSP) included coal combustion (37%), soil dust (19 %), road dust (17 %) and diesel combustion (15 %) at residential site, while soil dust (36 %), coal combustion (17 %), solid waste (17 %), road dust (16 %) and tyre wear (7 %) at industrial site.

In Mumbai, (Joseph et al., 2012) reported that $PM_{2.5}$ mass was mostly contributed by organic matter (36.0–52.0 %), secondary inorganic aerosols (21.0–27.0 %), crustal (6.00–12.0 %), non-crustal (4.0–8.00 %), and sea salt (6.00–11.0 %). Kothai et al. (2011) from Principal Component Analysis (PCA) based multivariate studies identified soil, sea salt and combustion as common sources for coarse and fine particles. Chelani et al. (2008) studied the sources of particulate matter of size less than 10 micron in Mumbai using chemical mass balance model and reported that in normal activity site which included commercial and residential and traffic sites, soil dust contribution were dominant while on the control site, industrial contributions dominate and in areas close to sea, marine contributions are significant.

In Ahmedabad, Sudheer & Rengarajan (2012) reported anthropogenic sources account for 80 % of $PM_{2.5}$ and the main sources were industrial and vehicular emissions, burning of biomass and resuspended or long range transported dust while for PM_{10}, mineral dust (43 %) to be a major contributor to PM_{10}.

A report by the Lancet Commission on pollution and health (Landrigan et al., 2018) has ranked India the highest country in pollution related deaths in 2015. Ambient air pollution accounted for 1.09 million deaths and household air pollution due to solid fuel accounted for 0.97 million deaths. WHO in 2015 attributed one in six deaths to air pollution worldwide i.e. 9.2 million deaths and out of this, India accounted for 28 % i.e. 2.51 million death.

A Lancet study (nations within a nation report) that estimated the disease burden and risk factors across all states of India from 333 disease conditions and injuries and 84 risk factors for each state of India from 1990 to 2016, ranked air pollution as the second leading risk factor for DALY (disability-adjusted life-years) after child and mother malnutrition (Global Burden of Disease Study, 2017).

2.6 Local scenario of Particulate Matters

Due to the absence of significant industrialization in the state, the main source of air pollution in the capital city Aizawl is vehicular emissions (MPCB, 2005). Jhum burning has also found to play a vital role in determining the quality of air in Mizoram (Lalrinpuii & Lalnuntluanga, 2013).

The Mizoram Pollution Control Board has been monitoring the air quality in the state since 2005 under the National Air Quality Monitoring Programme (NAMP), sponsored by Central Pollution Control Board. Initially, only 3 monitoring stations, Bawngkawn, Khatla and Laipuitlang were set up within Aizawl district and in 2011, 8 monitoring stations were added bring the total to 11 monitoring stations in 4 districts of Mizoram. Four air parameters, namely, PM_{10}, SPM, SO_2 and NO_2 are monitored at a frequency of 24 hrs. monitoring, twice a week.

In the State of Environment Report (MPCB, 2005), the ambient air quality data (RSPM and SPM) of Aizawl city for June and July, 2005 was reported to fall within the permissible limit of the National Ambient Air Quality Standard.

A study by Lalruatliana & Lalnuntluanga (2011) carried out in four different sites – Bawngkawn, Khatla, Laipuitlang and Aizawl Municipal dumping site found that the SPM was highest in the Aizawl municipal dumping site which was attributed to burning of garbage especially during dry season (December-April).

Zothanzama et al. (2013) monitored RSPM and SPM of Aizawl Municipal dumping site using High Volume Air Sampler, Envirotech Model APM 460 BL from August 2011 to May 2012 with a monitoring period of 8 hours and reported high concentrations exceeding the National Ambient Air Quality Standard. SPM shows highest concentration during April 2012 with mean values at 789.64 (SD ±1172.73) $\mu g/m^3$ and lowest during October 2011 which is 23.95 $\mu g/m^3$. For RSPM, the highest recorded mean value was during November 2011 which was 1345.99 (SD ± 108.29) $\mu g/m^3$.

There has been no study yet on the health and environmental effect of particulate matters within the state.

CHAPTER-3

STUDY AREA

3.1 A brief information about Mizoram

Mizoram is one of the eight sister states of North-East India bordering Myanmar and Bangladesh, covering an area of 21,081 km^2.It lies between coordinates 21^{0}58’ N to 24^{0}35’ N latitude and 92^{0}15’E to 93^{0}20’ E longitudes. The tropic of cancer run through the heart of Mizoram at 23^{0}30’N latitude dividing the state into almost two equal halves/parts. It lies between Myanmar in the east and south and Bangladesh in the west occupying an area of great strategic importance in the north-eastern corner of India with a long international boundary of 722 Kms. It is bordered by the states of Manipur and Assam border on the north and Tripura in the north-west.

According to 2011 census, the total population of Mizoram is 1,091,014 with males numbering 552,339 and females 538,675. It has a high literacy percentage (%), the third highest in the country i.e. 91.58 % as per statistics of Economic and Statistics Dept, Government of India.

Mizoram has a moderate climate which is neither too hot nor too cold. During winter (November through February), temperatures typically vary from 7 to 21 °C (45 to 70 °F) while in the warmest months (June through August), it varies from 20 to 29 °C (68 to 84 °F). It is influenced by south west monsoon bringing storms during March-April, just before or around the summer. Pre-monsoon rains are experienced from March to May while regular south-west monsoon commences from June till October. Annual rainfall of the State is about 2500 mm with 124 numbers of rainy days, but is concentrated between June to September with little rain in the dry (cold) season (Anon. 2011).

Mizoram is a hilly land with steep and rugged terrain. It is composed of 21 major hill ranges running through the state with only a few plains in between. These hills have an average height of about 1000 m in the west and 1300 m in the east. The highest peak in Mizoram is Phawngpui Tlang also known as the Blue Mountain, situated in the south-eastern part of the state at 2210 metres.

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). According to India State of Forest Report, 2019 the total forest cover is 18,006 km^2 which is 85.41 % of the total geographical area. Mizos are primarily cultivators and their festivals are much connected with agricultural operation.

3.2 Description of study site

Aizawl is the capital of the state of Mizoram situated on a ridge 1,132 meters (3,715 ft.) above sea level. Aizawl is located in the northern part of Mizoram with Tlawng river valley to its west and Tuirial river valley to its east. The geographic location of the heart of the capital Aizawl is 23.36° N 92.0° E.

The population of the Aizawl is highest within the state with a total population of 400,309 according to 2011 census. Aizawl has a mild, sub-tropical climate due to its location and elevation with temperature ranging from 20-35°C in summer and 11-21°C in winter. Annual rainfall received is around 209 cm (Anon. 2011).

Four sampling stations have been selected from which air quality data ($PM_{2.5}$, PM_{10} & SPM) and soil sample (pH) have been collected.

Station 1 – Mizoram University is situated on the outskirts of the city in the locality of Tanhril. As it is an educational institution area, it is a sparsely populated and the traffic volume is low. Expected particulate matter source consist mainly of emissions from burning of Jhum fields.

Station 2- Bawngkawn is a commercial area with very high traffic volume and dense population located in the northern part of the city. It is one of the most important entry and exit point for transport vehicles going in and out of the city.

Station 3- Laipuitlang is one of the most densely populated locality in the city. It is a residential area with moderate traffic volume located in the central part of the city having a higher elevation of 1134 m.

Station 4 – Khatla is one of the oldest localities situated in the southern part of the city. It is a commercial cum residential area and have a very high traffic volume as it is an important crossroad in the city.

Three sites have been selected to collect water sample where parameters like pH and turbidity were determined. The sites include MZU stream – located in the heart of MZU campus, Chite Lui/Stream – located in the eastern side of Aizawl city and Tuikual Lui/ Stream – located in the western side of Aizawl city.

Figure 3.1: Location Map of the Study Site

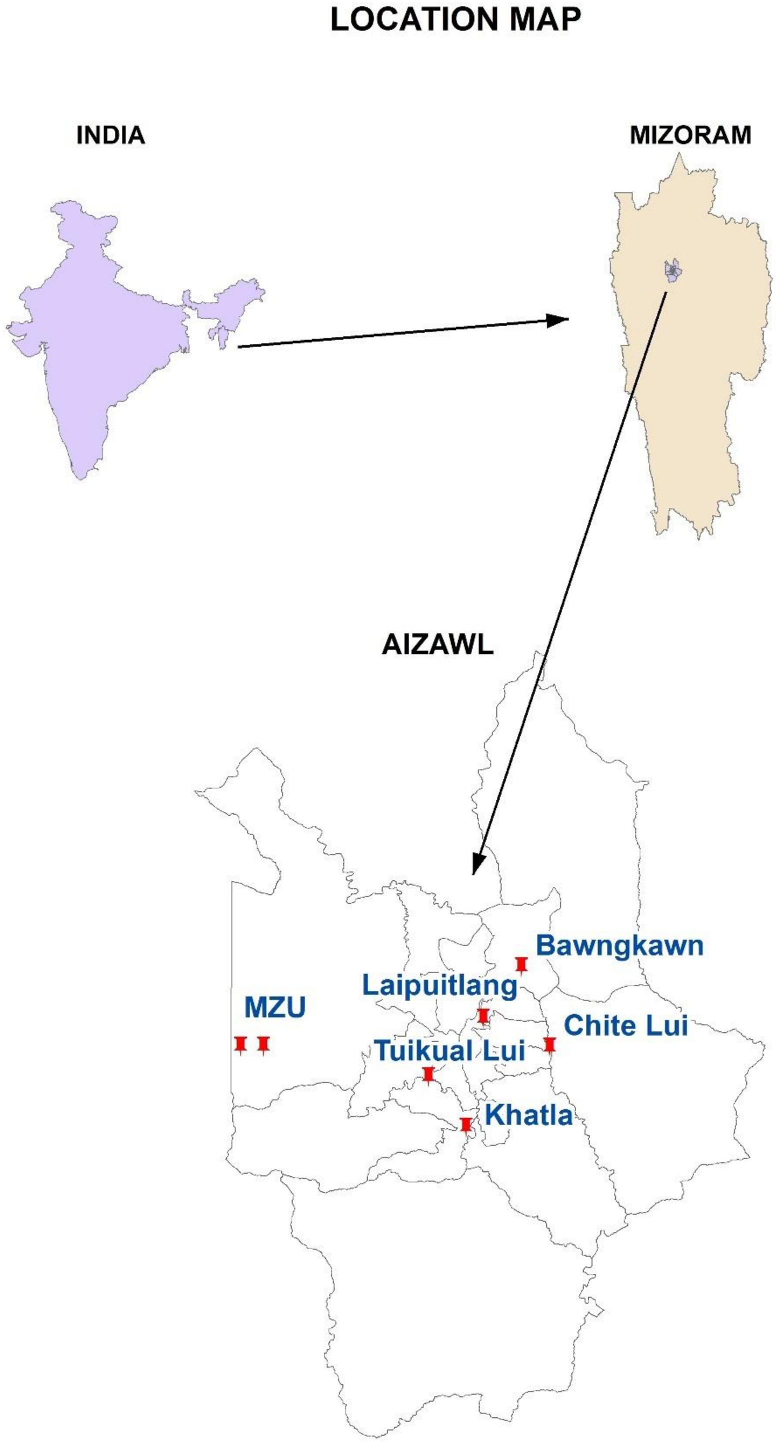
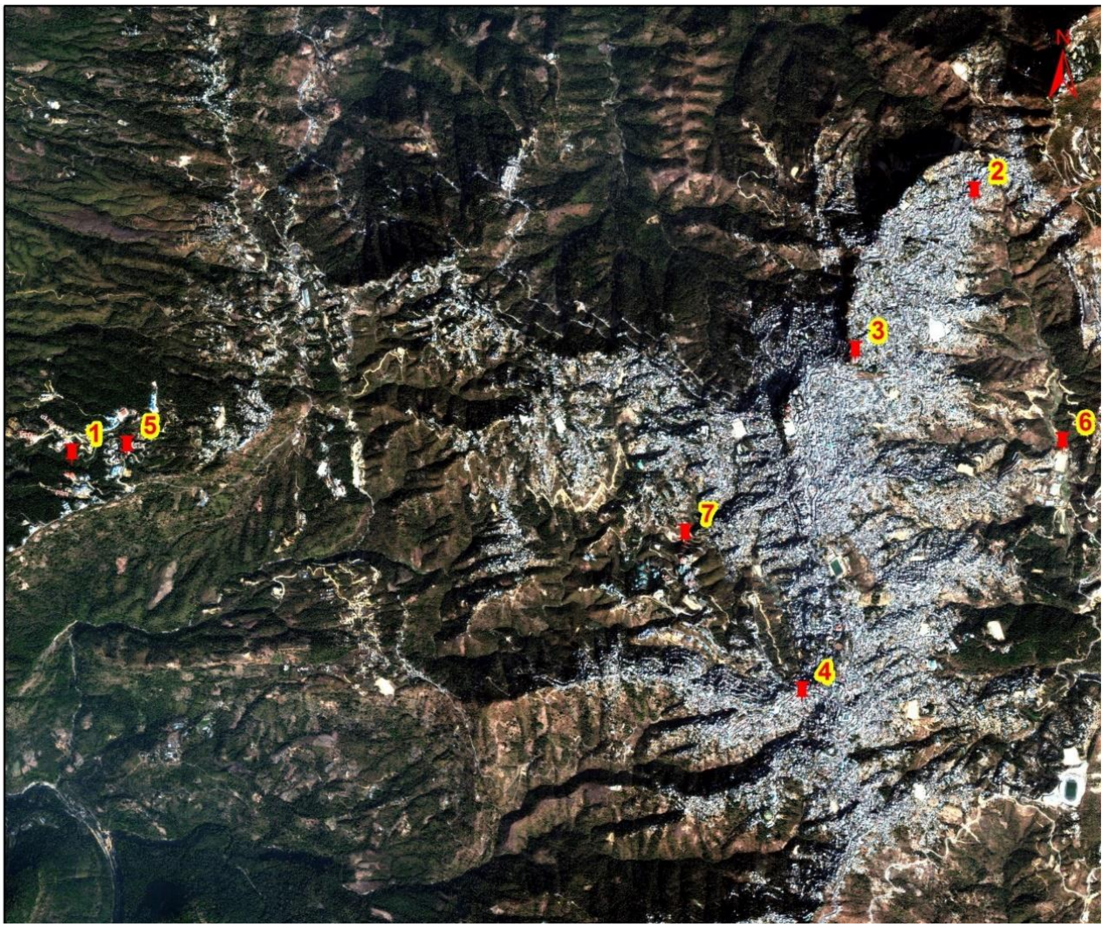


Figure 3.2: Map of Aizawl showing the study sites (Quickbird Image)



1- MZU Air Monitoring Station
2- Bawngkawn Air Monitoring Station
3- Laipuitlang Air Monitoring Station
4- Khatla Air Monitoring Station
5- MZU Stream
6- Chite Lui/Stream
7- Tuikual Lui/Stream

CHAPTER-4

MATERIALS AND METHODS

4.1 Estimation of Suspended Particulate Matter

To determine the Suspended Particulate Matter (SPM) level in the atmosphere, the High Volume Method was used. Sampling was done using a device called ‘Respirable Dust Sampler’, Envirotech Model APM 460 BL during the study period from June 2014 to May 2016.

Respirable Dust Sampler draws air through a size – selective inlet and through a 20.3 x 24.4cm (8x10in) filter at a flow rate which is typically 1132 L/min (40ft3/min). Particles with aerodynamic diameters less than the cut point of the inlet are collected by the filter the mass of these particles is determined by the difference in filter weights prior to and after sampling. The concentration of suspended particulate matter in the designated size range is calculated by dividing the weight gain of the filter by the volume of air sample.

Particles range in size from a diameter of 0.0002 µm (about the size of a small molecule) to a diameter of 500 µm (1m=10^{-6} µm) with lifetimes varying from a few seconds to several months. However, this lifetime depends on the settling rate, which again depends upon the size and density of the particles and turbulence of air. The particulates possess large surface areas in general and hence present good sites for sorption of various inorganic and organic matters. Their optical properties, viz. ability to scatter light and reduce visibility, are important in determining their effects on solar radiation. Suspended particulates being smaller in size, usually do not settle.

4.1.1 Calculation of Volume of Air Sampled

Air Volume Sampled (V), $m^3 = \frac{Q_1 + Q_2 x T}{2}$

Where,

$Q_1 = initial\ air\ flow\ rate,\ m^3 / min$

$Q_2 = final\ air\ flow\ rate,\ m^3 / \min$

4.1.2 Calculation of mass concentration of SPM

$$SPM\,(\mu g/m^3) = \frac{(W_f - W_t)x10^6}{V}$$

Where,

W_t = *initial weight of filter, g.*

W_f = *final weight of filter, g.*

V = Volume of Air sampled in m^3.

10^6 = *conversion of gram to* µg (1g = 10^6µg)

4.2 Estimation of PM_{10}

The method for determination of Respirable Suspended Particulate Matter in the ambient air is the Cyclonic Flow Technique. A device called Respirable Dust Sampler. Envirotech Model APM 460 BL is used for the estimation of PM_{10}.

Air is drawn through a size selective inlet and through a cyclone walls and are collected at the base by a grit pot, at a flow rate which is typically 1132 L/min. Particles with aerodynamic diameter less than the cut point of the inlet are collected by the filter. The mass of these particles is determined by the difference in filter weights prior to and after sampling. The concentration of PM_{10} in the designated size range is calculated by dividing the weight gain of the filter by the volume of air sampled.

Depending on the type of the filter media used, filter samples can be analyzed for lead, iron, organic and elemental carbon, extractable organic material, elements, radioactive materials, inorganic compounds, and single particles.

Calculations of Volume of Air Sampled:

$$V=QT$$

Where,

V = Volume of air sampled in m^3

Q = Average flow rate in m^3/minute

T = Total sampling in minute

Calculation of PM_{10} in Ambient Air:

Where,

PM_{10} = Mass concentration of particulate matter less than 10 micron diameter in mg/m^3

Wi = Initial weight of filter in g

Wf = Final weight of filter in g

V = Volume of air sampled in m^3

10^6 = Conversion of g to mg

4.3 Estimation of $PM_{2.5}$ and PM_{10}

The BAM-1020 (Beta Attenuation Monitor) is used for monitoring $PM_{2.5}$ and PM_{10}. BAM-1020 automatically measures and records airborne particulates (in milligrams or micro grams per cubic meter) using principle of beta-ray attenuation. Thousands of BAM-1020 units are currently deployed worldwide, making the unit one of the most successful air monitoring platforms in the world. A continuous supply of electricity is required for continuous monitoring of air. The monitor is also equipped with a computer so as to carry on its work and for recording and storing of data.

4.3.1 Data collection – All data files are automatically measured and record using the system mechanism powered by required software installed to the computer attached to it. The data files are accessible via an industry standard two-way RS-232 serial port using common terminal programs or Met One Instruments software such as Metro Met Plus® and Comet®. The data is available in a variety of formats including daily reports, last records, all data and new records since download. BAM-1020 (Beta Attenuation Monitor) allows data collection at different intervals of time such as 5 minutes, 1 hour, 12 hour and 24 hours or daily. For this study, data have been collected 12-hourly. Configuration files, error logs and flow statistics are also available.

4.4 Meteorology of Aizawl

The meteorology data for the study period from June 2014 to May 2016 has been obtained from The State Meteorological Centre, Directorate of Science &

Technology, Govt. of Mizoram. The meteorological parameters obtained are Temperature (°C), Relative Humidity (%) and Rainfall (mm).

4.5 Soil Analysis (Soil pH) – Soil samples were collected within a 10 m radius from the Respirable Dust Samplers. Samples were collected at monthly intervals for a period of two years. 10 gm of air-dried soil sample was mixed with 50 ml of De-ionized water and stirred with a glass rod. The pH was measured after one hour using a pH meter with combined electrode.

4.6 Water Analysis

Water samples were collected at monthly intervals for a period of two years (i.e., from June 2014 to May 2016) for analysis of various physicochemical parameters namely, pH and turbidity. The results have been expressed seasonally i.e., Pre-Monsoon/Summer (March - May), Monsoon (June - September), Autumn/Post-Monsoon (October - November) and Winter (December - February)

4.6.1 pH of Water

The pH of water was measured with help of digital ‘hydrogen ion electrode’.

4.6.2 Turbidity of Water

The turbidity of the sample was measured at sampling site using an electronic portable turbidity meter (TN100, Eutech Instrument Pte Ltd, Singapore) and recorded the turbidity in NTU. The turbidity meter is working on the principle of measuring the intensity of light scattering at 90° angle to the transmitted light using photometer.

4.7 Collection Hospital data

Data on hospital consultations in Out-patient Department of Civil Hospital, Aizawl due to Corrosion of Respiratory tract (CORT), Bronchitis, Asthma, Chronic obstructive pulmonary disease (COPD), Acute Nasopharyngitis (AN), Acute Sinusitis (AS), Acute Upper Respiratory Infection (AURI), Vasomotor Rhinitis (VR) have been collected for the study period i.e. from June 2014 to May 2016.

4.8 Collection of Vehicle Registration

The number of vehicles registered in Aizawl have been collected monthly from Directorate of Transport, Govt. of Mizoram throughout the study period. The vehicles include Heavy Motor Vehicles (HMV), Medium Motor Vehicles (MMV), Light Motor Vehicles (LMV), Three Wheelers (Auto-rickshaw) and Two Wheelers (Bike & Scooter).

4.9 Data Interpretation and Analysis

4.9.1 Statistical Package for the Social Sciences – The data collected from various sampling sites have been subjected to further statistical analysis using Statistical Package for the Social Sciences (SPSS). Correlation and Linear Regression was used to compare different data observed during the study.

4.9.2 Odds Ratio – The associations between PM_{10} exposure and respiratory diseases were obtained using an estimated odds ratio (OR) from 2 x 2 frequency tables (Figure 4.1). An odds ratio estimates the association between 2 variables, typically with 1 variable being the “disease” and 1 factor being an “exposure” (risk factor for the disease) (Levangie, 1999). OR represents the odds that an outcome (disease) will occur given a particular exposure, compared to the odds of the outcome (disease) occurring in the absence of that exposure. The odds ratio can also be used to determine whether a particular exposure is a risk factor for a particular outcome, and to compare the magnitude of various risk factors for that outcome (Szumilas, 2010).

	Disease	**No Disease**
Exposure	a	b
No Exposure	c	d

Figure 4.1: A 2x2 frequency table to compute odds ratio

where

a= No of people exposed to PM_{10} that have respiratory disease
b= No of people exposed to PM_{10} that do not have respiratory disease
c= No of people not exposed to PM_{10} that have respiratory disease
d= No of people not exposed to PM_{10} that do not have respiratory disease

OR = (odds of disease in exposed group)/(odds of disease in the non-exposed group)

Odds of disease in the exposed group = a/b

Odds of the event in the non-exposed group= c/d

Thus, the **odds ratio** is (a/b) / (c/d)

From this proportion, it can be seen that the odds ratio will be 1.0 if the odds of disease are similar among exposed and unexposed subjects. Odds ratios greater than 1.0 indicate an increased disease risk among exposed subjects, whereas odds ratios less than 1.0 indicate that the exposure did not increase the disease risk. In this study, the control group or the group with no exposure consist of the population of Tanhril locality where the annual mean concentration of PM_{10} is below 1 $\mu g/m^3$ and the exposure group consist of the population of the rest of Aizawl city where the annual mean concentration of PM_{10} is above 20 $\mu g/m^3$ (Maximum permissible limit set by WHO Air quality guidelines standard)

All odds ratios were calculated with 95 % confidence intervals (CIs) to indicate precision of the estimated OR using the general formula: 95 % CI = e ^ [ln(OR) ± 1.96 sqrt(1/a + 1/b + 1/c + 1/d)]

Where 'e' is the mathematical constant for the natural log, 'ln' is the natural log, 'OR' is the odds ratio calculated, 'sqrt' is the square root function and a, b, c and d are the values from the 2 x 2 table.

4.9.3 Attributable Risk (AR) – Also called Attributable Proportion or Attributable Fraction, it is a measure of the prevalence of a condition or disease. Given a group of people exposed to a risk, it’s the fraction who develop a disease or condition. AR is the cases that would be eliminated if the exposure were also eliminated (Coughlin et al., 1994). It is calculated using the formula

$$AR = (OR - 1)/OR$$

4.9.4 Population Attributable Fraction (PAF) – PAF is defined as the fraction of health consequences in public exposed to a specific air pollutant (Maji et al., 2017) The PAF was calculated by the following equation (Miettinen, 1974)

$$PAF = P_e \times AP = P_e \times \frac{(OR - 1)}{OR}$$

Where, P_e= Proportion of cases that have the exposure

CHAPTER-5

RESULTS AND DISCUSSION

5.1 Concentration of $PM_{2.5}$

The $PM_{2.5}$ concentration throughout the study period was very low, i.e. between 0.81-0.86 µg/m^3. The main reason is the location of the air monitoring station which is an institutional campus, MZU. It is an outskirts of Aizawl city and thus has less anthropogenic activities like vehicular pollution and other activities like burning biomass and resuspended road dust. The levels of $PM_{2.5}$ were within the limits of both the National Ambient Air Quality Standards and WHO Air Quality Guidelines.

Table 5.1: Monthly concentration of $PM_{2.5}$

Year	Months	$PM_{2.5}$
2014	June	0.81
	July	0.82
	August	0.81
	September	0.82
	October	0.82
	November	0.83
	December	0.83
2015	January	0.86
	February	0.85
	March	0.85
	April	0.85
	May	0.82
	June	0.85
	July	0.82
	August	0.82
	September	0.83
	October	0.81
	November	0.84
	December	0.85
2016	January	0.85
	February	0.84
	March	0.86
	April	0.84
	May	0.82

5.2 Concentration of PM_{10}

PM_{10} was monitored at MZU and at other three stations i.e. Bawngkawn (BK), Laipuitlang (LPT) and Khatla (KTL) inside Aizawl city. The PM_{10} concentration obtained at MZU was again very low due to lesser human activity. However, the situation is different at the other three stations. The lowest level was observed in MZU with 0.82 µg/m^3 and highest in Khatla with 268 µg/m^3. The high level of concentration in Khatla was due to vehicular pollution and construction near the air monitoring station.

The levels of PM_{10} are lower during the initial part of the study i.e. from June 2014 upto September 2015, falling mostly within the National Ambient Air Quality Standards (60 µg/m3). The latter part of the study showed an increase in levels of PM_{10} above the standards in two of the stations i.e. in Bawngkawn station (BK) from February 2016 to May 2016 and in Khatla Station(KS) from October 2015 upto May 2016 . The increase in the levels of pollution in the latter part of the study period may be due to increase in vehicle of Aizawl city by 18,766 vehicles during the study period.

Table 5.2: Monthly concentration of PM_{10}

PM_{10} (µg/m^3)					
Year	Months	MZU	BK	KTL	LPT
2014	June	0.83	30	36	37
	July	0.82	27	32	37
	August	0.85	26	33	37
	September	0.83	27	33	36
	October	0.84	32	36	33
	November	0.86	32	43	35
	December	0.85	32	46	33
2015	January	0.87	29	46	28
	February	0.89	29	42	25
	March	0.89	30	45	25
	April	0.85	64	58	32
	May	0.82	38	42	34
	June	0.85	29	31	21
	July	0.84	24	32	20
	August	0.83	26	38	18
	September	0.83	25	40	21

	October	0.85	28	85	24
	November	0.85	32	131	24
	December	0.87	28	214	52
2016	January	0.86	26	268	52
	February	0.86	94	128	54
	March	0.87	99	129	57
	April	0.83	76	66	26
	May	0.83	71	66	37

5.3 Concentration of SPM

The levels of concentration SPM were observed at three station in Aizawl city i.e. Bawngkawn (BK), Khatla (KTL) and Laipuitlang (LPT) during the study period and the levels were found to be low in almost all the months. However, a high concentration of SPM was observed during January 2016 in Khatla station with 502 $\mu g/m^3$ which was a dry or winter season and the lowest level was observed in Laipuitlang station with 32 $\mu g/m^3$ during August 2015 which was during rainy or monsoon season.

Table 5.3: Monthly concentration of SPM

SPM ($\mu g/m^3$)				
Year	Months	BK	KTL	LPT
2014	June	54	77	67
	July	48	68	68
	August	46	62	65
	September	51	70	66
	October	59	76	57
	November	60	114	64
	December	62	94	58
2015	January	55	96	49
	February	53	93	46
	March	57	97	44
	April	147	128	57
	May	88	98	48
	June	69	88	39
	July	56	85	34
	August	60	72	32
	September	56	81	36
	October	61	165	50

	November	73	265	47
	December	66	416	78
2016	January	61	502	85
	February	197	269	88
	March	215	189	86
	April	177	149	48
	May	165	142	59

5.4 Exceedance Factor

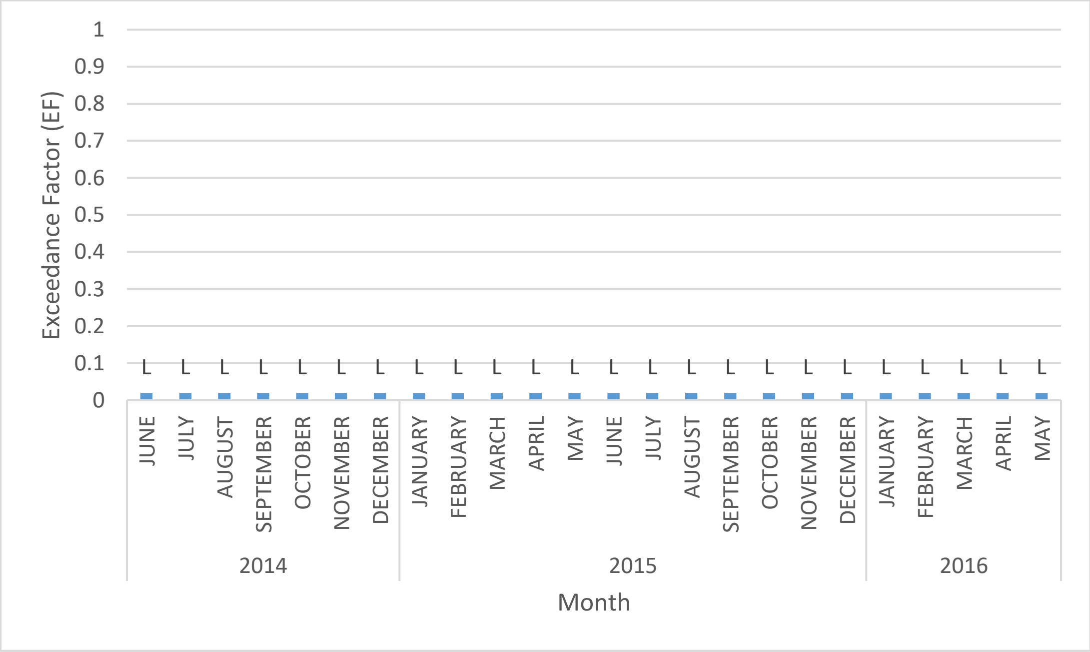
In order to evaluate the pollution intensity and air quality status, Exceedance Factor (EF) method has been applied (CPCB). EF is the “proportion of the average concentration of a pollutant and its particular standard”.

Under Exceedance Factor the four categories of air quality are critical pollution (C) when EF is more than 1.5, high pollution (H) when EF is between 1-1.5, moderate pollution (M) when EF is between 0.5-1 and low pollution (L) when EF is less than 0.5.

5.4.1 Exceedance factor of $PM_{2.5}$

The Exceedance Factor of $PM_{2.5}$ was found to be mostly low (EF<0.5) during the study period. This shows that the pollution intensity in low and the air quality is way below the standard.

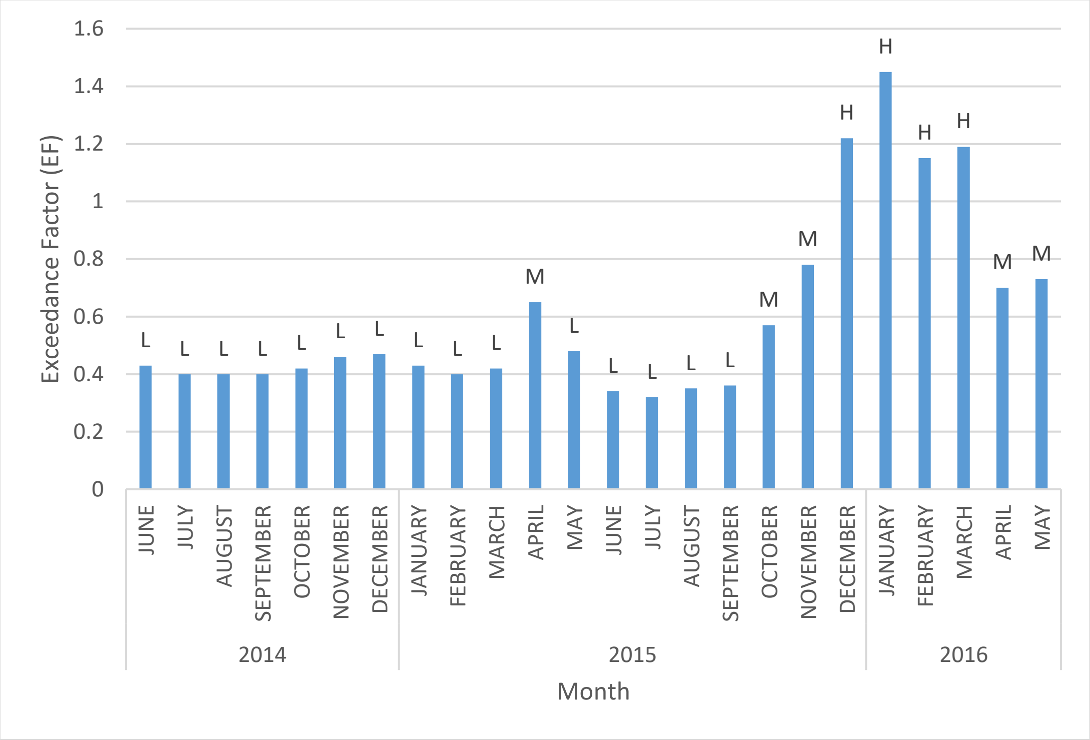
Figure 5.1: Exceedance factor of $PM_{2.5}$



5.4.2 Exceedance factor of PM_{10}

The Exceedance Factor of PM_{10} was found to be mostly low (EF<0.5) during the study period. However, Moderate pollution level (EF between 0.5-1) was found in pre-monsoon and post-monsoon and a High pollution level (EF between 1-1.5) was observed in some months particularly during winter or dry season.

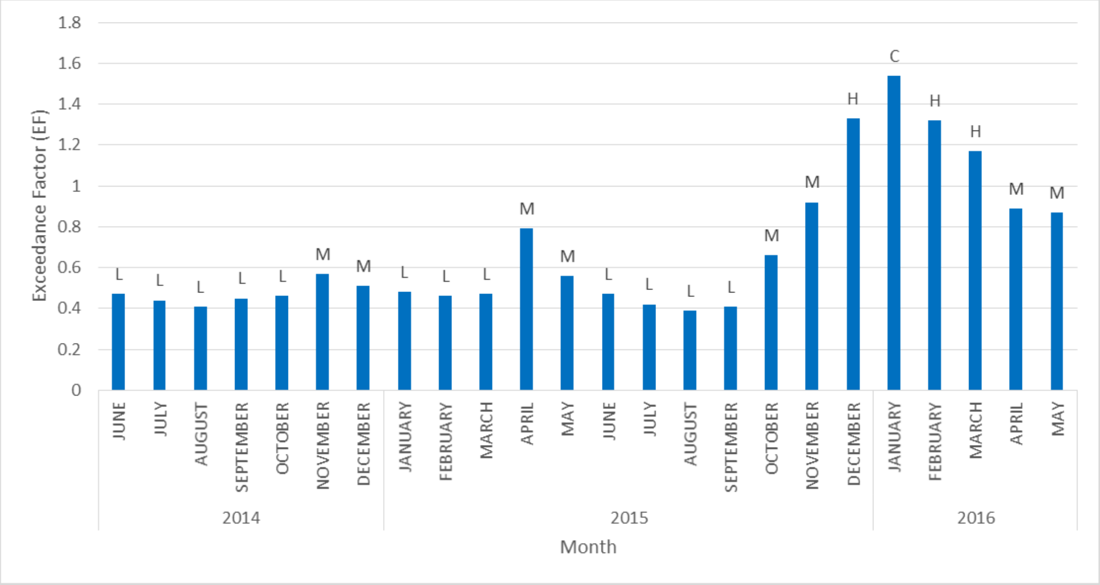
Figure 5.2: Exceedance factor of PM_{10}



5.4.3 Exceedance factor of SPM

The Exceedance Factor of SPM was found to be Low (EF<0.5) in 12 months i.e. mostly during monsoon seasons, Moderate pollution in pre-monsoon and post-monsoon (EF between 0.5 to 1) covering 8 months, High pollution (EF between 1 & 1.5) in 3 months during winter or dry season and reached Critical condition (EF>1.5) during January,2016.

Figure 5.3: Exceedance factor of SPM



5.5 Seasonal Variation of Particulate Matters

The seasonal variation of $PM_{2.5}$, PM_{10} and SPM was observed by calculating the mean values of the Particulate Matters and the Standard Deviation in each case. The season was categorized as Pre-Monsoon or summer (March to May), Monsoon (June to September), Post-Monsoon or Autumn (October to November) and Winter (December to February).

5.5.1 Seasonal Variation of $PM_{2.5}$

The annual mean concentration of $PM_{2.5}$ throughout the study period was found to be 0.83 µg/m^3 which was well below the annual standard (40 µg/m^3, NAAQS). The mean concentration of $PM_{2.5}$ was to be lowest during Monsoon season with 0.82 µg/m^3, followed by Post-Monsoon with 0.83 µg/m^3, then Pre-Monsoon with 0.84 µg/m^3 and the highest mean concentration was found during winter with 0.85 µg/m^3. Low concentration during monsoon season has been attributed to the process of wet deposition of particulate matter due to precipitation events (Murari et al., 2017). During winter, decrease in ambient temperature and wind speed creates stagnant meteorological conditions which prevents the dispersion of pollutants resulting in higher concentrations. (Tiwari et al., 2013).

Table 5.4: Seasonal Variation of $PM_{2.5}$

$PM_{2.5}$ (µg/m$^{3)}$			
SEASON	Mean ± SD	Minimum	Maximum
Annual	0.83±0.016	0.81	0.86
Pre-Monsoon/Summer (March-May)	0.84±0.017	0.82	0.86
Monsoon (June-September)	0.82±0.013	0.81	0.85
Post-Monsoon/Autumn (October-November)	0.83±0.013	0.81	0.84
Winter (December-February)	0.85±0.010	0.83	0.86

5.5.2 Seasonal Variation of PM_{10}

The seasonal variation shows a high concentration of PM_{10} pollution during winter or dry season with 51.3 µg/m^3 and low concentration during monsoon with 22.58 µg/m^3. This variation has also been observed in other cities such as Lucknow (Pandey et al., 2011), Kolkata (Chatterjee et al., 2012), Delhi (Sharma et al.,2014; Tiwari et al., 2015), Guwahati (Dutta & Jinsart, 2020) and Faisalabad (Aslam et al., 2020).

The annual mean concentration of PM_{10} was found to be 36.38µg/m^3 which was below the annual standard (60 µg/m3, NAAQS).

Table 5.5: Seasonal Variation of PM_{10}

PM_{10} (µg/m$^{3)}$			
SEASON	Mean ± SD	Minimum	Maximum
Annual	36.38±19.463	19.21	86.72
Pre-Monsoon/Summer (March-May)	41.67±14.94	25.22	71.47

Monsoon (June-September)	22.58±2.37	19.21	25.95
Post-Monsoon/Autumn (October-November)	33.65±9.66	27.72	46.96
Winter (December-February)	51.3±28.27	24.22	86.72

5.5.3 Seasonal Variation of SPM

The seasonal variation showed that the highest levels of SPM concentration were observed during winter or dry season with 131.56 µg/m3, followed by pre-monsoon with 110.78 µg/m^3, then autumn or post monsoon with 90.92 µg/m^3 and the least concentration was observed during monsoon with 60.42 µg/m^3. This variation was also observed in other cities like Delhi (Guttikunda, 2009), Allahabad (Srivastava & Vaishya, 2013).

The annual mean concentration of SPM was found to be 95.88 µg/m3, which was below the standard. (140 µg/m3 in residential and rural areas, NAAQS).

Table 5.6: Seasonal Variation of SPM

SPM (µg/m$^{3)}$			
SEASON	Mean ± SD	Minimum	Maximum
Annual	95.88±48.03	54.67	186.67
Pre-Monsoon or Summer (March-May)	110.78±35.10	66	163.33
Monsoon (June-September)	60.42±4.01	54.67	66
Post-Monsoon or Autumn (October-November)	90.92±27.45	64	128.33
Winter (December-February)	131.56±71.26	64	186.67

5.6 Respiratory Diseases

The total number of patients diagnosed with different respiratory diseases during the study period was obtained from Out-patient Department of Civil Hospital, Aizawl. The total number of patients with respiratory diseases was found to be 21,645.

The maximum number of hospital visit was recorded in the month of September, 2014 with 1695 cases while the least was recorded in the month of January, 2016 with 299 cases of respiratory disease.

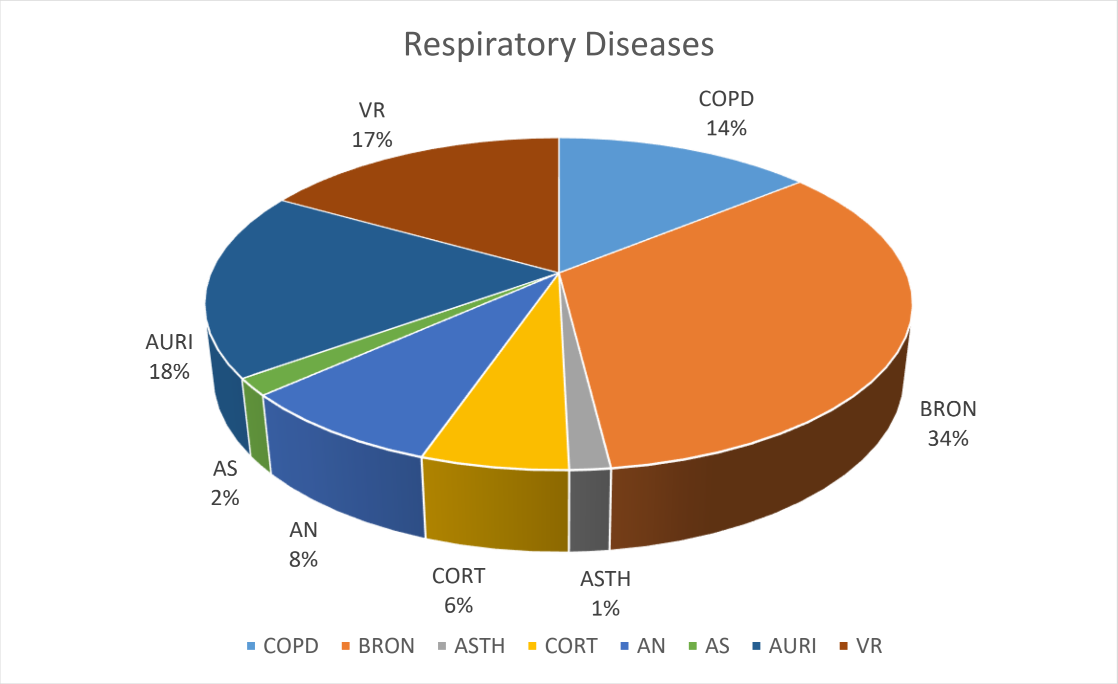
Table 5.7: Monthly cases of respiratory diseases.

Year	Month	CORT	Bron	Asth	COPD	AN	AS	AURI	VR	Total
2014	June	384	341	17	47	82	14	182	84	1151
	July	270	328	27	43	46	5	389	183	1291
	August	83	337	19	27	29	20	85	249	849
	September	181	446	16	66	38	17	749	182	1695
	October	106	115	14	24	27	16	172	114	588
	November	91	46	6	26	7	13	8	202	399
	December	11	107	2	5	72	3	60	97	357
2015	January	16	47	5	3	20	7	3	198	299
	February	24	110	4	3	53	1	8	138	341
	March	40	181	2	10	63	9	103	46	454
	April	184	305	17	46	41	7	142	39	781
	May	248	441	16	65	101	16	273	93	1253
	June	112	360	13	39	105	12	174	75	890
	July	214	331	34	70	57	9	103	159	977
	August	158	232	18	75	85	25	114	196	903
	September	115	324	17	90	101	19	54	121	841
	October	145	534	20	86	60	28	89	187	1149
	November	149	453	24	91	80	10	225	81	1113

	December	91	391	19	62	68	11	205	104	951
2016	January	135	316	13	89	63	30	181	139	966
	February	90	408	9	62	183	19	194	234	1199
	March	63	416	10	53	144	23	143	371	1223
	April	65	385	10	49	101	30	143	158	941
	May	77	394	8	92	123	18	141	181	1034
	Total	3052	7348	340	1223	1749	362	3940	3631	21645

Bronchitis contributes the maximum number of patients with 7348 cases or 34 % while Asthma contributes the minimum number of patients with 340 cases or 1 % of the total respiratory disease. The percentage (%) and total number of the selected respiratory diseases like Corrosion of Respiratory Tract (CORT), Bronchitis (Bron), Asthma (Asth), Chronic Obstructive Pulmonary Disease (COPD), Acute Nasopharyngitis (AN), Acute Sinusitis (AS), Acute Upper Respiratory Infections (AURI) and Vasomotor Rhinitis (VR) are listed below:

Figure 5.4: Pie-diagram showing different percentage (%) of Respiratory diseases



5.6.1 Association of PM exposure and Respiratory Diseases - Odds ratio was used to measure the association between PM_{10} exposure and Respiratory Diseases. The number of patients suffering from respiratory diseases in the exposure group (Tanhril population) and the no-exposure group (Rest of Aizawl population) are given in Table 5.8. A significant association was found between PM_{10} exposure and three of the respiratory diseases which are CORT, COPD and VR. Exposure to PM10 increased the likelihood of CORT by 66 % (OR=1.66), the likelihood of COPD was found to be 2.74 times higher (OR=2.74) and the likelihood of VR was also found to be 2.54 times higher (OR=2.54). No elevation in risk was observed for the other respiratory diseases.

Table 5.8: Respiratory diseases of Exposure group and No-exposure group.

Respiratory Disease	**No- Exposure group Total population = 2930**	**Exposure group Total population = 290486**	**Total**
CORT	18	3034	3052
Bronchitis	77	7271	7348
Asthma	0	340	340
COPD	4	1219	1223
AN	14	1735	1749
AS	4	358	362
AURI	34	3906	3940
VR	14	3617	3631

Table 5.9: Odds Ratio of Respiratory Diseases

Disease	OR	% 95 CI	
		Lower	Upper
CORT	**1.66**	1.05	2.63
Bronchitis	0.95	0.75	1.19
Asthma	6.88	0.43	110.22
COPD	**2.74**	1.09	6.92
AN	1.21	0.72	2.03
AS	0.80	0.32	2.04
AURI	1.14	0.82	1.60
VR	**2.54**	1.51	4.25

5.6.2 Attributable Risk of Respiratory Diseases– Also called the Attributable Fraction or the Attributable Proportion Percentage (AP (%)), it is the risk of developing respiratory disease amongst the exposed group or in other words, the cases that would be eliminated if the exposure were also eliminated. The AP has been calculated for those respiratory diseases which have a significant association with PM_{10} exposure. It was observed that from the exposed group, 40 % have the risk of developing CORT, 64 % have the risk of developing COPD and 61 % have the risk of developing VR.

Table 5.10: Attributable Risk of Respiratory Diseases

Disease	**AP (%)**
CORT	40
COPD	64
VR	61

5.6.3 Population Attributable Fraction (PAF)- Not all of the respiratory disease cases that were recorded during the study period can be attributed to PM_{10} exposure as respiratory disease was also observed in the no-exposure group. PAF gives the measure of the proportion of all cases of respiratory diseases in the overall population (the exposure and no exposure group) that could be attributed to the exposure. The PAF calculated for those respiratory diseases which have a significant association with PM_{10} exposure shows that from the total population, the fraction of CORT cases that can be attributed to the exposure is 40 %, the fraction of COPD cases that can be attributed to the exposure is 63 % and the fraction of VR cases that can be attributed to the exposure is 60 %.

Table 5.11: Population Attributable Fraction of Respiratory Diseases

Disease	PAF (%)
CORT	40
COPD	63
VR	60

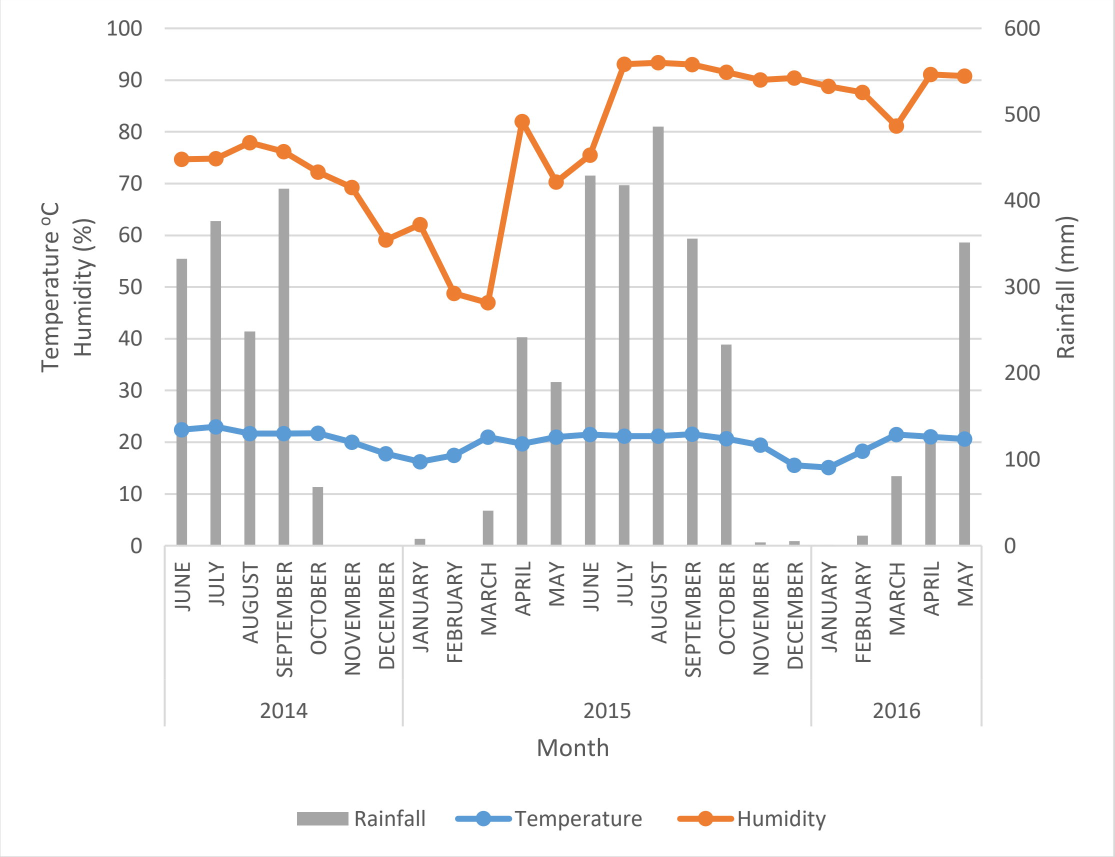
5.7 Meteorology of Aizawl

The meteorological parameters like Temperature, Humidity and Rainfall were observed during the study period. The average monthly temperature ranges between 15.1 to 23°C, where the coldest month was observed in the month of January and the hottest month was observed in the month of July.

The average monthly humidity throughout the study period was quite high crossing 90 % humidity in eight months, however, low % of humidity was observed during February and March of 2015 with 48 % and 49 % humidity respectively.

The total amount of rainfall received during the study period was 4421.9 mm. The highest amount of monthly rainfall was observed during August 2015 with 486 mm of rainfall. However, there was no rainfall during November and December 2014 and February 2015. A hot and wet summer in contrast to a dry and cold winter was observed during the study period.

Figure 5.5: Chart showing Temperature, Humidity and Rainfall



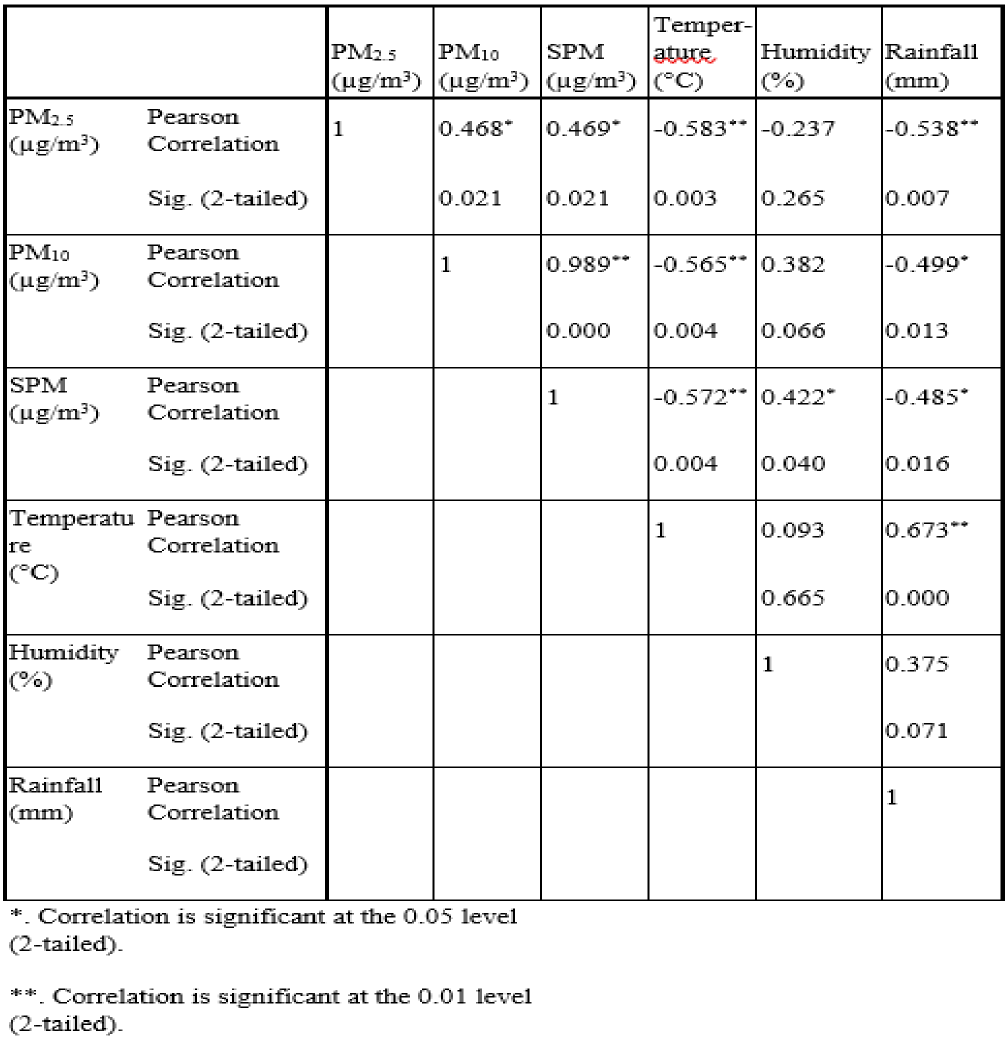
5.7.1 Correlations between Particulate Matters and Meteorological Parameters

It was observed that $PM_{2.5}$, PM 10 and SPM correlate negatively with temperature. The same phenomenon have been observed in Milan where PM_{10} concentrations were negative correlated with daily average temperature (Zoran et al., 2020). Motor vehicles have been found to be one of the primary sources of PM in the city. Nam et al. (2010) have shown that the amount of particulate matters given out by motor vehicles increased exponentially as temperature decreased with the PM emissions doubling for every 20^oF (6.7^oC) drop in ambient temperature. Thermal inversion may also play a part for this relationship as seen in studies such as Trinh et al. (2018), Hernandez et al. (2017) and Barmpadimos et al. (2010).

It was also observed that $PM_{2.5}$, PM 10 and SPM correlate negatively with rainfall. This may be explained by washing effect of particulate matters as seen in various studies such as Ouyang et al. (2015) and Gao et al. (2019) in Beijing,

A moderate positive correlation was found between SPM and humidity. The relationship between particulate matters and humidity is not definite and clear cut in literature with several contradictory reports. Zolan et al. (2020) and Apostolopoulou et al. (2020) found a positive correlation between particulate matter concentrations and humidity. Zalakeviciute et al. (2018) found a positive correlation in the case of residential areas with high traffic densities, while the more industrial areas showed the opposite effect. Hernandez et al. (2017) also reported a positive correlation between particulate matters and humidity upto a certain threshold beyond which no correlation was observed. Tai et al. (2010) found the correlation positive in Northeast and Midwest US but negative in the Southeast and the West US.

Table 5.12: Correlation between Particulates Matters and Meteorological Parameters



		PM$_{2.5}$ ($\mu g/m^3$)	PM$_{10}$ ($\mu g/m^3$)	SPM ($\mu g/m^3$)	Temper-ature (°C)	Humidity (%)	Rainfall (mm)
PM$_{2.5}$ ($\mu g/m^3$)	Pearson Correlation	1	0.468*	0.469*	-0.583**	-0.237	-0.538**
	Sig. (2-tailed)		0.021	0.021	0.003	0.265	0.007
PM$_{10}$ ($\mu g/m^3$)	Pearson Correlation		1	0.989**	-0.565**	0.382	-0.499*
	Sig. (2-tailed)			0.000	0.004	0.066	0.013
SPM ($\mu g/m^3$)	Pearson Correlation			1	-0.572**	0.422*	-0.485*
	Sig. (2-tailed)				0.004	0.040	0.016
Temperature (°C)	Pearson Correlation				1	0.093	0.673**
	Sig. (2-tailed)					0.665	0.000
Humidity (%)	Pearson Correlation					1	0.375
	Sig. (2-tailed)						0.071
Rainfall (mm)	Pearson Correlation						1
	Sig. (2-tailed)						

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

5.8 pH of Soil

The pH of soil during the study period lies between 5.1 and 5.6. Acidic soil is a characteristic of Mizoram soil which has been attributed to high rainfall.

Table 5.13: Monthly readings of soil pH

Soil pH					
Year	Months	MZU	BK	KTL	LPT
2014	June	5.3	5.5	5.4	5.4
	July	5.2	5.4	5.5	5.3
	August	5.1	5.3	5.4	5.3
	September	5.4	5.4	5.3	5.2

	October	5.3	5.4	5.3	5.3
	November	5.3	5.5	5.3	5.4
	December	5.2	5.5	5.5	5.4
2015	January	5.4	5.6	5.5	5.4
	February	5.3	5.5	5.4	5.4
	March	5.3	5.5	5.3	5.3
	April	5.2	5.4	5.3	5.3
	May	5.3	5.3	5.3	5.2
	June	5.3	5.4	5.5	5.3
	July	5.5	5.3	5.4	5.4
	August	5.3	5.2	5.4	5.4
	September	5.2	5.2	5.5	5.3
	October	5.1	5.3	5.4	5.3
	November	5.4	5.5	5.6	5.2
	December	5.3	5.4	5.5	5.3
2016	January	5.4	5.6	5.6	5.4
	February	5.4	5.5	5.6	5.3
	March	5.3	5.5	5.5	5.4
	April	5.3	5.6	5.5	5.4
	May	5.5	5.5	5.5	5.4

5.9 pH of Water

The water pH was also found to be in the normal range but tends to be on the alkaline side in Chite & Tuikual rivers. The reason may be because of presence of soap and other detergents from household effluents and also particles of cement from construction sites and go-downs.

Table 5.14: Monthly readings of water pH

Water pH				
Year	Months	MZU	Chite	Tuikual Lui
2014	June	7.2	7.6	7.6
	July	7.3	7.9	8
	August	7.2	7.5	7.6
	September	7.2	7.8	7.9
	October	7.4	6.9	7.2
	November	7.1	7.8	7.8

	December	7	7.3	7.5
2015	January	7	7.6	8
	February	7.1	7.6	7.4
	March	7	8.1	8
	April	7.4	8	7.7
	May	7.4	8.2	7.8
	June	7.3	7.7	7.7
	July	7.1	7.8	7.9
	August	7.1	7.3	7.7
	September	7.1	7.5	7.8
	October	7.3	7	7.6
	November	7.2	7.9	7.5
	December	7.1	7.5	7.1
2016	January	7.1	7.5	7.9
	February	7.1	7.6	7.5
	March	7.3	8	8.1
	April	7.2	7.9	7.7
	May	7.5	7.9	7.9

5.10 Turbidity of Water

Variation in turbidity was also observed during the study period. The main cause of this variation is also due to flash flood, dumping of soil and other wastes in river. The highest level of turbidity was observed in the month of March 2015 in Chite river with 67 NTU while the MZU steam has lowest level of turbidity 0.2 NTU during dry or winter season.

Table 5.15: Monthly readings of turbidity of water

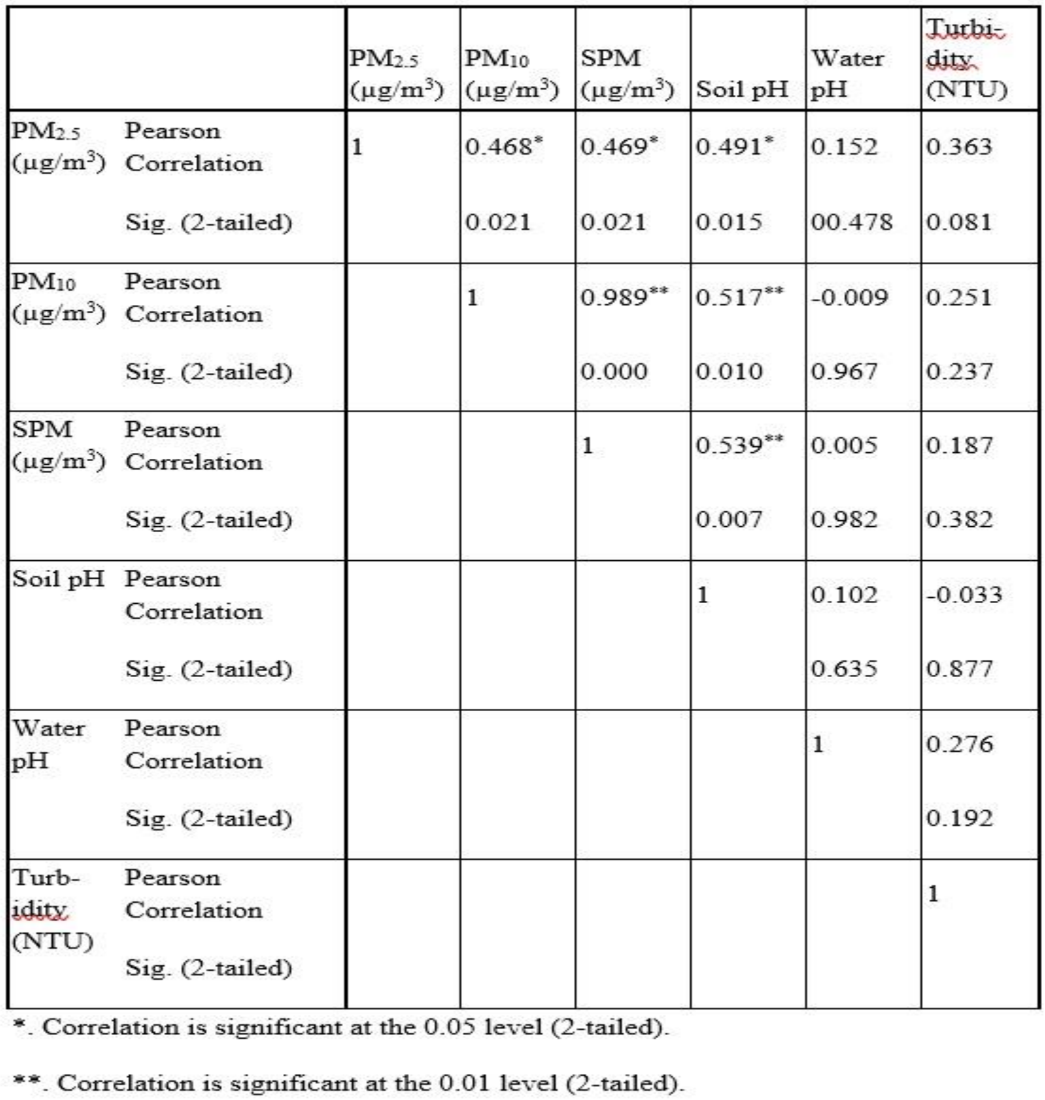
Water (Turbidity, NTU)				
Year	Months	MZU	Chite	Tuikual Lui
2014	June	1.9	2.7	3.7
	July	3.1	6.7	5.7
	August	1.8	3.5	40.5
	September	2.5	9.5	11.5
	October	2.8	19	15
	November	0.5	2.3	2.3
	December	0.3	4.2	3.2

2015	January	0.3	12	8
	February	0.2	9	5.8
	March	0.2	67	38.6
	April	0.6	19.1	21.4
	May	1.4	1.9	2.4
	June	1.7	3.7	4.2
	July	2.9	4.7	6.7
	August	1.7	5.5	11.6
	September	2.7	13.5	15
	October	2.6	23.8	12.1
	November	0.4	5.3	3.3
	December	0.2	3.2	2.2
2014	January	0.2	23	12
	February	0.2	21	9.8
	March	0.1	78	45
	April	0.5	26.1	23
	May	1.2	0.9	1.7

5.11. Impact of Particulates Matters on soil pH, water pH and turbidity –

A positive correlation was found between particulate matters and soil pH which indicated that for every increase in concentration of $PM_{2.5}$, PM_{10} and SPM, there will be an increase in soil pH. Environmental effect of particulate matters has been attributed more to particle composition than to particle size (Grantz et al., 2003). Acidification of soil and water has been reported in some studies which is caused by both wet deposition via precipitation and dry deposition of gases and particles of N and S from the atmosphere. (Greaver et al., 2012). However, in the study area, one of the source of PM pollution is cement dust. A high level of deposition of cement in the soil surfaces was observed during the study period due to construction works near the monitoring stations. These cement depositions are highly alkaline in nature and have been shown to have alkalination effect on soil (Ibanga et al.,2008). No correlation was found between particulate matter and water pH and turbidity.

Table 5.16: Correlation between Particulates Matters and Environmental Parameters



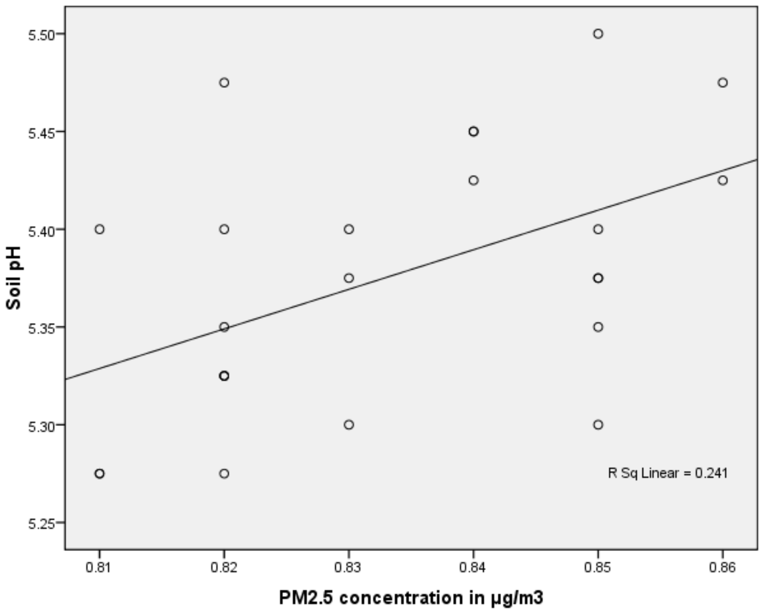
		$PM_{2.5}$ ($\mu g/m^3$)	PM_{10} ($\mu g/m^3$)	SPM ($\mu g/m^3$)	Soil pH	Water pH	Turbidity (NTU)
$PM_{2.5}$ ($\mu g/m^3$)	Pearson Correlation	1	0.468*	0.469*	0.491*	0.152	0.363
	Sig. (2-tailed)		0.021	0.021	0.015	00.478	0.081
PM_{10} ($\mu g/m^3$)	Pearson Correlation		1	0.989**	0.517**	-0.009	0.251
	Sig. (2-tailed)			0.000	0.010	0.967	0.237
SPM ($\mu g/m^3$)	Pearson Correlation			1	0.539**	0.005	0.187
	Sig. (2-tailed)				0.007	0.982	0.382
Soil pH	Pearson Correlation				1	0.102	-0.033
	Sig. (2-tailed)					0.635	0.877
Water pH	Pearson Correlation					1	0.276
	Sig. (2-tailed)						0.192
Turbidity (NTU)	Pearson Correlation						1
	Sig. (2-tailed)						

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

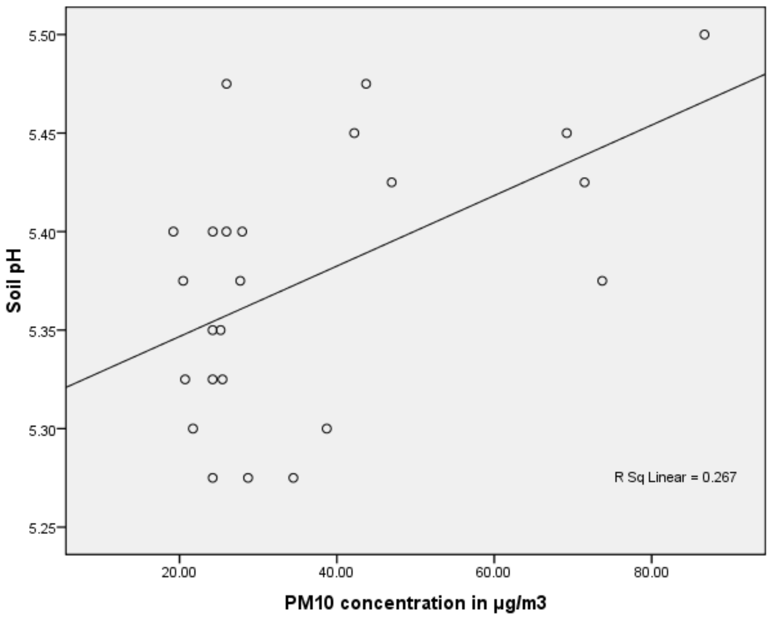
5.11.1 Linear Regression between $PM_{2.5}$ and Soil pH - A linear regression was used to test if the annual mean concentration of $PM_{2.5}$ significantly predicted soil pH. A significant regression equation was found ($F(1,22)= 6.981$, $p < .015$), with an R2 of .241. (i.e 24.1 % of total variation in soil pH is explained by $PM_{2.5}$). Predicted soil pH is equal to 3.689 + 2.024 ($PM_{2.5}$).

Figure 5.6: Scatterplot between $PM_{2.5}$ and Soil pH



5.11.2 Linear Regression between PM_{10} and Soil pH – A linear regression was used to test if the annual mean concentration of PM_{10} significantly predicted soil pH. A significant regression equation was found (F(1,22)= 8.021, $p < .01$), with an R^2 of .267. (i.e 26.7 % of total variation in soil pH is explained by PM10). Predicted soil pH is equal to 5.311+0.002 (PM_{10}).

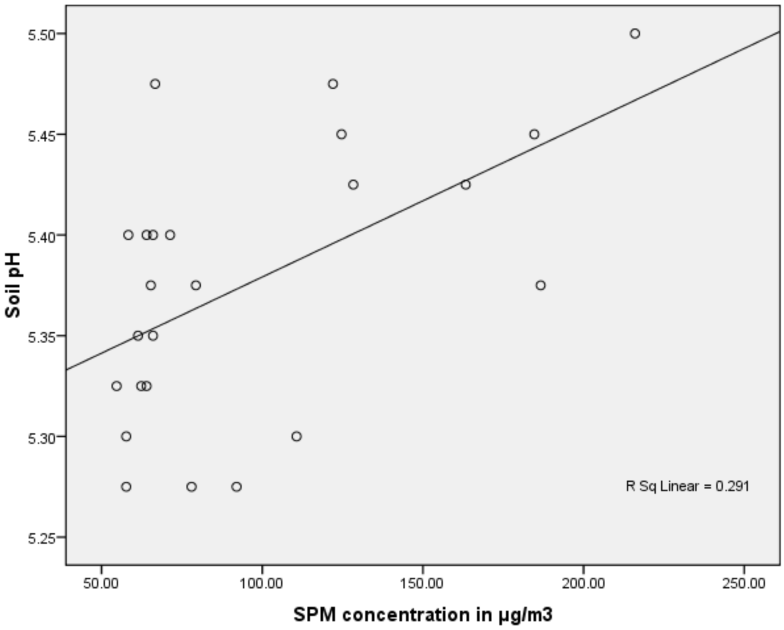
Figure 5.7: Scatterplot between PM_{10} and Soil pH



5.11.3 Linear Regression between SPM and Soil pH

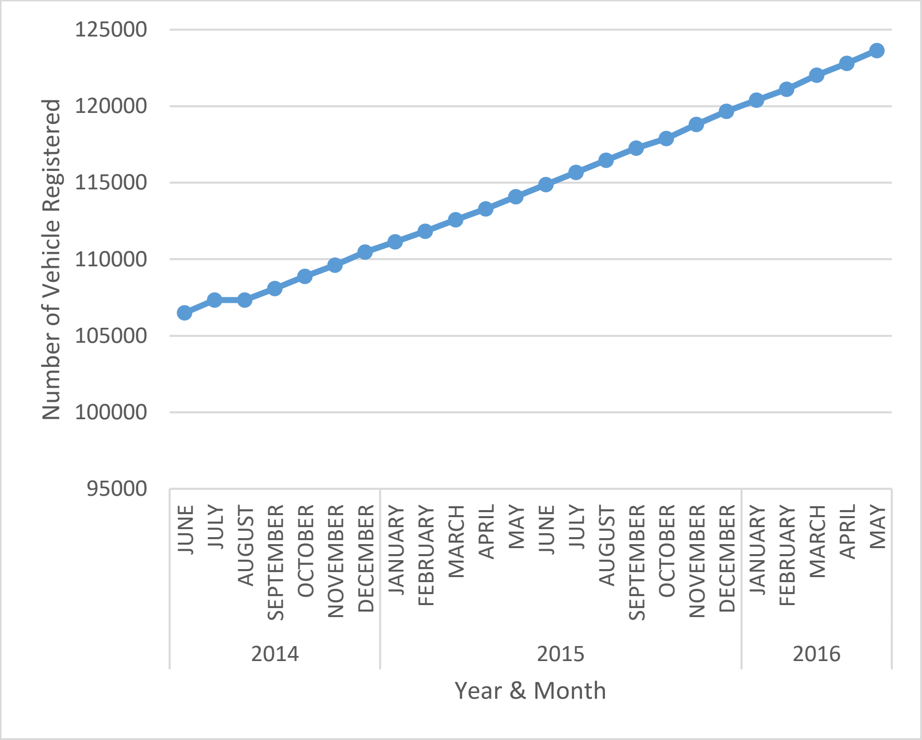
A linear regression was used to test if the annual mean concentration of SPM significantly predicted soil pH. A significant regression equation was found (F(1,22)= 9.019, $p < .01$), with an R^2 of 0.291. (i.e 29.1 % of total variation in soil pH is explained by SPM). Predicted soil pH is equal to 5.304+0.001(SPM).

Figure 5.8: Scatterplot between SPM and Soil pH



5.12 Number of Vehicle Registration – The number of vehicles newly registered during the study period is 18766. Monthly registration of vehicles falls between 627 vehicles and 928 vehicles. The total number of vehicles registered in Aizawl prior to the study (May 2014) was 105594 vehicles. At the end of the study (May 2016), the total number of vehicles registered sums up to 1,24,360.

Figure 5.9: Graph showing monthly increase in number of registered vehicles



5.12.1 Impact of number of vehicles on concentration of Particulate matters–

A positive correlation was found between the concentration of PM_{10} and SPM and the number of registered vehicles which indicated that the increase in number of vehicles in Aizawl led to an increase in the concentration of PM_{10} and SPM in Aizawl City. No correlation was found between $PM_{2.5}$ and the number of registered vehicles.

Table 5.17: Correlation between Number of Registered Vehicles and Particulate Matters

		$PM_{2.5}$	PM_{10}	SPM	Number of registered vehicles
$PM_{2.5}$	Pearson Correlation	1	0.468*	0.469*	0.368
	Sig. (2-tailed)		0.021	0.021	0.077
PM_{10}	Pearson Correlation	0.468*	1	0.989**	0.659**
	Sig. (2-tailed)	0.021		0.000	0.000
SPM	Pearson Correlation	0.469*	0.989**	1	0.705**
	Sig. (2-tailed)	0.021	0.000		0.000
Number of registered vehicles	Pearson Correlation	0.368	0.659**	0.705**	1
	Sig. (2-tailed)	0.077	0.000	0.000	

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

CHAPTER-6

SUMMARY AND CONCLUSION

From the results and discussions above we may summarize and conclude the following:

The particulate matter concentration in Aizawl city was low compared to other cities in India and did not exceed the National Ambient Air Quality Standard (NAAQS). This may be due to the absence of industries, the topography and lesser number of vehicles as compared to other Indian cities.

Seasonal variations in concentration of particulate matters observed were highest in Winter and lowest in Monsoon. This is due to atmospheric washout during monsoon and temperature inversion during winter. More construction work was also done during winter or dry season which contributes to more suspended particulate matters in the environment. Jhum cultivation also play a role where a huge amount of biomass was burnt during dry season, particularly in the month of March.

Particulate matters showed a negative correlation with Temperature and rainfall which means that with every increase in temperature and rainfall, there will be a decrease in concentration of particulates. However, a positive correlation with humidity was observed.

Particulate matters showed a strong association with respiratory diseases. Exposure to PM increases the odds of having Corrosion of Respiratory Tract (CORT) disease by 66 %. There is also 2.74 times higher likelihood of having the disease Chronic Obstructive Pulmonary Disease (COPD) and 2.54 times higher likelihood of having Vasomotor Rhinitis (VR) disease respectively.

Attributable Risk or Attributable Proportion (AP) has been calculated for those respiratory diseases which have a significant association with PM_{10} exposure. It was observed that from the exposed group, 40 % have the risk of developing CORT, 64 % have the risk of developing COPD and 61 % have the risk of developing VR.

Population Attributable Fraction (PAF**)** calculated for those respiratory diseases which have a significant association with PM_{10} exposure shows that from the total population, the fraction of CORT cases that can be attributed to the exposure is 40 %, the fraction of COPD cases that can be attributed to the exposure is 63 % and the fraction of VR cases that can be attributed to the exposure is 60 %.

A significant correlation was found between soil and PM. It was found that the increase in concentration of PM will result in increase in soil pH. This may be due to cement deposition on soil surfaces due to construction works all around Aizawl city including Mizoram University Campus.

From the Linear regression between soil pH and particulate matter, it was found that for $PM_{2.5}$, the predicted soil pH is equal to 3.689 + 2.024 ($PM_{2.5}$); for PM_{10}, predicted soil pH is equal to 5.311+0.002 (PM_{10}) and for SPM, predicted soil pH is equal to 5.304+0.001(SPM). It was also found that there was no significant correlation between pH of water and PM and at the same time no significant correlation was found between turbidity and PM.

Increase in number of vehicles in Aizawl city was also observed throughout the study period and was found that there was an increase of 18766 vehicles in Aizawl with a monthly average increase of 782 vehicles. A positive correlation was found between PM_{10} and SPM and the number of registered vehicles which shows that with every increase in number of vehicles there will be an increase in concentration of PM_{10} and SPM.

Vehicular pollution plays a vital role in PM pollution since there are no industries and other thermal power plant in and around Aizawl city. However, the main source of PM pollution in Aizawl is dust from construction works like building, roads or earth removal as well as resuspended dust in roadways triggered by movement of vehicles.

PHOTO PLATES

PLATE 1

Plate 1 (a): Inlet of Air in BAM 1020

Plate 1 (b) & (c): BAM 1020, front and rear view. Located in EVS, Department, MZU

PLATE 2

Plate 2 (a): Respirable Dust Sampler (Envirotech APM 460 BL)

Plate 2 (b): Respirable Dust Sampler at one of the Monitoring Station (Bawngkawn)

PLATE 3

Plate 3 (a): Inner Section of the Respirable Dust Sampler with new filter paper before operation

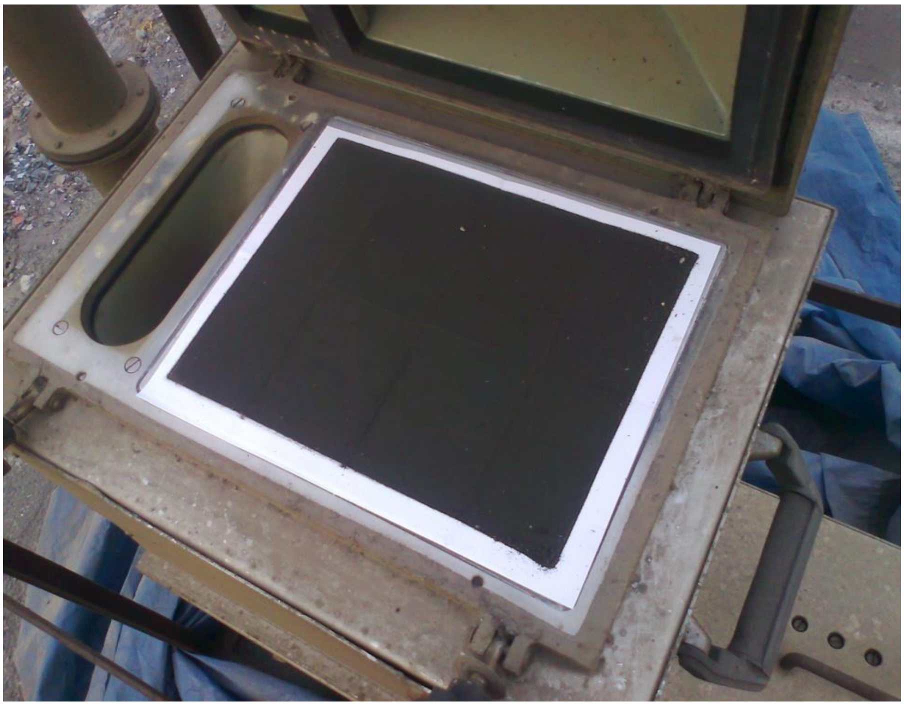


Plate 3 (b): Inner section of the Respirable Dust Sampler after operation

PLATE 4

Plate 4 (a) & (b): Chite Lui / Chite Stream

Plate 4 (c) & (d): Tuikual Lui / Tuikual Stream

Plate 4 (e) & (f): MZU Stream

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(ABSTRACT)

MONITORING OF PARTICULATE MATTERS AND ITS IMPACTS ON HUMAN HEALTH AND ENVIRONMENT IN AIZAWL, MIZORAM

A THESIS
SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF DOCTOR OF
PHILOSOPHY

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MZU REGISTRATION: 100 OF 2011
PHD REGISTRATION: MZU/PH.D. 634 OF 02.05.2014

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APRIL, 2021

The study site Aizawl is the capital of the state of Mizoram situated on a ridge 1,132 meters above sea level. Aizawl is located in the northern part of Mizoram with Tlawng river valley to its west and Tuirial river valley to its east. The geographic location of the heart of the capital Aizawl is 23.36° N 92.0° E.

The population of the Aizawl is highest within the state with a total population of 400,309 according to 2011 census. Aizawl has a mild, sub-tropical climate due to its location and elevation with temperature ranging from 20-35°C in summer and 11-21°C in winter. Annual rainfall received is around 209 cm (Anonymous, 2011).

The thesis consists of six chapters which are as follows:

The first chapter is the introduction which consist of the introduction of air pollution, its historical perspective, air pollutants, meaning and classification of Particulate Matters (PM), the effects of air pollution in human and environment as a whole, the current status of particulate pollution in the world and lastly the scope and objectives of this study, which includes:

i. To assess particulate matters: $PM_{2.5}$, PM_{10} and Suspended Particulate Matters (SPM)

ii. To study human health related problems caused by particulate matters.

iii. To study environmental problems caused by particulate matters.

The second chapter is the review of literature which is further classified at the global level, national level including northeast India and local level. It includes the study of different particulate matters throughout the world with its impacts on human health and the adverse impact it caused on the natural environment as a whole. Studies made by World Health Organisation with regards to the health effects are pointed out. The study of particulate matters in different cities of India are highlighted in seasonal variation which showed a low concentration of particulates in monsoon and a high concentration of particulates in winter or dry season. The works done at the local level, i.e. in Mizoram are also pointed out. It shows that particulate matters are result of vehicular pollution and burning of biomass due to Jhum cultivation.

The third chapter deals with the study area, its location, the climate, rainfall, season, population, geology and drainage. The different sites for monitoring of particulates and collection of water and soil samples are also listed. It includes:

Site 1 – Mizoram University which is situated on the outskirts of the city in the locality of Tanhril. As it is an educational institution area, it is a sparsely populated and the traffic volume is low.

Site 2 – Bawngkawn, a commercial area with very high traffic volume and dense population located in the northern part of the city.

Stite 3 – Laipuitlang, a residential area with moderate traffic volume located in the central part of the city having a higher elevation of 1134 m.

Site 4 – Khatla, which is a commercial cum residential area and have a very high traffic volume as it is an important crossroad in the city.

Three sites have also been selected to collect water sample where parameters like pH and turbidity were determined. The sites include MZU stream – located in the heart of MZU campus, Chite Lui/Stream – located in the eastern side of Aizawl city and Tuikual Lui/ Stream – located in the western side of Aizawl city.

The fourth chapter is concerned with the research methodology followed in this study for the analysis particulate matters like $PM_{2.5}$, PM_{10} and SPM. Water and soil samples were also collected for analysis of different parameters. Apart from these, secondary data of patients with respiratory diseases was also collected from Civil Hospital, Aizawl during the study period. The data of registration of vehicles throughout the study period was also collected from the Directorate of Transport Department, Govt. of Mizoram. Statistical analysis like Correlation, Linear Regression, Odds Ratio, Attributable Risk and Population Attributable Fraction was used to analyse the different data collected.

The fifth chapter constitutes the result and discussion. The main observation and findings of the study are summarized below.

The concentrations of $PM_{2.5}$, PM_{10} and SPM are collected month-wise and the lowest and highest levels of concentration of respective particulates are noted down. From the month-wise concentrations of particulates the exceedance factor is calculated so as to analyse pollution intensity and air quality status. The exceedance factor showed low pollution in $PM_{2.5}$, a low pollution in the first half of the study mixed with moderate and high pollution in PM_{10} at the latter part of the study and a fairly mixed low and moderate pollution in SPM with high pollution in some dry months and a critical pollution of SPM in January, 2016.

Seasonal variation of the particulate matters was also observed and found that the concentration of $PM_{2.5}$, PM_{10} and SPM all falls within permissible limit or standards given by National Ambient Air Quality Standards (NAAQS). It was also found that the PM levels of concentration are high during winter or dry months and low in monsoon or rainy season which was also observed in other studies or cities.

Hospital records of patients diagnosed with respiratory diseases was collected, the disease includes Corrosion of Respiratory Tract (CORT), Bronchitis, Asthma, Chronic Obstructive Pulmonary Disease (COPD), Acute Nasopharyngitis (AN), Acute Sinusitis (AS), Acute Upper Respiratory Infections (AURI) and Vasomotor Rhinitis (VR). The total number of patients with respiratory diseases during the study period was found to be 21,645. The maximum number of patients was recorded in the month of September, 2014 with 1695 cases while the least was recorded in the month of January, 2016 with 299 cases of respiratory disease. Bronchitis contributes the maximum number of patients with 7348 cases or 34 % while Asthma contributes the minimum number of patients with 340 cases or 1 % of the total respiratory disease.

The meteorological parameters like temperature, humidity and rainfall were also observed during the study period which was then correlated with the Particulate Matters. It was found that a negative correlation was observed between all the Particulate Matters with temperature and rainfall. A positive correlation was also observed between SPM and humidity.

Odds ratio (OR) was used to measure the association between PM_{10} exposure and Respiratory Diseases. A significant association was found between PM_{10} exposure and three of the respiratory diseases which are CORT, COPD and VR. Exposure to PM_{10} increased the likelihood of CORT by 66 % (OR=1.66), the likelihood of COPD was found to be 2.74 times higher (OR=2.74) and the likelihood of VR was also found to be 2.54 times higher (OR=2.54). No elevation in risk was observed for the other respiratory diseases.

Attributable Risk (AR) was also determined, which is the odd of developing respiratory disease amongst the exposed group or in other words, the cases that would be eliminated if the exposure were also eliminated. The AR has been calculated for those respiratory diseases which have a significant association with PM_{10} exposure. It was observed that from the exposed group, 40 % have the risk of developing CORT, 64 % have the risk of developing COPD and 61 % have the risk of developing VR.

Population Attributable Fraction (PAF) was also determined for the respiratory diseases. PAF gives the measure of the proportion of all cases of respiratory diseases in the overall population (the exposure and no exposure group) that could be attributed to the exposure. The PAF calculated for those respiratory diseases which have a significant association with PM_{10} exposure shows that from the total population, the fraction of CORT cases that can be attributed to the exposure is 40 %, the fraction of COPD cases that can be attributed to the exposure is 63 % and the fraction of VR cases that can be attributed to the exposure is 60 %.

Soil pH was also observed throughout the study period and was found that all the samples lie between pH 5.1 and 5.6. A correlation between soil pH and PM shows a significant relation. A linear regression between soil pH and PM shows an increase in pH of soil by 0.002 in PM and increase in soil pH by 0.001 in SPM will occur with each unit of increase in annual concentration of the respective PM.

Water parameters like pH and turbidity was also observed throughout the study period. It was found that the pH of water falls toward the alkaline side. This may be due to deposition of cement in water bodies or through run-off after rainfall and also due to huge composition of soap or detergents in the water bodies. The turbidity shows a huge variation during the study period. A low value of turbidity below 1 NTU were observed in different months whereas the readings go above 30 NTU in some months. The high level of turbidity was mainly due to waste disposal at water bodies, soil dumping and also due to flash flood after heavy rainfall. There was no correlation between PM and pH of water and turbidity.

The increase in number of vehicle registration in Aizawl city was also observed during the study period. Monthly registration of vehicles was collected from IT Cell, Directorate of Transport, Govt, of Mizoram. It was found that the monthly average increase of vehicles as per newly registered vehicles was 782 vehicles. There was a total of 18766 vehicles registered throughout the study period. Correlation between the number of registered vehicles with PM shows a positive correlation with PM_{10} and SPM which proves that for every increase in number of vehicles, there will be an increase in concentration of PM_{10} and SPM.

The sixth chapter deals with summary and conclusion of the findings in the study site. The main conclusion is that the concentration of PM in Aizawl city is much lower than those of other cities of India, with an annual average lower than the standards. PM pollution is high in winter or dry months and low in rainy season or monsoon which was also observed in other cities. Since there are no prominent industries or thermal power plant, the main contributing factors of PM in Aizawl are dust or resuspended dust in roadways, construction works, earth removal for roads and structures, burning of biomass during the process of jhum cultivation and vehicular pollution.

The work is supplemented by exhaustive references.