Micro-Characterization of Indoor Particulate Matter in Selected Areas of Jashore University of Science and Technology

By

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Declaration

This is to certify that the M.Sc thesis work entitled as "Micro-characterization of indoor particulate matter in selected areas of Jashore University of Science and Technology" has been carried out by Md. Helal Uddin Patwary in the department of Civil Engineering, Khulna University of Engineering &Technology, Khulna, Bangladesh. The above research work has not been submitted anywhere for the award of any degree or diploma.

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Approval

This is to certify that the thesis work submitted by Md. Helal uddin Patwary entitled *"Micro-characterization of indoor particulate matter in selected areas of Jashore University of Science and Technology"* has been approved by the board of examiners for the fulfillment of requirements for the degree of Master of Science in Civil Engineering, Khulna University of Engineering & Technology, Khulna, Bangladesh in July 2019.

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My father

Whose inspiration helped me to be an Engineer

ABSTRACT

Indoor air pollution has drawn considerable attention in recent years. Indoor air quality is very important for human health especially for vulnerable group of people (the asthmatic, the children and the elderly). The indoor environment can be subdivided into different micro-environments such as residents, transport, offices, educational institutions etc. and each may have a different source of indoor pollution. Indoor particulate matter has harmful impact on human health and environment. The finer the size of particles the higher the harmful impact.In this research work an attempt has been made for characterization of indoor particulate matter at three buildings named10-storied residential Tower, Administrative and Academic building of Jashore University of Science and Technology (JUST) campus.

In the dust sample, presence of heavy metals (Ti,Fe,Cu,Zn,As,Pb,Zr) and criteria air pollutant(Pb)was found. The concentration of PM_{10} (µg/m^3) and $PM_{2.5}$ (µg/m^3) measured by Tactical Air Sampler (TAS) was found highest value (PM_{10}, 170µg/m^3 and $PM_{2.5}$,103µg/m^3) in Academic building among the three buildings. The reason is that this building is situated near road side and construction work is going on adjacent the building. Again concentration of $PM_{2.5}$ is found higher inside than outside the building in all cases. Concentration of PM_{10} (130µg/m^3) is found higher inside than outside (76µg/m^3) in Administrative Building. Concentration of PM_{10} and $PM_{2.5}$ in all cases exceeds WHO guideline limit (WHO guideline for PM_{10} in 24 hour- 50µg/m^3 and 1 year is 20µg/m^3; For $PM_{2.5}$ in 24 hour- 25µg/m^3 and 1 year is 10µg/m^3) and in academic building exceeds Bangladesh standard both in outdoor and indoor(Bangladesh standard for PM_{10} in 24 hour- 150µg/m^3 and 1 year is 50µg/m^3). Concentration of PM_{10} in administrative building both in outdoor and indoor and 10-storied residential tower building in outdoor is within Bangladesh 24 hour standard but exceeds Bangladesh 1 year standard. In academic building exceeds Bangladesh standard both in outdoor and indoor (Bangladesh standard for $PM_{2.5}$ in 24 hour- 65µg/m^3 and 1 year is 15µg/m^3). Concentration of $PM_{2.5}$ in administrative building exceeds Bangladesh standard in indoor but in outdoor within 24 hour standard but exceeds 1 year standard. Concentration in 10-storied residential tower in outdoor within the 24 hour standard but exceeds 1 year standard.

In XRF analysis presence of Pb (667±0.19,ppm) and Ca (61340±919,ppm) was found highest in academic building PM. Inter elemental correlation was calculated. Strong correlation (R^2 >0.90) was found Pb with Zr; Sr with Ca, Ti, Zn and As; Rb with K and Cu; As with Ca, Fe and Zn; Zn with Ti and Fe; Cu with K; Fe with Ca and Ti. Strongly correlated elements originated from same source such as re-suspended road dust, trace element of earth crust, cement, paint and other construction materials. Adequate control, management, housekeeping can minimize the exposure of indoor dust to occupants.

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ABBREVIATION

ACM	Asbestos Containing Materials
AQI	Air Quality Index
AQMP	Air Quality Management Project
ASTM	American Society for Testing Material
ATR	Attenuated Total Reflectance
BNAAQS	Bangladesh National Ambient Air Quality Standard
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DNA	Deoxyribonucleic Acid
EPA	Environmental Protection Agency
FTIR	Fourier Transform Infra-Red spectroscopy
GoB	Government of Bangladesh
EBD	Environmental Burden of Diseases
IAP	Indoor Air Pollution
IAQ	Indoor Air Quality
IPCC	Intergovernmental Panel on Climate Change
IR	Infra-Red
JUST	Jashore University of Science and Technology
PM	Particulate Matter
$PM_{2.5}$	Particulate Matter having diameter smaller than 2.5 Micrometers
PM_{10}	Particulate Matter having diameter of 2.5 to 10 Micrometers
XRF	X-Ray Fluorescence
XRD	X-Ray Diffractometry
SEM	Scanning Electron Microscopy
SO_2	Sulfur Dioxide
VOC	Volatile organic compound
USAID	United States Agency for International Development
WHO	World Health Organization

UNITS OF MEASUREMENT

%	Percentage
t/yr	Ton per year
Kg	Kilogram
gm	Gram
m	meter
m^3	Cubic meter
cm	Centimeter
$\mu g/m^3$	Microgram per cubic meter
cm^{-1}	Per centimeter
t	Ton
mm	Millimeter
µm	Micrometer
ha	Hector
ppm	Parts per million

Chapter 1

Introduction

1.1 General: Population exposure to various air pollutants is likely to be higher in the indoor micro-environment than outdoors due to the amount of time people spend there. Consequently, indoor air quality has drawn considerable attention in recent years. There are noticeable differences in the types and strength of air pollution sources across the globe and they are closely linked to socio-economic developments. Typically higher indoor concentrations occur in developing rather than developed countries. The types, concentration, and sources of indoor air pollutants vary considerably from one micro-environment to another. Hence, an understanding of the concentration of pollutants in different micro-environments is of great importance for improving exposure estimates and, in turn, for developing efficient control strategies to reduce human exposure and health risk. 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} (particles in the 2.5–10 μm range). All-cause daily mortality is estimated to increase by 0.2–0.6% per $10 \mu g/m^3$ of PM_{10}. Long-term exposure to $PM_{2.5}$ is associated with an increase in the long-term risk of cardiopulmonary mortality by 6–13% per $10 \mu g/m^3$ of $PM_{2.5}$ (WHO, Health effects of particulate matter,2013) .Susceptible groups with pre-existing lung or heart disease, as well as elderly people and children, are particularly vulnerable. The exposure is ubiquitous and in voluntary, increasing the significance of this determinant of health. It is estimated that approximately 3% of cardiopulmonary and 5% of lung cancer deaths are attributable to PM globally. In the European Region, this proportion is 1–3% and 2–5%, respectively, in various sub regions. A recent study estimates that in 2010, ambient air pollution, as annual $PM_{2.5}$, accounted for 3.1 million deaths and around 3.1% of global disability-adjusted life years. The WHO Air Quality Guidelines 2005 recommended the development of guidelines specific for indoor air quality. These guidelines will cover three groups of issue: specific pollutants, biological agents and indoor combustion products. In the recent update, WHO reported that 4.3 million people die due to illnesses which are attributable to indoor air pollution (IAP), it was estimated that in developing countries, nearly 2 million excess deaths might occur due to exposure to IAP. Though various measures have been undertaken to protect outdoor air pollutants as well as to eliminate or reduce it and already much progress has been achieved but to reduce indoor pollutant not much work has been progressing. The limit value of indoor pollutants yet to be adopted in many countries. However, currently as like with the outdoor pollutants, importance has also been given to handle indoor pollutants.

Now good Indoor Air Quality (IAQ) is considered as an important factor for a healthy indoor environment, particularly for the children, pregnant women and elderly people, because they are more vulnerable to develop the disease by the indoor pollutants.

1.2 Rationale of the study: Since people spend a great proportion of time indoors, typically 65-90% or more, indoor pollution is frequently the predominant factor in total exposure. According to the EPA, our indoor environment is 2 to 5 times more toxic than our outdoor environment**,** and in some cases, the air measurements indoors have been found to be 100 times more polluted. The International Agency for Research on Cancer and the World Health Organization(WHO) have concluded that 80% of all cancers are attributed to environmental rather than genetic factors, including exposure to carcinogenic chemicals, many of which are found in household cleaning products. According to the World Health Report, 2002 indoor air pollution (IAP) is responsible for 2.7% of the global burden of disease and nearly 2.5 million people die due to air pollution, mainly (65%) because of IAP (WHO, Health effects of particulate matter,2013).WHO reported that every year IAP is responsible for the death of 1.6 million people, which contributes to one death in every 20 seconds. Assessment of the contribution of various risk factors to the burden of disease by WHO, revealed that IAP ranked the 8th most important risk factor and contributes to 2.7% of the global burden of disease. Further in developing countries where mortality rate is high, the indoor smoke is responsible for an estimated 3.7% of the overall disease burden. Indoor pollution cause more respiratory disorders compared to outdoor pollution. Besides these impacts, indoor pollution leads to a significant cost burden to the economy. It was estimated in Australia that the cost of poor indoor air quality might be as high as $12 billion per year. On the basis of recent studies, EPA ranked IAP among the top five environmental risks to public health. It has been reported that indoor air may contain more than 900 different organic compounds, in addition to particles, microbes, and allergens. In most of cases IAP disproportionately affects women and children who spend most time near the domestic hearth. IAP from solid fuel use is the 10th biggest threat to public health WHO (2007). Global estimates document that 4-5% of the 50-60 million global deaths in rural and urban areas of developing countries occur every year from indoor exposures to particulate matter (Bruce et al., 2002). There is a growing awareness of the importance of the indoor environment on health and exposure to IAP has been given higher attention in policy making (Harrison, 2002). Several countries including Germany, Norway and

Poland, have already established target concentrations for various indoor pollutants, and the UK has issued guidance on indoor air pollutants that includes numerical standards for nitrogen dioxide, carbon monoxide, formaldehyde, benzene and benzo (a) pyrene. Australia has adopted the approach of identifying indicators of good air quality rather than defining quantitative limits.

Problems of indoor air quality are recognized as important risk factors for human health in both low- and middle- and high-income countries. In residences, day-care centers, retirement homes and other special environments, IAP affects population groups that are particularly vulnerable owing to their health status or age. In low and middle income countries like Bangladesh the total burden of disease associated with indoor air pollution was estimated to be 3.6%. Respiratory diseases caused by air pollution are believed to be the epidemic in major cities of Bangladesh. According to the the Air Quality Management Project (AQMP), funded by the Government of Bangladesh (GOB) and world bank, fifteen thousand deaths and several million cases of pulmonary, respiratory and neurological illness occur every year due poor air quality in Dhaka (Haque, 2015). Researcher measured excessive concentration of dust in dhaka which was three times from the standard level of Bangladesh and UK and Norway (Haque,2015).Study reveals that, though the government has taken several steps to minimize air pollution but the concentration of $PM_{2.5}$ and PM_{10} remains almost same in Dhaka and can never comply the Bangladesh National Ambient Air Quality Standard (BNAAQS) (Hoque et al.,2015). Extreme effects of air pollution include high blood pressure and cardiovascular problems (sanjay, 2008). Hence abating air pollution is very important to reducing exposure to public health and environment.

Jashore is an old district of Indian subcontinent and oldest district of Bangladesh which established in 1781AD. It is an important hub of agriculture, fisheries of Bangladesh. An airport, cantonment, University, Medical college and many other important institutions situated here. It has been reported that in Bangladesh industrial and transportation sectors are the principle sources of outdoor air pollution (Alam, 2009). Since people spent their major portion of time in indoor; So it is important to know the exposure of indoor air pollutant. Students are the future leaders of the country and they pass their maximum time in classroom and Laboratory. In this study an attempt has been made to determine the air quality of Jashore University of Science and

Technology campus. Indoor dust sample of 10-storied residential tower, administrative and academic building of JUST campus analyzed by X-ray fluorescence(XRF),X-ray diffractometry (XRD) with scanning electron microscopy(SEM) and Fourier transform infra-red(FTIR) spectroscopy. Some abatement strategies have been suggested for enhancing air quality.

1.3 Objectives of the study

The overall objective of this research work is to characterize the indoor particulate matter of Jashore University of Science and Technology (JUST) campus.

The specific objectives of the research are-

- To determine the elemental composition (K,Ca,Ti,Fe,Cu,Zn,As,Rb,Sr,Zr,Pb) of atmospheric particle in deposited dust.
- To measure the bioavailability of Fe and As in dust.
- To estimate the emission rate of PM_{10} and $PM_{2.5}$ of dust.
- To establish a correlation among the elemental compositions of dust.

1.4 Outline of the Dissertation

The dissertation is being presented in following six distinct chapters comprising different aspects of study.

Chapter 1: This chapter provides the problem statement, a general overview of background information, specific objectives and structure of dissertation.

Chapter 2: This chapter reviews the relevant existing literature regarding aerosols, air pollution, indoor air pollution, sources of particulate matter, their impact on human health and environment. The impact of heavy metals on human health, air quality index and monitoring of air pollutants also described in this chapter.

Chapter 3: This chapter describes the various methods adopted for characterization of indoor particulate matter, bioavailability test of metals, correlation of elements, determination of particulate matter (PM_{10} and $PM_{2.5}$) in ambient air.

Chapter 4: In this chapter the results are described following the methodologies adopted in chapter three.

Chapter 5: This chapter describes the control and management strategies of indoor particulate matter to reduce exposure to inhabitants and enhance good indoor air quality.

Chapter 6: This chapter includes the conclusions as the summary of findings of the study and provides recommendations for further research.

References: List of relevent publications and reports cited in the texts are included in this section.

Appendices: This section provides the lists of appendices used in this study.

Chapter 2

Literature Review

2.1 **General**

In this chapter the relevant existing literature regarding aerosols, air pollution, indoor air pollution, sources of particulate matter, their impact on human health and environment are described.

2.2 **Aerosols**

The atmosphere contains solid and liquid particles that are suspended in the air. These particles are referred to as aerosols or particulate matter (PM). Aerosols in the atmosphere typically measure between 0.01 and 10 micrometers in diameter, a fraction of the width of a human hair (Figure-2.1). In the atmosphere, particles can change their size, adsorb gaseous molecules onto their surface, coalesce with each other and can be removed by deposition processes. Most aerosols are found in the lower troposphere, where they have a residence time of a few days. They are removed when rain or snow carries them out of the atmosphere or when larger particles settle out of suspension due to gravity. Large aerosol particles (usually 1 to 10 micrometers in diameter) are generated when winds blow sea salt, dust, and other debris into the atmosphere. Fine aerosol particles with diameters less than 1 micrometer are mainly produced when precursor gases condense in the atmosphere. Major components of fine aerosols are sulfate, nitrate, organic carbon, and elemental carbon. Sulfate, nitrate, and organic carbon particles are produced by atmospheric oxidation of SO_2, NO_x and VOC's. Elemental carbon particles are emitted by combustion, which is also a major source of organic carbon particles. Light-absorbing carbon particles emitted by combustion are called black carbon or soot; they are important agents for climate change and are also suspected to be particularly hazardous for human health.

High concentrations of aerosols are a major cause of cardiovascular disease and are also suspected to cause cancer. Fine particles are especially serious threats because they are small enough to be absorbed deeply into the lungs, and sometimes even into the bloodstream. Scientific research into the negative health effects of fine particulate air pollution spurred the U.S. Environmental Protection Agency to set limits in 1987 for exposure to particles with a diameter of 10 micrometers or less, and in 1997 for particles with a diameter of 2.5 micrometers or less.

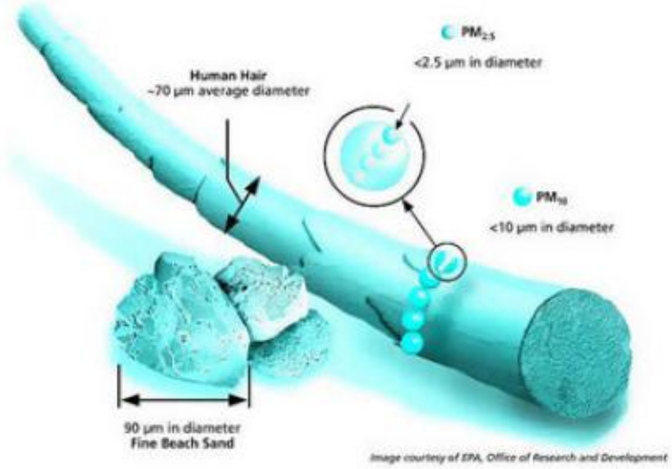

Figure-2.1: Size comparisons for aerosol pollution
Courtesy: United States Environmental Protection Agency

Aerosols also have important radiative effects in the atmosphere. Particles are said to scatter light when they alter the direction of radiation beams without absorbing radiation. This is the principal mechanism limiting visibility in the atmosphere, as it prevents us from distinguishing an object from the background. Air molecules are inefficient scatterers because their sizes are orders of magnitude smaller than the wavelengths of visible radiation (0.4 to 0.7 micrometers). Aerosol particles, by contrast, are efficient scatterers.When relative humidity is high, aerosols absorb water, which causes them to swell and increases their cross-sectional area for scattering, creating haze. Without aerosol pollution our visual range would typically be about 200 miles, but haze can reduce visibility significantly.

Fine particles ($PM_{2.5}$), with an aerodynamic diameter smaller than 2.5µm, is considered to be more hazardous than larger size PM because of its longer residence time in the atmosphere and can penetrate deep into the alveolus of human beings through breathing (Feng et al., 2009; Massey et al., 2009;Satsangi et al., 2011). Contaminated, heterogeneous geosolids, when ingested, act as an important vehicle for the non-dietary intake of many toxic chemicals, including trace metals, by humans (Gupta et al., 2010). Not only vehicles, which are important emitters of fine particles in the city, combustion of residential fuels for heating and cooking, construction and renovation, surface coatings and solvents (e.g.,VOCs) are often of equal or greater importance (Chow et al., 2004; Masih et al., 2012a, b). (Kulshrestha et al.,2014).

The size of atmospheric particle can be distributed with aerodynamic diameter of (Dp) as coarse (10< Dp <2.5 μm), intermodal (2.5 < Dp < 1 μm), submicron (Dp <1μm) and ultrafine (Dp <0.1μm) particles. (K.Mohiuddin et al.,).Among them submicron and ultrafine particles are most hazardous.

2.3 Indoor pollutants

Indoor pollutants may originate from many sources including infiltration of outdoor pollutants, cookers and heaters, building and furnishing materials, smoking, consumer products, and incense burning (Madany et al., 1994; Taneja et al., 2008; Massey et al., 2012a). One category of indoor pollutant, which is known to be toxic, is that of heavy metals. Heavy metals find their way into residential homes either as airborne dust or through items used or activities carried out within the house like renovation or different cooking methods. Especially vulnerable in this respect are young children, who may ingest several milligrams of indoor and outdoor dusts per day through the repetitive mouthing of non-food objects (Fergusson and Marsh, 1993). Most of the focus to date has been on soils that are contaminated by specific industrial sources or events or by more general urbanization (Madrid et al., 2008) and on indoor dusts (Turner and Ip, 2007; Habil et al., 2013). The makeup of the latter is often dominated by external solids, like soils and road-dusts, but also contains appreciable quantities of particulates generated internally from cooking, smoking, heating, decorating and the application of cosmetics, upholstered furniture. (Kulshrestha et al., 2014)

The indoor environment can be subdivided into different micro-environments (e.g. school, transport, restaurant and residential) and each may have a different source of indoor pollution.

There is a growing awareness of the importance of the indoor environment on health and exposure to indoor air pollution has been given higher attention in policy making (Harrison 2002). Several countries including Germany, Norway and Poland, have already established target concentrations for various indoor pollutants, and the UK has issued guidance on indoor air pollutants that includes numerical standards for nitrogen dioxide, carbon monoxide, formaldehyde, benzene and benzo(a) pyrene. Australia has adopted the approach of identifying indicators of good air quality rather than defining quantitative limits. The WHO Air Quality Guidelines 2005 recommended the development of guidelines specific for indoor air quality.

These guidelines will cover three groups of issue: specific pollutants, biological agents and indoor combustion products.

On a global scale, the bulk of exposure to air pollution is experienced indoors, as most people spend most of their time there. Indoor concentrations are a complex interaction of various factors such as outdoor concentrations, indoor sources and sinks, pollutants, depletion, filtration and ventilation. The types, concentration, characteristics and sources of different air pollutants differ both in outdoor and indoor air.

2.4 Ingestion of Indoor Particulate matter

Ingestion of indoor dust is a significant exposure pathway for children in residential settings(Calabrese and stanek,1992,Dust;Stanek and Calabrese,1992;Chuang et al.,1995;Fergusson and Kim,1991).In one study, Stanek and Calabrese(1992) demonstrated that almost 50 percent of the soil ingested by children came from ingestion of soil in indoor dust. The composition of indoor dust differs strongly from the composition of the soil outside a house. only a fraction of dust is composed of soil which has been carried into the house(e.g, on shoes).the remainder consists of dust particles derived from materials inside the house such as lint from carpets and clothes, human hair and skin, pet hair and skin, household plant material, pieces of paper, paint chips, wood chips from furniture, pieces of insulation, flakes of construction materials, bacteria, viruses, allergens and insects (e.g., dust mites)(Thatcher and Layton,1995).Some indoor dust also derived from particles carried through open windows by the wind.

Because indoor dust is a mixture of particles generated inside the house (“particles”) and soil carried into the house on clothing, the concentration of a chemical in indoor dust must fall between its concentration in these two media. If the concentration of the chemical in the particles is negligible compared with its concentration in soil, the dust concentration of the chemical can be predicted from the physical dilution of the soil by particles. Chemicals for which the particle concentration is negligible compared to the soil concentration is known as” conservative tracer chemicals”.

Assuming that the soil carried into the house has the same chemical and physical properties as the outdoor soil, the ratio of the dust concentration to the soil concentration for conservative tracer chemicals is equal to the fraction of the household dust which consists of soil.The ration can be defined as " Transfer coefficient"(TC) of a chemical

$$TC=C_{dust}/C_{soil}$$

Where C_{dust} is the dust concentration of the element with units of mg/kg and C_{soil} is the soil concentration of the element with units of mg/kg. The TC is dimensionless. The TC can reach a maximum value of one for pure soil. In reality it would be impossible for a conservative tracer chemical to have a TC value of one because of the large fraction of organic material which is always present in indoor dust(Rothenberg et al.,1989).The fraction of indoor dust originally derived from soil is generally 31%.

2.5 Visible impact of air pollution

The visible impact of air pollution is haze, a layer of particles from biomass burning and industrial emissions. The haze consists of a combination of droplets and solid particles. The liquid droplets in the haze are generally less than 1.0 µm in radius (Pandve, 2008). Begum et al. (2011a) found that Black carbon (BC) particles are mainly in the PM_1 range that can contribute to haze formation. Scientists studied that the cloud of haze that frequently lingers over parts of Asia from Pakistan to China and even the Indian and Pacific Oceans has called the pollution the "Asian Brown Cloud". This Asian Brown Cloud has a brownish color and this brown cloud phenomenon is a common feature of industrial and rural regions around the world. Because of long–range transport of air pollutants, mostly urban (fossil fuel related)and/or rural (biomass burning and brick kilns) phenomenon is transformed into a regional haze (or cloud) that Can span large areas including a substantial part of a continent. It is now becoming clear that the brown cloud may have huge impacts on agriculture, health, climate, and the water budget of the planet (Ramanathan et al., 2005; Ramanathan and Carmichael, 2008). The Asian Brown Cloud is the mixture of aerosols (tiny particles suspended in the air) includes smoke from agricultural and home heating and cooking fires, vehicle exhaust, and industrial emissions. In addition to the respiratory problems the persistent haze can cause, it also appears to hinder crops by blocking sunlight and could be altering regional weather. Concentration of particulate matter influence on climate change and cause adverse health effects (Hoque et al.).

The characterization of fine particles is very important because of their potential impact on human health, their ability to travel thousands of kilometers crossing international borders and their influence on climate forcing and global warming (IPCC,2007).

2.6 Health impact of indoor air pollution

Evidence has now emerged showing a link of IAP with a number of other conditions, including asthma, cancer of the upper airway, cataracts, low birth weight, otitis media, prenatal mortality (stillbirth and deaths in the first week of life), and tuberculosis (WHO, 2000). Besides these, a plethora of studies in both developed and developing countries have found the same associated relationship between IAP and certain diseases. For instance, the association of IAP with ALRI5, asthma (Smith et al.,2004) COPD6, lung cancer (WHO, 2000; Duflo et al., 2007) low birth weight (WHO, 2000; Donna and Harding, 2005) and tuberculosis (WHO, 2000; Bruce et al., 2002) was found. The common adverse health effects that result from various indoor pollutants are mainly respiratory disorders like cough, rhinitis, asthma, in addition to these there may occur irritation to the skin, eyes and throat; neurotoxic symptoms; headache, dizziness, drowsiness, hypersensitivity reaction, immunodeficiency, cardiovascular diseases, adverse pregnancy outcomes and cancers.

2.7 Impacts of Particulate matter

Atmospheric particles can have potential adverse impacts on human health through inhalation and respiratory deposition, with children, the elderly and people with respiratory problems being especially vulnerable groups of the population. Metals associated with atmospheric particles can cause harmful effects on human health (Lippmann et al., 2006; Lippmann and Chen, 2009; Bollati et al., 2010) and ecosystems (Berggren et al., 1990; de Vries et al., 2007). The impact of atmospheric particles on human health and environment depends on their physical and chemical properties. In Bangladesh, particulate matter (PM) is the air pollutant that is most harmful to public health and the environment when compared to other measured criteria pollutants (Begum et al., 2012). Epidemiological investigations strongly suggest that human mortality and morbidity is increased due to higher concentration of inhalable particles (Pope, 2000; Lin and Lee, 2004; Querol et al., 2004; Arditsoglou and Samara, 2005; Dominici et al., 2005; Namdeo and Bell, 2005; Ning and Sioutas, 2010), but respirable particles in the size range of $PM_{2.5}$ and PM_1 are particularly hazardous as they can be transported deep into the alveolar region of the lungs and the bloodstream (Krombach et al., 1997; Park and Wexler, 2008; Valiulis et al., 2008).(K. Mohiuddin et al.,)

2.8 Health effect of Heavy metals

Heavy metals are generally referred to as those metals which possess a specific density of more than 5 g/cm^3 and adversely affect the environment and living organisms (Järup, 2003). Although it is acknowledged that heavy metals have many adverse health effects and last for a long period of time, heavy metal exposure continues and is increasing in many parts of the world. Heavy metals are significant environmental pollutants and their toxicity is a problem of increasing significance for ecological, evolutionary, nutritional and environmental reasons (Jaishankar et al., 2013; Nagajyoti et al., 2010). The major target organ of toxic effects of heavy metals like arsenic, mercury and lead, is central nervous system. Heavy metal toxicity can lower energy levels and damage the functioning of the brain, lungs, kidney, liver, blood composition and other important organs. Long-term exposure can lead to gradually progressing physical, muscular, and neurological degenerative processes that imitate diseases such as multiple sclerosis, Parkinson's disease, Alzheimer's disease and muscular dystrophy. Repeated long-term exposure of some metals and their compounds may even cause cancer (Jarup,2003). The toxicity level of a few heavy metals can be just above the background concentrations that are being present naturally in the environment. Hence thorough knowledge of heavy metals is rather important for allowing to provide proper defensive measures against their excessive contact (Ferner,2001).

2.8.1 Sources of Heavy metals

Heavy metals enter the surroundings by natural means and through human activities. Various sources of heavy metals include soil erosion, natural weathering of the earth's crust, mining, industrial effluents, urban runoff, sewage discharge, insect or disease control agents applied to crops, and many others (Morais et al., 2012).

Figure- 2.2 shows the global production and consumption of selected toxic metals during 1850–1990 (Nriagu,1996).

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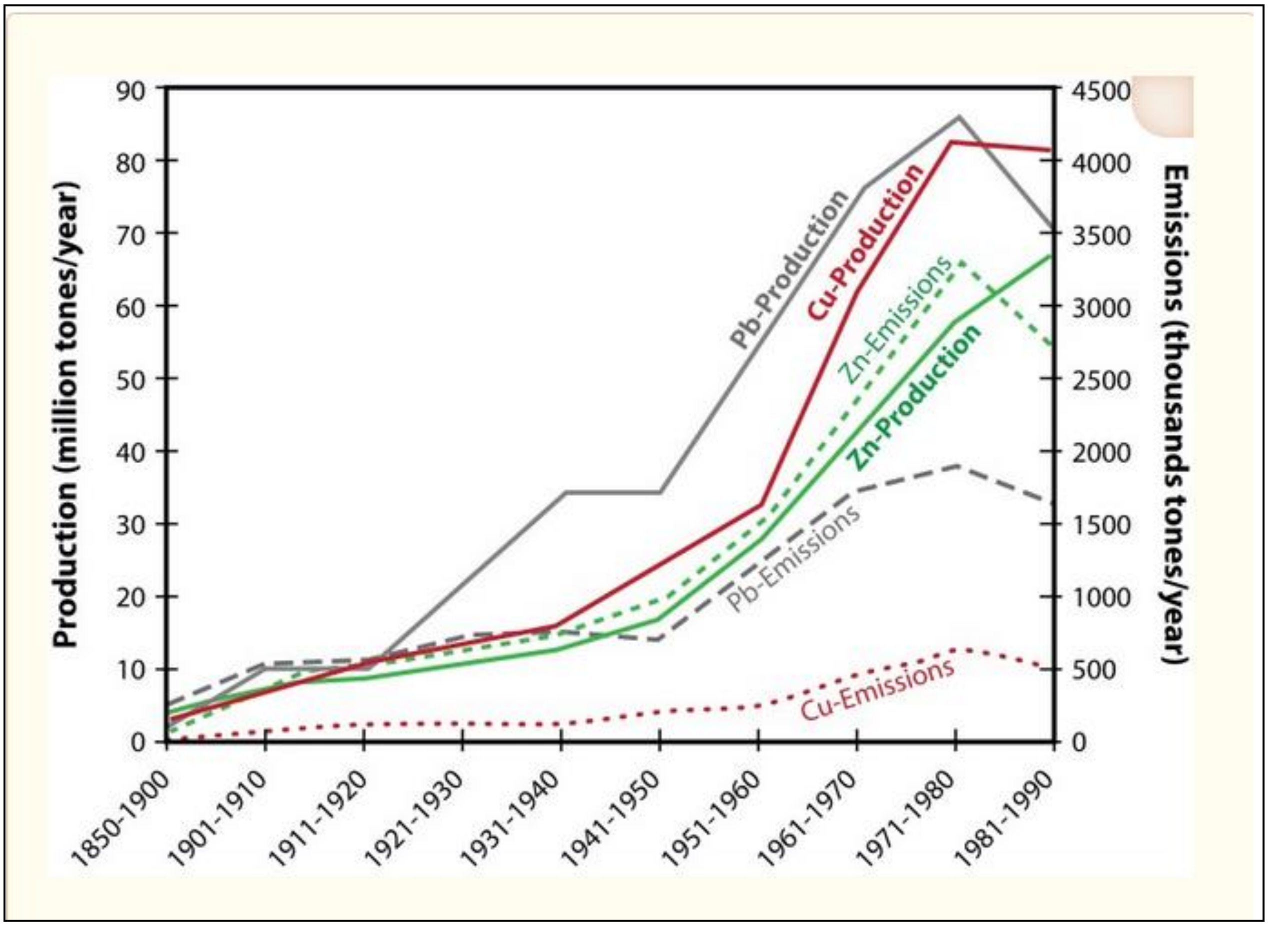


Figure-2.2: The global production and consumption of selected toxic metals during 1850-1990

Adopted from Nriagu1996

Heavy metals are commonly found in the environment and diet. In small amounts they are required for maintaining good health but in larger amounts they can become toxic or dangerous.

2.8.2 Arsenic(As)

Arsenic is semi metallic in nature and widely present in the earth-crust in the forms of oxides or sulfides or as a salt of iron, sodium, calcium, copper etc. Arsenic and its compound are well known for its toxicity and carcinogenicity. Individual exposes to arsenic from various sources like food, air, water, occupational settings and medicines.

The clinical manifestations of chronic arsenic exposure are skin lesions, cardiovascular disease, neurological effects, chronic lung disease, cerebrovascular disease, reproductive disease, adverse renal affects, developmental abnormalities, hematological disorders, diabetes mellitus and cancers of skin, lung, liver, kidney and bladder. Low birth weight and adverse pregnancy outcomes are also documented by chronic toxicity of arsenic.

Arsenic is a naturally occurring ubiquitous element with metalloid properties. Arsenic is widely present in soil, rocks, sediments and metals ores in the form of oxyhydroxide or sulfide or compounds of various metals in the most part of world (Aronson, 1994). Human population is mostly exposed to arsenic through ingestion, inhalation and dermal contact. Ingestion of arsenic contaminated water, foods, drugs, wines, smoke of cigarette and fossil fuels are the various routes of arsenic exposure to the population both acute and chronically (NTP, 1999). In occupational exposure, the workers are exposed to airborne arsenic from the industries of smelting and refining metals, producing and using arsenic-containing chemicals, manufacturing of glass, semiconductors and various pharmaceutical substances (USPHS, 1989).

Skin manifestation is the most common and initial sign of chronic arsenic exposure. Chronic ingestion of arsenic causes characteristic melanosis, keratosis, basal cell carcinoma and squamous cell carcinoma (Maloney, 1996). An affect of inorganic arsenic in the form of airborne particles (mostly arsenic trioxide) on respiratory system mainly occurs in industrial area. Initially, the lesions of mucous membrane of respiratory system including the irritation of nasal mucosa, larynx, bronchi and later perforation of nasal septum were observed (Hine et al.1977). Inorganic arsenic is indirect-genotoxic carcinogen of lungs, skin and several internal organs in the humans (IARC,1987).Arsenic has been associated with lung cancer to the workers of manufacturing unit and peoples linked with the industries of arsenic containing pesticides, chemicals and metals smelting area. The trivalent (As^{lll}) form of inorganic arsenic has shown the activity of carcinogenesis.

Arsenic is one of the most important heavy metals causing disquiet from both ecological and individual health standpoints (Hughes et al., 1988). It has a semi metallic property, is prominently toxic and carcinogenic, and is extensively available in the form of oxides or sulfides or as a salt of iron, sodium, calcium, copper, etc. (Singh et al., 2007). Arsenic is the twentieth most abundant element on earth and its inorganic forms such as arsenite and arsenate compounds are lethal to the environment and living creatures. Humans may encounter arsenic by natural means, industrial source, or from unintended sources. Deliberate consumption of arsenic in case of suicidal attempts or accidental consumption by children may also result in cases of acute poisoning (Mazumder, 2008; Saha et al., 1999). Arsenic is a protoplastic poison since it affects primarily the sulphydryl group of cells causing malfunctioning of cell respiration, cell enzymes and mitosis (Gordon and Quastel,1948).

Most of the paints, dyes, soaps, metals, semi-conductors and drugs contain arsenic. Certain pesticides, fertilizers and animal feeding operations also release arsenic to the environment in higher amounts. The inorganic forms of arsenic such as arsenite and arsenate are found to be more dangerous to human health. They are highly carcinogenic and can cause cancer of lungs, liver, bladder and skin. Humans are exposed to arsenic by means of air, food and water.

Lower levels of arsenic exposure can cause nausea and vomiting, reduced production of erythrocytes and leukocytes, abnormal heart beat, pricking sensation in hands and legs, and damage to blood vessels. Long-term exposure can lead to the formation of skin lesions, internal cancers, neurological problems, pulmonary disease, peripheral vascular disease, hypertension and cardiovascular disease and diabetes mellitus (Smith et al., 2000). Chronic arsenicosis results in many irreversible changes in the vital organs and the mortality rate is higher. In spite of the magnitude of this potentially lethal toxicity, there is no effective treatment for this disease (Mazumder,2008).

2.8.3 Zirconium (Zr)

Zirconium (Zr) is a toxic metal that contaminate terrestrial ecosystems are increasingly of environmental and sanitary concern (Uzu et al. 2010, 2011; Shahid et al. 2011a, b, 2012a). Zirconium (Zr) has the atomic number 40 and is a transition metal that resembles titanium in physical and chemical properties (Zaccone et al. 2008).Zr is widely used in many chemical industry processes and in nuclear reactors (Sandoval et al. 2011; Kamal et al. 2011), owing to its useful properties like hardness, corrosion-resistance and permeable to neutrons (Mushtaq 2012) .

Zr is the twentieth most common element in the earth’s crust (Fodor et al. 2005). It is generally considered to be immobile in soil (Muhs et al. 2007, 2010; Muhs and Budahn 2009 ; Aznar et al. 2009 ; Feng 2010, 2011 ; Little and Lee 2010 ; Hao et al.2010 ; Bern et al. 2011), because it has low water solubility and a strong tendency to polymerize (Clearfield 1964). Moreover, Zr forms strong complexes with soil components, via zirconium dioxide and zirconocene dichloride, among others. The rate of adsorption/desorption of Zr to soil depends on its speciation and the characteristics of the soil involved. This element can be mobile in soil under a wide range of geological settings such as tropical weathering (Duvallet et al. 1999; Kurtz et al. 2000 ; Hodson 2002 ; Davydov et al. 2006)

Relative to other inorganic trace elements, Zr has a high natural abundance in the earth's crust (Jones 1998; Martínez Cortizas et al. 2003; Chow et al. 2003; Alleman et al. 2010; Kumpiene et al. 2011).The natural level of Zr in soils varies from 32 to 850 mg/kg (Kabata-Pendias and Pendias 1992 ; Fodor et al. 2005).Bowen (1979) gave 400 mg/kg as an average Zr soil concentration, and Pais and Jones (1983) reported a value of 250 mg/kg. In soil, Zr is more than twice as abundant as copper and zinc and has ten times the abundance of lead. Its geochemistry is dominated by its lithophilic nature: Zr occurs in more than 140 recognized mineral species, but zircon ($ZrSiO_4$) and baddeleyite (ZrO_2) are the main naturally observed compounds (Ryzhenko et al. 2008) .

Zr emissions to the atmosphere are increasing from anthropogenic activities such as its use in industry and nuclear reactors. Zr exists in several forms in the soil and in liquid media, and these forms have different levels of solubility and bioavailability (Fodor et al. 2005; Davydov et al. 2006; Ryzhenko et al. 2008 ; Prisyagina et al. 2008 ; Louvel et al. 2009) .

2.8.3.1 Health effect of Zirconium: Zirconium and its salts generally have low systemic toxicity. It can cause contact irritation to the skin and eyes. If exposed, people should wash their skin or flush their eyes. And it may be a good idea to see a doctor if zirconium has entered someone's eyes. This element can also cause the formation of granulomas in the lungs if it is inhaled. These clusters of immune system cells are formed when the body reacts to foreign particles. This element does not appear to be biologically necessary, although trace amounts are found in many organisms, including people. The estimated dietary intake is about 50 micro g. Most passes through the gut without being adsorbed, and that which is adsorbed tends to accumulate slightly more in the skeleton than in tissue.

Zirconium 95 is one of the radionuclides involved in atmospheric testing of nuclear weapons. It is among the long-lived radionuclides that have produced and will continue to produce increased cancer risk for decades and centuries to come.

2.8.4 Rubidium (Rb)

Rubidium is a soft, silvery-white metallic element of the alkali metals group (Group 1). It has atomic number 37.It is one of the most electropositive and alkaline elements. Rubidium can be liquid at ambient temperature, but only on a hot day given that its melting point is about 40°C. It ignites spontaneously in air and reacts violently with water and even with ice at -100°C, setting fire to the liberated hydrogen. As so with all the other alkali metals, it forms amalgams with mercury. It alloys with gold, cesium, sodium, and potassium. Its flame is yellowish-violet.

2.8.4.1Applications of rubidium

Rubidium and its salts have few commercial uses. The metal is used in the manufacture of photocells and in the removal of residual gases from vacuum tubes. Rubidium salts are used in glasses and ceramics and in fireworks to give them a purple colour. Potential uses are in ion engines for space vehicles, as working fluid in vapor turbines, and as getter in vacuum tubes.

2.8.4.2 Rubidium in the environment

Rubidium is considered to be the 16th most abundant element in the earth's crust. The relative abundance of rubidium has been reassessed in recent years and it is now suspected of being more plentiful than previously calculated. It is very like potassium and there are no environments where it is seen as a threat.

No minerals of rubidium are known, but rubidium is present in significant amounts in other minerals such as lepodite (1.5%), pollucite and carnallite. It is also present in traces in trace amounts in other minerals such as zinnwaldite and leucite.

2.8.4.3 Health effects of rubidium

2.8.4.3.1 Effects of exposure: Water reactive, Moderately toxic by ingestion. If rubidium ignites, it will cause thermal burns. Rb readily reacts with skin moisture to form rubidium hydroxide, which causes chemical burns of eyes and skin.

2.8.4.3.2 Signs and symptoms of overexposure: Skin and eye burns.Failure to gain weight, ataxia, hyper irritation, skin ulcers, and extreme nervousness. Medical condition aggravated by exposure: heart patients, potassium imbalance.

2.8.4.3.3 First aid: Eye: Immediately flush with running water for 15 minutes while holding eyelid. Obtain medical attention immediately. **Skin:** remove material and flush with soap and water. Remove contaminated clothing. Get medical attention promptly. **Inhalation:** move to fresh air immediately. If irritation persists, get medical attention. **Ingestion:** do not induce vomiting. Get medical attention immediately.

2.8.5 Strontium (Sr)

Strontium is a natural and commonly occurring element. Strontium can exist in two oxidation states: 0 and +2. Under normal environmental conditions, only the +2 oxidation state is stable enough to be important. Pure strontium is a hard, white-colored metal, but this form is not found in the environment. Strontium is usually found in nature in the form of minerals. There are two types of strontium compounds, those that dissolve in water and those that do not. Natural strontium is not radioactive and exists in four stable types (or isotopes), each of which can be written as 84Sr, 86Sr, 87Sr, and 88Sr, and read as strontium eighty-four, strontium eighty-six, etc. Any combination of the four have the same chemical effect on body. Rocks, soil, dust, coal, oil, surface and underground water, air, plants, and animals all contain varying amounts of strontium. Strontium compounds, such as strontium carbonate, are used in making ceramics and glass products, pyrotechnics, paint pigments, fluorescent lights, medicines and other products.

Stable and radioactive strontium compounds in the air are present as dust. Emissions from burning coal and oil increase stable strontium levels in air. Very small dust particles of stable and radioactive strontium in the air fall out of the air onto surface water, plant surfaces, and soil either by themselves or when rain or snow falls. These particles of strontium eventually end up back in the soil or in the bottoms of lakes, rivers, and ponds, where they stay and mix with stable and radioactive strontium that is already there. In water, most forms of stable and radioactive strontium are dissolves, so it is likely to move deeper into the ground and enter groundwater.

The typical concentration of strontium is found naturally in soil is 0.2 mg/kg. The disposal of coal ash, incinerator ash, and industrial wastes may increase the concentration of strontium in soil. Higher concentrations of 90Sr in soil may be found near hazardous waste sites, radioactive waste sites, and Department of Energy facilities.

If a person breathes in vapors or dust containing a chemical form of strontium that is soluble in water, then the chemical will dissolve in the moist surface inside the lungs and strontium will enter the bloodstream relatively quickly. If the chemical form of strontium does not dissolve in water easily, then particles may remain in the lung for a time. Studies in animals suggest that infants may absorb more strontium from the intestines than adults.

Strontium is eliminated from the body through urine, feces, and sweat. Elimination through urine may occur over long periods, when small amounts of strontium are released from bone and do not get recaptured by bone. When strontium is taken in by mouth, the portion that does not pass through the intestinal wall to enter the bloodstream is eliminated through feces during the first day or so after exposure.

The harmful effects of radioactive strontium are caused by the high energy effects of radiation. Since radioactive strontium is taken up into bone, bone itself and the soft tissues nearby may be damaged by radiation released over time. Because bone marrow is the essential source of blood cells, blood cell counts may be reduced if the dose is too high. This has been seen in humans who received injections of radioactive strontium (89Sr) to destroy cancer tissue that had spread to the bone marrow. Radiation damage may also occur from exposure to the skin. Radioactive strontium may cause cancer as a result of damage to the genetic material (DNA) in cells. The international Agency for Research on Cancer (IARC) has determined that radioactive strontium is carcinogenic to humans, because it is deposited inside the body and emits beta radiation. The EPA has determined that radioactive strontium is a human carcinogen.

Excess stable strontium causes problems with growing bone. For this reason, children are more susceptible to the effects of stable strontium than adults who have mature bone. Evidence suggests that stable strontium can be transferred from the mother to nursing infants through breast milk, but the presence of calcium and protein in milk protects against bone problems during nursing.

2.8.6 Titanium (Ti)

Ti can trigger clinically significant hypersensitivity and other immune problems in certain individuals (Vijayaraghavan et al., 2012). Significant radiation scattering can occur when Ti dental implants are irradiated,Titanium dioxide (TiO_2) NPs are considered a possible source of oral toxicity (Bettini and Houdeau, 2014). Inhalation of TiO_2 may increase the risks from respiratory illnesses such as asthma, according to a recent animal study (Jonasson et al., 2013). Animal studies also suggest that TiO_2 NPs can impact liver and heart tissues (Husain et al., 2015; Liu et al., 2009). NPs of TiO_2 can cause risk to the brain and other areas of the body due to oxidative stress (Long et al., 2006). Titanium has been linked to allergic reactions. In 2013, researchers cautioned: “Although titanium is the preferred choice for dental implants as it is an inert material, if used in oral implants, it may encourage toxic or allergic type I or IV reactions” (Chaturvedi, 2013). Allergic reactions have been documented in patients with titanium implants.

2.8.7 Zinc (Zn)

In the periodic table of the elements, zinc can be found in group IIb, together with the two toxic metals cadmium and mercury. Compared to several other metal ions with similar chemical properties, zinc is relatively harmless. Only exposure to high doses has toxic effects. Zn can induce inflammatory cells and protein in lung lavage fluid and DNA synthesis in lung cells (Kulshrestha et al., 2014) Excessive concentration of Zn in food and feed plants are of great concern because of its toxicity to humans and animals (Kabata-Pendias and Mukherjee, 2007). Cultivation of crops for human or livestock consumption can potentially lead to the uptake and accumulation of this metal in edible plant parts with a resulting risk to human and animal health (Lim et al., 2008) (Kulshrestha et al., 2014). Zn may come from the galvanizing factories and to increase the reflective properties. There are two–stroke motorcycles and motorbikes in use and they would also produce Zn from the combusted lubrication oil.

The gastrointestinal tract is directly affected by ingested zinc, before it is distributed through the body. Therefore, multiple gastrointestinal symptoms after oral uptake of zinc have been reported.

Brown et al. described several cases in which high zinc ingestion resulted from storage of food or drink in galvanized containers. Ingestion was caused by the moderately acidic nature of the food or drink, enabling the removal of sufficient zinc from the galvanized coating. The resulting symptoms included nausea and vomiting, epigastric pain, abdominal cramps, and diarrhea [40].

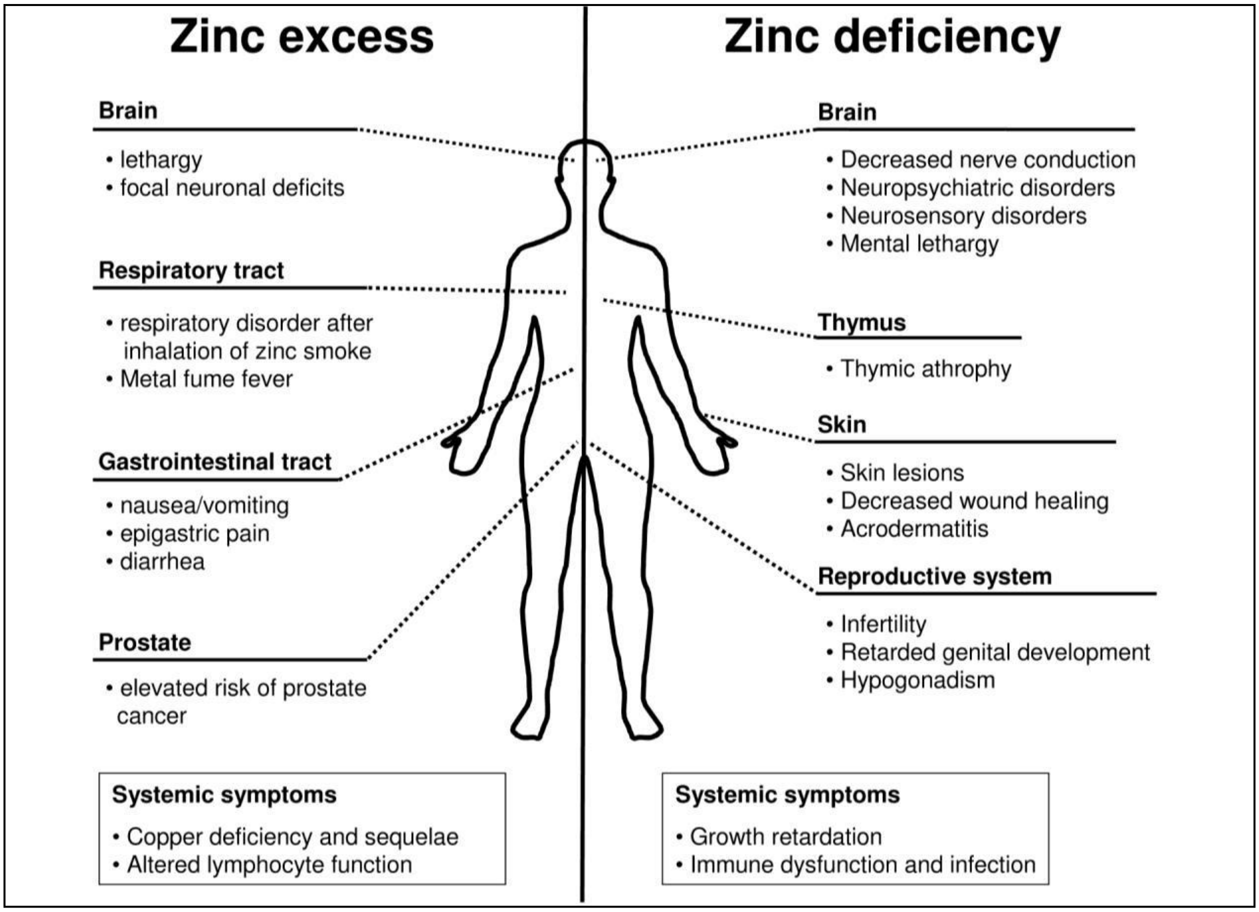


Figure-2.3**:** Comparison of the effects of zinc intoxication *versus* deficiency. Intoxication by excessive exposure to, or intake of, zinc (left hand side), and deprivation of zinc by malnutrition or medical conditions (right hand side), have detrimental effects on different organ systems. Effects that could not be attributed to a certain organ system or affect several organs are classified as systemic symptoms.

2.8.8 Iron (Fe)

2.8.8.1 Nature and sources

Iron is the second most abundant metal on the earth's crust (EPA, 1993). Iron occupies the 26th elemental position in the periodic table. Iron is a most crucial element for growth and survival of almost all living organisms (Valko et al., 2005). It is one of the vital components of organisms like algae and of enzymes such as cytochromes and catalase, as well as of oxygen transporting proteins, such as hemoglobin and myoglobin (Vuori, 1995). Iron is an attractive transition metal for various biological redox processes due to its inter-conversion between ferrous (Fe^{2+}) and ferric (Fe^{3+}) ions (Phippen et al., 2008). The source of iron in surface water is anthropogenic and is related to mining activities. The production of sulphuric acid and the discharge of ferrous (Fe^{2+}) takes place due oxidation of iron pyrites (FeS_2) that are common in coal seams (Valko et al., 2005). The following equations represent the simplified oxidation reaction for ferrous and ferric iron (Phippen et al., 2008):

$2FeS_2 + 7O_2 \rightarrow 2FeSO_4 + H_2SO_4$ (ferrous)

$4FeSO_4 + O_2 + 10H_2O \rightarrow 4Fe(OH)_3 + 4H_2SO_4$ (ferric)

2.8.8.2 Mechanism of iron toxicity

A wide range of harmful free radicals are formed when the absorbed iron fails to bind to the protein, which in turn severely affects the concentration of iron in mammalian cells and biological fluids. This circulating unbound iron results in corrosive effect of the gastrointestinal tract and biological fluids. An extremely higher level of iron enters into the body crossing the rate-limiting absorption step and becomes saturated. These free irons penetrate into cells of the heart, liver and brain. Due to the disruption of oxidative phosphorylation by free iron, the ferrous iron is converted to ferric iron that releases hydrogen ions, thus increasing metabolic acidity. The free iron can also lead to lipid peroxidation, which results in severe damage to mitochondria, microsomes and other cellular organelles (Albretsen, 2006). The toxicity of iron on cells has led to iron mediated tissue damage involving cellular oxidizing and reducing mechanisms and their toxicity towards intracellular organelles such as mitochondria and lysosomes. A wide range of free radicals that are believed to cause potential cellular damage are produced by excess intake of iron. The iron produced hydrogen free radicals attack DNA, resulting in cellular damage, mutation and malignant transformations which in turn cause an array of diseases (Grazuleviciene et al., 2009).

2.8.8.3 Health effects of Iron (Fe)

Fe, has been reported to be the primary determinant of acute inflammatory infection (Kulshrestha et al., 2014) .Inhalation of iron dust has been linked to chronic bronchitis, breathlessness, chronic cough (Xu et al., 1992), chronic phlegm (Chen et al., 2006), pneumoconiosis (Kuo et al.,1998), reduced lung function (Banks et al.,1999), and can lead to chronic obstructive pulmonary disease (COPD) (Driscoll et al., 2005).(K. Mohiuddin et al.)

2.8.9 Lead (Pb)

2.8.9.1 Nature and sources

Lead is a highly toxic metal whose widespread use has caused extensive environmental contamination and health problems in many parts of the world. Lead is a bright silvery metal, slightly bluish in a dry atmosphere. Human activities such as mining, manufacturing and fossil fuel burning has resulted in the accumulation of lead and its compounds in the environment, including air, water and soil. Lead is used for the production of batteries, cosmetics, metal products such as ammunitions, solder and pipes, etc. (Martin and Griswold, 2009). The main sources of lead exposure are lead based paints, gasoline, cosmetics, toys, household dust, contaminated soil, industrial emissions (Gerhardsson et al., 2002). It begins to tarnish on contact with air, thereby forming a complex mixture of compounds, depending on the given conditions. Figure-2.4 shows various sources of lead pollution in the environment (Sharma and Dubey, 2005). The sources of lead exposure include mainly industrial processes, food and smoking, drinking water and domestic sources. The sources of lead were gasoline and house paint, which has been extended to lead bullets, plumbing pipes, pewter pitchers, storage batteries, toys and faucets (Thürmer et al., 2002). In the US, more than 100 to 200,000 tons of lead per year is being released from vehicle exhausts. Some is taken up by plants, fixation to soil and flow into water bodies, hence human exposure of lead in the general population is either due to food or drinking water (Goyer,1990). Lead is an extremely toxic heavy metal that disturbs various plant physiological processes and unlike other metals, such as zinc, copper and manganese, it does not play any biological functions. A plant with high lead concentration fastens the production of reactive oxygen species (ROS), causing lipid membrane damage that ultimately leads to damage of chlorophyll and photosynthetic processes and suppresses the overall growth of the plant (Najeeb et al., 2014).

2.8.9.2 Health effects of Pb

Pb are considered potential carcinogens (Dundar and Altundag, 2006; Massey et al.,2013) and are associated with etiology of a number of diseases, especially cardiovascular, kidney, blood, nerves, and bone diseases (Jarup, 2003). Low levels of Pb also interfere with crucial nuclear functions such as DNA replication, DNA repair and gene expression through competition with nuclear uptake, homeostasis and the function of essential metal ions (Hechtenberg and eyersmann,1995).(Kulshrestha et al., 2014) Lead paint dust is toxic to the nervous system. Lead-contaminated house dust is one factor in childhood lead poisoning.

Motor vehicles are considered the primary source of airborne Pb (Chiaradia et al., 1997; Dundar and Altundag, 2002). It is therefore expected that regions of high Pb in household dust will correspond with areas of high traffic flows. Analysis of household dust by Gulson et al. (1995) in Sydney suggests that lead in ‘‘contaminated’’ households can originate from either gasoline or paint, depending on the proximity to major traffic thoroughfares and Pb in household dust is more consistent with gasoline lead. There has been unprecedented boom in the housing sector which is expected to satisfy the demand for over 30 million new homes; hence, the increased use of lead-based paints. Studies in London concluded that road sources were the largest source of Pb household dust levels (Hunt et al., 1993). Maharachpong et al. (2006) found elevated concentrations of Pb in soils and house dusts in areas surrounding boat yards in southern Thailand. Here, contamination was attributed to residues of plumboplumbic oxide (Pb3O4) used in the caulking mixture applied between wooden planks of the hulls of wooden boats. In the home environment, the authors suggested that boat-repairers tracked in Pb-rich dust on their clothing, skin, hair and shoes. Madany et al. (1994) mentioned the smoking of cigarettes, cosmetics and paint chips resulting in elevated Cd, Zn and Cr content.

A study on lead poisoning in Malaysia (Wan, 1976) disclosed that 76% of workers in a lead storage battery factory had excessively high blood lead levels, while 37.3% were observed to have high urinary-ALA concentrations. Durvasula (1990) also reported high prevalence of lead poisoning, with 67% of the workers in the same branch of industry presenting clinical symptoms.

Lead poisoning was considered to be a classic disease and the signs that were seen in children and adults were mainly pertaining to the central nervous system and the gastrointestinal tract

(Markowitz, 2000). According to the Environmental Protection Agency (EPA), lead is considered a carcinogen. Lead has major effects on different parts of the body. Lead distribution in the body initially depends on the blood flow into various tissues and almost 95% of lead is deposited in the form of insoluble phosphate in skeletal bones (Papanikolaou,2005). Toxicity of lead, also called lead poisoning, can be either acute or chronic. Acute exposure can cause loss of appetite, headache, hypertension, abdominal pain, renal dysfunction, fatigue, sleeplessness, arthritis, hallucinations and vertigo. Acute exposure mainly occurs in the place of work and in some manufacturing industries which make use of lead. Chronic exposure of lead can result in mental retardation, birth defects, psychosis, autism, allergies, dyslexia, weight loss, hyperactivity, paralysis, muscular weakness, brain damage, kidney damage and may even cause death (Martin and Griswold, 2009). Figure-2.4 shows the increase in blood lead concentration affecting a person's IQ (Taylor et al., 2012). Although lead poisoning is preventable it still remains a dangerous disease which can affect most of the organs. The plasma membrane moves into the interstitial spaces of the brain when the blood brain barrier is exposed to elevated levels of lead concentration, resulting in a condition called edema (Teo et al. 1997). It disrupts the intracellular second messenger systems and alters the functioning of the central nervous system, whose protection is highly important. Environmental and domestic sources of lead ions are the main cause of the disease but with proper precautionary measures it is possible to reduce the risk associated with lead toxicity (Brochin et al., 2008).

Figure-2.4: Various sources of lead pollution in the environment

Adapted from Sharma and Dubey,2005

2.8.10 Copper (Cu)

2.8.10.1 Identification and sources

Copper is a reddish metal that occurs naturally in rock, soil, water, sediment, and, at low levels, air. Its average concentration in the earth's crust is about 50 ppm or, stated another way, 50 grams of copper per 1,000,000 grams of soil (1.8 ounces or 0.11 pounds of copper per 2,200 pounds of soil). Copper also occurs naturally in all plants and animals. It is an essential element for all known living organisms including humans and other animals at low levels of intake. At much higher levels, toxic effects can occur. Metallic copper can be easily molded or shaped. The reddish color of this element is most commonly seen in the U.S. penny, electrical wiring, and some water pipes. It is also found in many mixtures of metals, called alloys, such as brass and bronze. Many compounds (substances formed by joining two or more chemicals) of copper exist. These include naturally occurring minerals as well as manufactured chemicals. The most commonly used compound of copper is copper sulfate. Many copper compounds can be recognized by their blue-green color.

Copper can enter the environment through releases from the mining of copper and other metals, and from factories that make or use copper metal or copper compounds. Copper can also enter the environment through waste dumps, domestic waste water, combustion of fossil fuels and wastes, wood production, phosphate fertilizer production, and natural sources such as windblown dust, from native soils, volcanoes, decaying vegetation, forest fires, and sea spray etc. Therefore, copper is widespread in the environment. About 1,400,000,000 pounds (640,000,000,000 grams) of copper were released into the environment by industries in 2000. Copper is often found near mines, smelters, industrial settings, landfills, and waste disposal sites. When copper is released into soil, it can become strongly attached to the organic material and other components (e.g., clay, sand, etc.) in the top layers of soil and may not move very far when it is released. When copper and copper compounds are released into water, the copper that dissolves can be carried in surface waters either in the form of copper compounds or as free copper or, more likely, copper bound to particles suspended in the water. Even though copper binds strongly to suspended particles and sediments, there is evidence to suggest that some water-soluble copper compounds do enter groundwater. Copper that enters water eventually collects in the sediments of rivers, lakes, and estuaries. Copper is carried on particles emitted from smelters and ore processing plants, and is then carried back to earth through gravity or in rain or snow. Copper is also carried into the air on windblown metallurgical dust. Indoor release of copper comes mainly from combustion processes (for example, kerosene heaters). Elemental copper does not break down in the environment. Copper is also found in a range of concentrations in many foods and beverages that we eat and drink, including drinking water. Copper is common in the environment. One may be exposed to copper by breathing air, drinking water, eating food, and by skin contact with soil, water and other copper-containing substances. Most copper compounds found in air, water, sediment, soil and rock are strongly attached to dust and dirt or embedded in minerals. Copper can taken into body upon ingestion of water or soil that contains copper or by inhalation of copper-containing dust.

2.8.10.2 Health effects of Cu

Cu is a carcinogenic transition metal which catalyze the generation of reactive oxygen species that may result in damage to cell membranes, mitochondria, proteins and DNA (Kasprzak, 1995). (Kulshrestha et al., 2014) Excessive concentration of Cu in food and feed plants are of great concern because of its toxicity to humans and animals (Kabata-Pendias and Mukherjee, 2007). Long term exposure to copper dust can irritate nose, mouth, and eyes, and cause headaches, dizziness, nausea, and diarrhea. Intentionally high intakes of copper can cause liver and kidney damage and even death. Cultivation of crops for human or livestock consumption can potentially lead to the uptake and accumulation of this metal in edible plant parts with a resulting risk to human and animal health (Lim et al., 2008). (Kulshrestha et al., 2014)

2.9 Environmental impact of PM.

Farmers claim that dust damage to crops are common. Even very low concentrations of dust can affect plant and fruit growth. Plant growth is especially susceptible to dusts that are highly alkaline, for example, limestone and cement dusts.

2.10 Air Quality Index

In order to have an efficient air quality management (AQM) system and its related regulatory approaches, it is important to have reliable air quality data and understand its temporal and spatial distributions (Begum et al., 2012).

Air Quality Index (AQI) helps in understanding the level at which air is polluted and the associated health effects that might concern.AQI values are derived from air quality data readings, which allows for more meaningful comparison of pollutants affecting air quality. The index is derived using the following formula (according to NSW-Australia EPA)

$$AQI_{pollutant} = (\text{Pollutant data reading/standard}) \times 100$$

The highest AQI value at each site becomes the site AQI. In Bangladesh the AQI is calculated by based on five criteria pollutants, such as PM (PM_{10} and $PM_{2.5}$), NO_X, CO, SO_2 and O_3.The DoE of Bangladesh has set national air quality standards for these pollutants given as below:

Table- 2.1: Approved Air Quality Index (AQI) for Bangladesh

AQI range	Category	Colour	Cautionary Statement
0-50	Good	Green	Little potential to affect public health
51-100	Moderate	Yellow Green	Unusually sensitive individuals
101-150	Caution	Yellow	Identifiable groups at risk-different groups for different pollutants
151-200	Unhealthy	Orange	General public at risk; sensitive groups at greater risk
201-300	Very Unhealthy	Red	General public at greater risk; sensitive groups at greatest risk
301-500	Extremely Unhealthy	Purple	All public at greatest risk

(Source: CASE, 2015)

2.11 Maintaining Indoor Air Quality During Construction and Renovation Projects

Construction and renovation projects present a variety of situations which may release contaminants and pollutants that can impact the indoor air quality (IAQ) of a building. These contaminants may be transported to other areas via the heating, ventilation and air conditioning systems and subsequently affect populations beyond the immediate project area. Advance planning by Project Managers, appropriate contract language, material review and selection processes, and effective control strategies combined with proactive communication efforts can successfully control pollutant levels, allay concerns, and maintain occupant comfort during and after construction activities.

Most building occupants expect to work in a building free of pollutants. Indoor air pollutants are typically complex mixtures of low level contaminants which are difficult to measure. Rather than attempting to quantify levels of contamination which may be present in indoor air, it is more realistic to subjectively approach the issue and attempt to maintain an environment which is perceived to be clean, well ventilated, odor free, and comfortable in terms of temperature.

The Environmental Health and Safety Office staff is available to work with Project Managers during the planning phases to design strategies to control potential hazards and eliminate common concerns associated with construction projects. The following information and recommendations are presented as an overview of the issues to consider in an effort to maintain acceptable indoor air quality. The intent of this guidance document is to increase awareness and to encourage the practice of utilizing the least toxic material suitable for the application.

2.12 Monitoring of air pollutants

2.12.1 Air quality monitoring

Air quality monitoring helps us in better understanding the sources, levels of different air pollutants, effects of air pollution control policy and exposure of various substances in the air we breathe. Air quality monitoring program assists us in improving and developing air pollution control programs to reduce the effect of air pollution. The purpose of air monitoring is not merely to collect data, but also to provide the information necessary for engineers, scientists, policymakers, politicians and planners to make informed decisions on managing and improving the air environment.

The EPA has established ambient air monitoring methods for the criteria pollutants (Six criteria pollutants are: PM, CO,SO_2,NO_2,O_3 and Pb),as well as for toxic organic compounds and inorganic compounds. The methods specify precise procedures that must be followed for any monitoring activity related to the compliance provisions of the Clean Air Act. These procedures regulate sampling, analysis, calibration of instruments, and calculation of emissions. The concentration is expressed in terms of mass per unit volume, usually micrograms per cubic meter ($\mu g/m^3$).

Monitoring stations continuously monitor and collect information about the presence and level of atmospheric contaminants as well as the meteorological indices. A typical monitoring station include sophisticated gaseous pollutant analyzers, particle collectors and weather sensors that are continuously maintained and operated. Minimum number of Monitoring stations is three. The location is dependent upon the wind rose diagram that gives predominant wind directions and speed. One station must be at upstream of predominant wind direction and other two must at downstream pre dominant wind direction. More than three stations can also be established depending upon the area of coverage. The components of an air pollution monitoring system include the collection or sampling of pollutants both from the ambient air and from specific sources, the analysis or measurement of the pollutant concentrations, and the reporting and use of the information collected.

2.12.2 Frequency of data collection

- Gaseous pollutants: continuous monitoring
- Particulates: once every three days

2.12.3 Particulate Monitoring

- Particulate monitoring is usually accomplished with manual measurements and subsequent laboratory analysis.
- A particulate matter measurement uses gravimetric principles. Gravimetric analysis refers to the quantitative chemical analysis of weighing a sample, usually of a separated and dried precipitate.
- In this method, a filter-based high-volume sampler (a vacuum- type device that draws air through a filter or absorbing substrate) retains atmospheric pollutants for further laboratory weighing and chemical analysis. Particles are trapped or collected on filters, and the filters are weighed to determine the volume of the pollutant. The weight of the filter with collected pollutants minus the weight of a clean filter gives the amount of particulate matter in a given volume of air.
- Chemical analysis can be done by atomic absorption spectrometry (AAS), atomic fluorescence spectrometry (AFS), inductively couple plasma (ICP) spectroscopy, and X-ray fluorescence (XRF) spectroscopy.

2.12.4 Gaseous pollutant monitoring

- Gaseous pollutant monitoring can be accomplished by the following most common techniques.
  - Spectrophotometry,
  - Chemiluminescence,
  - Gas Chromatography-Flame Ionization Detector (GC-FID),
  - Gas Chromatography-Mass Spectrometry (GC-MS), and
  - Fourier Transform Infrared spectroscopy (FTIR).

2.13 Pollution reduction

Efforts to reduce air pollution have largely fallen into three categories: a) Regulatory, b) Technological, and c) Economic or Market-based solutions.

2.13.1 Regulatory Solutions: Regulatory solutions involve the passage of laws and the establishment of government agencies which attempt to reduce air pollution through government monitoring and punitive measures (usually fines but, in exceptional cases, criminal sentences as well).

2.13.2 Technological Solutions: This includes the progress in emissions technology (e.g, reformulated gasoline), pre-warmed catalytic converters, and in the extension of emissions rules to trucks and pickup.

2.13.3 Market-based solutions: These solutions allow firms the flexibility to select cost-effective solutions to achieve established environmental goals.

Chapter 3

Research methods

3.1 General

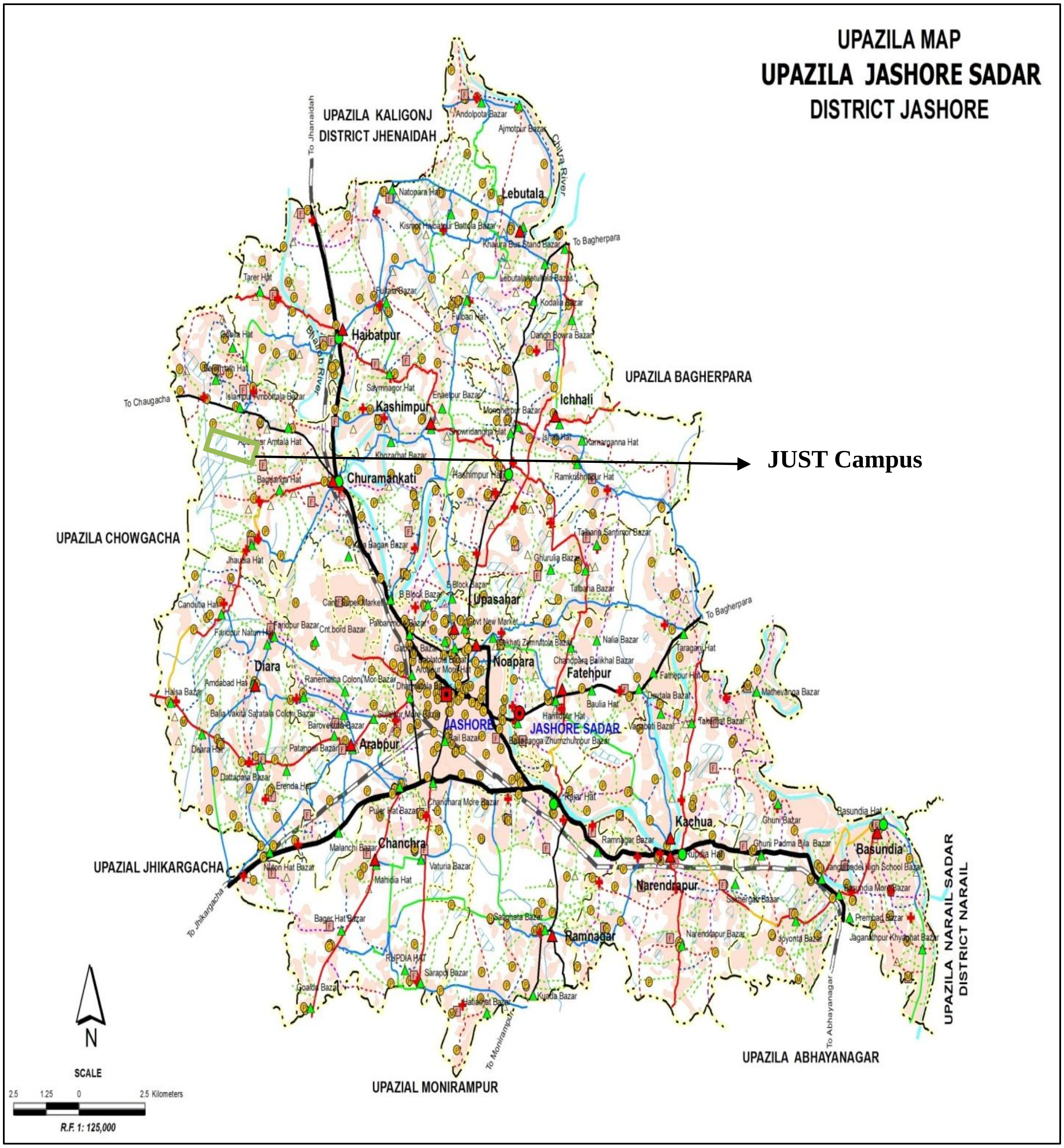
In this chapter the research methods that have been employed in this study to perform the research objectives as stated in section 1.3 has illustrated. This chapter describes the methods of finding elemental composition of indoor particulate matter (PM_{10} and $PM_{2.5}$), their deposition rate, Bioavailability, correlation of elements, concentration of particulate matter (PM_{10} and $PM_{2.5}$) in ambient air and indoor of three buildings of Jashore University of Science and Technology (JUST) campus.

3.2 Meteorological conditions of Bangladesh

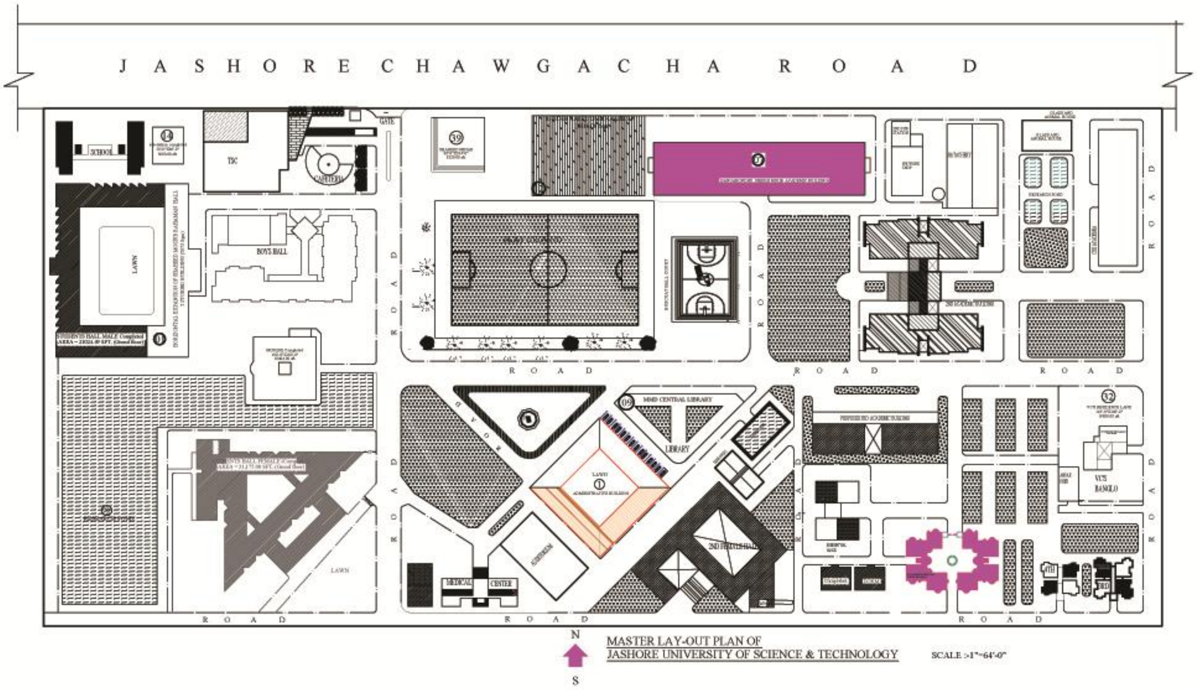
In Bangladesh, the climate is characterized by high temperatures, high humidity most of the year, and distinctly marked seasonal variations in precipitation. According to meteorological conditions, the year can be divided into four seasons, pre–monsoon (March–May), monsoon (June–September), post–monsoon (October–November) and winter (December–February) (Salam et al.,2003).The winter season is characterized by dry soil conditions, low relative humidity, scanty rainfall, and low northwesterly prevailing winds. The rainfall and wind speeds become moderately strong and relative humidity increases in the pre–monsoon season when prevailing direction changes to southwesterly (marine). During monsoon season, the wind speed further increases and the air mass is purely marine in nature. In the post–monsoon season, the rainfall and relative humidity decreases as does the wind speed. The direction starts shifting back to northeasterly.

3.3 Site Description

Jashore University of Science and Technology (JUST) (23°14’0”N/89°07’31”E), with an area of 35.00 acre is located in south-west region of Bangladesh and about 15 Kilometers north west of Jashore Town. This public University is situated at the south side of Jashore-chowgasa road. Academic building is situated near road side, administrative building at middle and 10-storied residential tower building at the south –east side of University campus.



Figure–3.1: Location of JUST campus



Figure–3.2: Master plan of JUST campus

3.4 Sample Collection

Sampling was done at three sites of Jashore University of Science and Technology campus. These are (1) 10-storied residential tower Building (2) Administrative Building and (3) Academic Building.

3.5 Determination of deposition rate

Deposition rate of indoor dust of three buildings was calculated. At first top of some Almirah and File cabinet cleaned and their surface area calculated. The date was noted. After some days the deposited dust collected and weight measured. Then by dividing the weight of dust to the surface area and time (days) the rate of deposition per square feet per day was found.

3.6 Bioavailability test of elements

Bioavailability is defined as the fraction of total element in soil that can be absorbed by a biological target (Shahid et al. 2012b).The degree to which a metal is bio-available depends on its soil mobility.

3.6.1 Iron (Fe)

Bioavailability test of Fe was performed in Environmental Engineering Laboratory of Khulna University of Engineering & Technology (KUET).The test was conducted using Spectrophotometer,Model-DR-2700.Ferrover iron reagent was used to perform the test. At first one gram dust sample was taken in a tube. 100 ml distilled water was used to dilute the sample. Then, a blank sample tube was inserted in the cell of Spectrophotometer to set the zero reading. After that, the diluted dust sample was inserted into the cell. The reaction time was three minutes. Finally, the reading was recorded. By this test we got how much portion of Fe was readily available in the environment.

3.6.2 Arsenic (As)

Bioavailability test of As was performed in Environmental Engineering Laboratory of KUET. The test was conducted using Spectrophotometer, Model-DR-2700. EZ Arsenic reagent was used to perform the test. At first one gram dust sample was taken in a tube. 100 ml distilled water was used to dilute the sample. Then, a blank sample tube was inserted in the cell of Spectrophotometer to set the zero reading. After that, the diluted dust sample was inserted into the cell. The reaction time was three minutes. Finally, the reading was recorded. By this test we got how much portion of As was readily available in the environment.

Figure-3.3: Bioavailability test of Fe and As is performing in the Environmental Engineering Laboratory of KUET

3.7 Determination of PM_{10} and $PM_{2.5}$ in ambient air

3.7.1 Tactical Air Sampler (TAS)

The Mini Vol™ Tactical Air Sampler (TAS) is used for measuring Particulate matter (PM_{10} and $PM_{2.5}$) in ambient air. TAS is a portable ambient air sampler for particulate matter that can also be configured for sampling various air toxics. The Mini Vol™ TAS is ideal for sampling at remote sites or areas without power. The Mini Vol™ TAS features a 7-day programmable timer, a constant flow control system, an elapsed time totalizer, rechargeable battery packs, and an all-weather enclosure.

This is basically a pump controlled by a programmable timer which can be set to make up to six "runs" within 24 hours or throughout a week. It was hunged from a universal mounting bracket mounted on a electric pole. The sampler is equipped to operate from a battery pack.

In the particulate matter (PM) sampling mode, air is drawn through a particle size separator and then through a filter medium. Particle size separation is achieved by impaction. Critical to the collection of the correct particle size is the correct flow rate through the impactor. For the Mini Vol™ TAS, the actual volumetric flow rate must be 5 liters per minute (5 lpm) at ambient conditions. To assure a constant 5 lpm flow rate through the size separator at differing air temperatures and atmospheric pressures, the sampler adjusted for each sampling. Impactors are available with a 10 micron cut-point (PM_{10}) and a 2.5 micron cut-point ($PM_{2.5}$). Operating the sampler without an impactor allows for collection of total suspended particulate matter (TSP). The inlet tube downstream from the filter takes the air to the twin cylinder diaphragm pump. From the pump, air is forced through a standard flow meter where it is exhausted to the atmosphere inside the sampler body. The programmable timer automatically turned the pump off at the end of a sampling period. The sampler then serviced and set up for the next sampling period. Servicing includes removing the filter holder with the exposed filter inside from the sampler, and attaching a new filter holder with a fresh filter and replacing the battery pack with a fully charged pack.

3.7.2 Particulate Matter Sampling Procedure

After the sampler has been assembled, adjusted, verified to be in proper working order, and a filter loaded in the Filter Assembly, the sampler is ready to collect air samples.

1. Carefully transported the sampler to the field site. The sampler finally installed in such a position that the intake upward in an unobstructed area at least 30 cm from any obstacle to airflow.
2. Placed the sampler on a firm level surface.
3. Loosen the inlet tube compression nut and extended the inlet tube to the maximum height and re-tighten the nut. Checked for leaks.
4. Removed the clean Impactor/Filter Holder Assembly from the plastic transport bag or case. Then attached the assembly to the top of the sampler inlet tube.

Figure-3.4: Mini Vol™ Tactical Air Sampler (TAS) is attached in Electric pole near administrative building for sample collection.

5. Recorded the following information on the PM Field Data Sheet: Site ID, number of the filter, the battery ID, sampler ID, ambient temperature and pressure, flow-meter reading, and elapsed time meter reading.

6. Opened the sampler case and obtain the beginning flow rate, then pressed the ON/AUTO/OFF button to start the pump. On the LCD display, the horizontal bar moved to "ON".

7. Using the Flow Rate Adjustment control flow meter within specifications for the project temperature and pressure conditions has set.Then reading of the flow meter taken.

8. Pressed the ON/AUTO/OFF button twice to stop pump.

9. Pressed the ON/AUTO/OFF button to set the timer to "Auto" mode. The Sampler must be in “Auto” mode before the operator leaves if the sampler is to run at a pre-programmed time.

10. Then closed the sampler case.

During particulate matter sampling, the following consumables are needed for proper operation of the MiniVol™ TAS:

Impactor grease- Glisseal ® Ht, Apiezon® M Grease, etc.,47 mm filters - pure quartz, pure Teflon®, Teflon®-coated glass, etc., Petrislides™ - for storage and transport of the filters, A microbalance accurate to one microgram is needed to weigh the filters.

Figure-3.5: Taking reading from Mini Vol™ Tactical Air Sampler (TAS) at JUST campus.

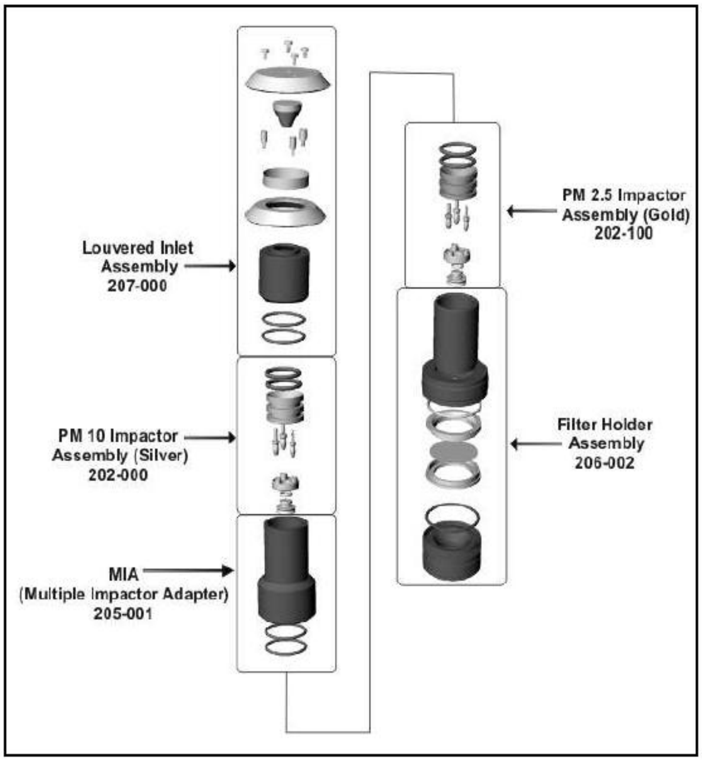


Figure-3.6: $PM_{2.5}$ Impactor/ Filter Holder Assembly

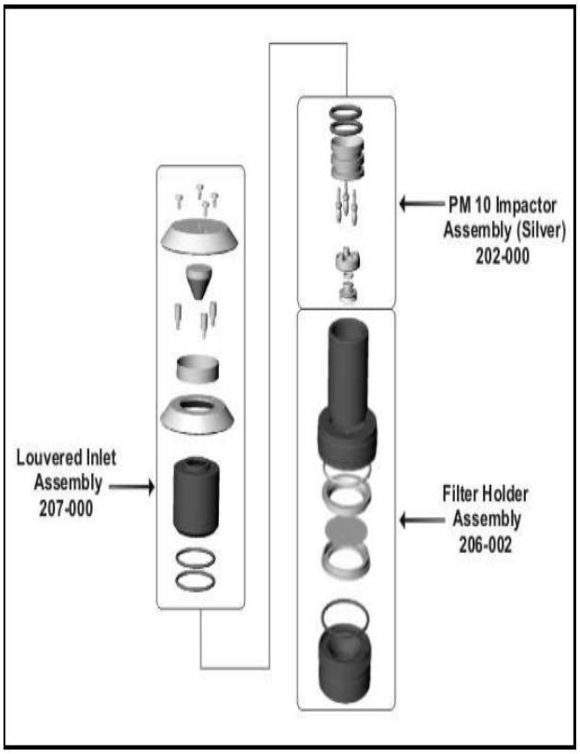


Figure-3.7: PM_{10} Impactor/ Filter Holder Assembly

Impactors are removed from the filter holder assembly prior to sampling.

PM_{10}-PM_{10} impactor is used in the filter holder assembly (Figure-3.7). Greasing and cleaning of the impactor's target disk performed initially and after every sampling.

$PM_{2.5}$ - $PM_{2.5}$ impactor is used in the filter holder assembly and a PM_{10} impactor in a multiple impactor adapter mounted on the filter holder assembly tube (Figure -3.6). Greasing and cleaning of the impactors' target disks performed initially and after every sampling.

3.8 XRF Analysis

XRF Analysis is a fast, accurate and non destructive analytical method to determine the chemical composition of all kinds of materials. X-Ray Fluorescence is the emission of characteristic secondary or fluorescent X-rays from a material that has been excited by bombarding with high energy X-rays or gamma rays (Xrf and sem-eds icdd.e Book, 2016).When high energy photons (X-rays or gamma rays) are absorbed by atoms, inner shell electrons are ejected from the atom, becoming “photoelectrons”. This leaves the atom in an excited state, with a vacancy in the inner shell. Outer shell electrons then fall into the vacancy, emitting photons with energy equal to the energy difference between the two states. Since each element has a unique set of energy levels, each element emits a pattern of X-rays characteristic of the element, termed” characteristic X-rays”. XRF is basically a reference method where calibration standards are required for quantitative analysis. The intensities of characteristic X-ray of unknown samples are compared to those of known (calibration standards) by XRF instruments. The composition of standards must be similar to that of the sample.

Deposited dust sample from 10-storied residential tower, Administrative and Academic building of JUST campus were collected and send to Atomic Energy Centre, Dhaka for XRF analysis. The samples were analyzed using standard analytical XRF Technique.

3.9 SEM Analysis

In SEM Analysis an electron beam is scanned across a samples surface. When the electrons strike the sample; a variety of signals are generated and they produce images or sample’s elemental compositions. The generated three signals i,e secondary electrons, back scattered electrons, and X-rays usually provide the greatest information in SEM analysis. Secondary electrons are emitted from the atoms occupying the top surface and produce a readily interpretable image of the surface morphology of the sample. Back scattered electrons are the beam electrons which are ‘reflected’ from atoms in the solid. The contrast in the image produced is determined by the atomic number of the elements in the sample. The image will therefore show the distribution of different chemical phases in the sample. Interaction of the electron beam with the atoms in the sample causes shell transitions which result in the emission of an X-ray and the emitted X-ray has an energy characteristic of the percent element. Detection and measurement of the energy permits elemental analysis.

3.10 XRD Analysis

XRD is a tool that may afford greater understanding for identifying the atomic and molecular structure of a crystal, in which the crystalline atoms cause a beam of incident X-rays to diffract into many specific directions. By measuring the angles and intensities of these diffracted beams, a crystallographer can produce a three dimensional picture of the density of electrons within the crystal. From this electron density the mean position of the atoms in the crystal can be determined, as well as their chemical bonds, their disorder and various other information.XRD is one of the chief methods for characterizing the atomic structure of new materials and in discerning materials that appear similar by other experiments. The Cambridge Structural Database contains over 800,000 structures as of September 2016; over 99% of these structures were determined by X-ray diffraction (Revolvy, 2016).

3.11 FTIR Analysis

FTIR is a technique which is used to obtain an infrared spectrum of absorption or emission of a solid, liquid or gas. A FTIR spectrometer simultaneously collects high spectral resolution data over a wide spectral range. The term Fourier transform infrared spectroscopy originates from the fact that a Fourier transform (a mathematical process) is required to convert the raw data into the actual spectrum. The goal of this analysis is to measure how well a sample absorbs light at each wave length. A molecule absorbs electromagnetic radiation with characteristic frequencies and this ‘characteristic frequencies’ is used to identify molecules or specific groups present in a compound or sample. Sending electromagnetic radiation of known frequency through the sample and measuring the change in intensity of the radiation provides the characteristic wave numbers of an infrared (IR) spectrum. The IR spectra are usually presented as plots of intensity versus wave number. Two substances absorbing at the same wave numbers are most likely identical. An IR spectrum represents a fingerprint of a sample. As each different material is a unique combination of atoms and no two compounds produce the exact same infrared spectrum. In addition; the size of the peaks in the spectrum is a direct measurement of the amount of material present. Therefore infrared spectroscopy is an excellent tool for quantitative analysis with modern software algorithm.

Appropriate quantity of potassium bromide (KBr) and sample (in the ratio100:0.1) were mixed by grinding in an agate morter. Pellets were made with about 100mg mixture. FT-IR spectra were recorded with FT-IR 8400S Shimadzu spectrophotometer in the range of 4000-400cm^{-1}. Resolution: 4cm^{-1}; No. of scans: 30 times.

Chapter 4

Results and Discussion

4.1General

This chapter presents the rate of deposition of indoor dust per square feet per day in10-storied residential tower, Administrative and Academic building of JUST campus. Bio-availability test of elements, the XRF, XRD, SEM and FTIR analysis of deposited dust sample of three buildings were determined. PM_{10} and $PM_{2.5}$ in ambient air at indoor and outdoor of the buildings also determined using Tactical Air sampler (TAS).

4.2 Rate of deposition of dust in indoor

The Deposition rate of indoor dust measured is as follows:

Table- 4.1: Indoor dust deposition rate

Name of Building	Deposition rate
10-storied residential tower building	2.57 mg/sft/day
Administrative building	1.31 mg/sft/day
Academic building	3.62mg/sft/day

From table -4.1; it is seen that highest dust deposition observed in Academic building because it is situated in road side and construction work (Vertical extension of building) is going on near the building.

4.3 Bioavailability test Result

The test results for bioavailability are shown in table 4.2. The bioavailability of Iron (Fe) was observed highest in Academic Building (0.05 mg/l). Then 10- storied residential Tower Building 0.03 mg/l and in Administrative Building 0.02 mg/l. Bioavailability test of Arsenic(As) was also performed but no Arsenic content was bio-available.

Table-4.2: Bioavailability of Fe

Name of Building	**Bioavailability of Fe**(mg/l)
10- storied residential Tower Building	0.03
Administrative Building	0.02
Academic Building	0.05

4.4 XRF Analysis

Elemental analysis by XRF of dust sample was performed in Atomic Energy Centre, Dhaka (AECD),Bangladesh.The result is shown below.

Table-4.3: XRF analysis

Sample ID	Parameter	Result(ppm)
10-storied residential Tower	K	9940±863
	Ca	29390±5006
	Ti	3708±412
	Fe	38355±3472
	Cu	28.75±6.08
	Zn	226±16
	As	8.31±0.06
	Rb	133±8
	Sr	161.10±12
	Zr	249±19
	Pb	176±10

Sample ID	Parameter	Result(ppm)
Administrative Building	K	6977±86
	Ca	54490±2022
	Ti	3115±37
	Fe	41590±1018
	Cu	16.29±4.96
	Zn	378±13
	As	9.55±0.93
	Rb	125±8
	Sr	205.97±2.12
	Zr	246.60±15.75
	Pb	134.22±19.13

Sample ID	Parameter	Result(ppm)
Academic Building	K	9948±14
	Ca	61340±919
	Ti	3322±574
	Fe	41360±71
	Cu	33.92±2.98
	Zn	350±11
	As	9.64±0.39
	Rb	134.50±5.37

	Sr	203.49±4.09
	Zr	196.52±2.35
	Pb	667±0.19

From XRF analysis eleven elements were found in dust samples out of which seven (Ti, Fe, Cu,Zn,As,Zr,Pb) are heavy metals. Ca was found maximum in academic building because construction work was going on adjacent to this building, cement is used for construction and Ca comes from cement dust. Pb, which is a highly toxic metal, was also found highest in academic building because this building was situated near road. The sources of Pb may be due to Pb based paints, gasoline, vehicle emission from nearby road and contaminated soil.

4.5 Inter elemental correlation

Inter elemental correlation was calculated from the data found by XRF analysis. Table -4.4 shows the correlation matrix of K,Ca,Ti, Fe, Cu, Zn,As, Rb, Sr and Zr for coarse (PM_{10}), and fine ($PM_{2.5}$) particles obtained from the 10-storied residential tower, Administrative, and Academic Building of Jashore University of Science and Technology(JUST) campus and the value represents the linear coefficient of correlation (R^2) between two elements. The sources which contribute to the atmospheric elemental loads around the sampling sites were qualitatively identified from the correlation matrix. The results show that K and Rb have a very high correlation (R^2>0.98), K and Cu have a high correlation (R^2>0.92) in particles which demonstrates that the air particles most likely originated from the same source. Cu is usually emitted in the environment through combustion of fuel.

Table-4.4: inter elemental co-relation of elements

	Pb	Zr	Sr	Rb	As	Zn	Cu	Fe	Ti	Ca
K	.32	.22	.29	**.98**	.20	.41	**.92**	.30	.59	.10
Ca	.37	.48	**.94**	.03	**.98**	.86	00	**.93**	.72	
Ti	.01	.04	**.91**	.44	.84	**.97**	.31	**.92**		
Fe	.14	.23	1	.18	**.98**	**.99**	.09			
Cu	.60	.49	.08	**.98**	.03	.16				
Zn	.08	.14	**.98**	.27	**.95**					
As	.24	.34	**.99**	.10						
Rb	.46	.35	.17							
Sr	.15	.24								
Zr	**.99**									

Ca shows very high correlation with Sr (R^2 >0.94), with As (R^2>0.98) and with Fe (R^2 > 0.93) which means Ca, Sr,As and Fe originates from the same source. Ti has strong correlation with Sr (R^2 > 0.91), Zn (R^2 > 0.97) and Fe (R^2 > 0.92) which indicates these three elements originated from the same source.

Fe has strong correlation with As (R^2 > 0.98) and Zn (R^2>0.99). Cu has strong correlation with Rb (R^2>0.98). Zn has strong correlation with Sr (R^2 > 0.98) and As (R^2 > 0.95). As has strong correlation with Sr (R^2 > 0.99) and Zr has very strong correlation with Pb (R^2 > 0.99).

Fe, As and Zn show strong correlation, therefore these metals are also originated from outdoor dust. Zn normally originates from tyres, lubricating oils and the usage of motor vehicle brakes while Fe is in the re-suspended road dust.

4.6 FTIR Analysis

The sampled particles were assessed using Fourier Transform Infra-Red (FTIR) technique. The FTIR analysis aims here to determine the chemical compositional analysis of dust particles according to their absorption capacity of infra-red light of a sample at each wavelength. The frequency where atoms bonded together (commonly referred to as “functional groups”) absorb correspond to the strength of the bond; stronger bonds absorb at higher frequencies, vice-versa. Every functional group absorbs at its own frequency, making it possible to elucidate chemical structure of a material from its IR spectrum. FTIR technique is used to determine the dominant functional groups. This study revealed variable distributions between and among bonding groups. The hydroxyl (–OH) group (in alcohol compounds, surface OH on crystals, salt hydrate), aliphatic carbon ($–CH_2$) group (in methylene compounds, n- alkane), carbonyl (–CO) group (in acid halide, aryl carbonate, ketone, conjugated ketone), and amino ($–NH_2$) group (in primary amino compounds such as n-butylamine) in atmospheric particles were identified and most likely originated from combustion processes (industrial, transport, and domestic), sea spray, long range transport particles. Organic compounds (carbonaceous and nitrogenous molecules) in atmospheric particles can have negative impacts on human health (Dockery et al., 1993; Alcock, 2003; Shah and Balkhair, 2011), ecosystem (Cupr et al., 2013) and the radiation balance (Hallquist et al., 2009; Ehn et al., 2014).These compounds can be generated from both natural (secondary organic particles from biogenic sources) and anthropogenic (industrial process, vehicle exhaust, wood heaters) sources.

The spectra of the size resolved atmospheric particles collected from 10-storied residential tower, Administrative and Academic Building of JUST campus are shown in Figure- 4.1, 4.2 and 4.3.The qualitative absorbance frequencies in the PM_{10} and $PM_{2.5}$ size particles at all studied sites are presented in Table-4.5.The interpretation of the spectra was limited to the selected organic absorbance groups as mentioned below.

4.6.1 Aliphatic Carbon (–CH_2) Group

The aliphatic carbon molecules can constitute of –CH_3, –CH_2, and –CH carbon bonds which may include n-alkanes, branched alkanes, carbonyl containing molecules, alkanes and aromatics aliphatic substituents (Roos,1997). The simple C-H stretching vibrations for saturated aliphatic species occur at 2800-3000 cm^{-1}, and the corresponding simple bending vibrations nominally occur at 1300 -1500 cm^{-1}(John Coates, 2000). The absorption at 2862.36 and 2926.01 cm^{-1} (10-storied residential Tower), 2854.65 and 2924.09 cm^{-1} (Administrative Building) and 2856.58 and 2926.01 cm^{-1} (Academic Building) is attributed to –CH_2 asymmetric vibration. This aliphatic carbon bond was identified in the atmospheric particles (PM_{10} and $PM_{2.5}$) at all three sampling sites. The stretching vibration at 2800–3000 cm^{-1} was selected for the relative quantification of the –CH_2 group.

4.6.2 Hydroxyl (–OH) Group

Hydroxyl group mainly occurs at the 3250–3650 cm^{-1} absorption range. Moderate to strong, and broad stretching vibrations were observed at 3439.08, 3421.72 and 3419.79 cm^{-1} in this study (Table-4.5,Figure-4.1,4.2,4.3) which may be depicted as free OH and hydrogen bonding of an alcohol functional group (Coates, 2000) in addition to the IR bands of surface OH on crystals and salt hydrates. Moderate bending vibrations were also found in the region of 1400–1500 and 1000–1050 cm^{-1} which can be assigned to OH bending of phenol or tertiary alcohol (Coates, 2000). Thus, aromatic compounds with OH groups, such as phenol, could exist in atmospheric particles. From the structural point of view, these alcohols may be derived by replacing the H–atoms from a parent water molecule by a C–based alkyl group. The structural modification of organic compounds, such as alcohol and ether, may also result in significant changes in physical and chemical properties of these compounds, depending on their hydroxyl content and ability to participate in the H–bonding. The surfaces of crystals are also covered with hydroxyl groups, the vibration of which may appear at 3250–3650 cm^{-1}.In addition, water strongly adsorbed on aerosol salts absorbs at 1600–1700 cm^{-1} and broadly at 3100–3600 cm^{-1} (Allen, 1994).The vibrations at 3250–3650 cm^{-1} were used to calculate the relative quantity of organic –OH group in the atmospheric particles by subtracting fraction of inorganic –OH groups from goethite (FeO_2H) and halite.

Table- 4.5: Absorbance observed in the FTIR spectra of PM

Functionality		Absorption frequencies	Sampling site	Peaks observed
-CH_2	Aliphatic carbons	2800-3000 1300-1500	RtBl	2862.36, 2926.01 1433.11,1467.83
			AdBl	2854.65,2924.09 1382.96,1433.11
			AcBl	2856.58,2926.01 1382.96,1433.11
-OH	Hydroxyl	3250-3650 1400-1450 1000-1050	RtBl	3439.08 1433.11 1037.70
			AdBl	3421.72 1433.11 1035.77
			AcBl	3419.79 1433.11 1043.49
-NH_2	Amino	3300-3500 1550-1650 660-900	RtBl	3439.08 1627.92 682.80,773.46
			AdBl	3421.72 1625.99 682.80,771.53
			AcBl	3419.79 1627.92 677.01,773.46
-CO	Carbonyl carbons	1650-1850	RtBl	1656.85,1807.30
			AdBl	-
			AcBl	1656.85,1807.30

*RtBl-10-storied residential tower Building, AdBl-Administrative Building, AcBl- Academic Building

Table- 4.6: Aliphatic organohalogen compound group frequencies

Origin	Group frequency, Wave number(cm^{-1})	Sampling site	Peaks observed	Tentative assignment
C-F	1000-1150	RtBl	1037.70	Aliphatic fluoro compounds, C-F stretch
		AdBl	1035.77	
		AcBl	1043.49	
C-Cl	700-800	RtBl	773.46	Aliphatic chloro compounds, C-Cl stretch
		AdBl	771.53	
		AcBl	773.46	
C-Br	600-700	RtBl	682.80	Aliphatic bromo compounds, C-Br stretch
		AdBl	682.80	
		AcBl	677.01	
C-I	500-600	RtBl	-	Aliphatic iodo compounds, C-I stretch
		AdBl	-	
		AcBl	596.00	

Table-4.7: Group frequencies of common inorganic ions

Group frequency, Wave number(cm^{-1})	Sampling site	Peaks observed	Functional group/ assignment
860-880 1410-1490	RtBl	1433.11,1467.83	Carbonate ion
	AdBl	1433.11	
	AcBl	1433.11	
610-680 1080-1130	RtBl	-	Sulfate ion
	AdBl	-	
	AcBl	677.01,1107.14	
1000-1100	RtBl	1037.70	Phosphate ion
	AdBl	1035.77	
	AcBl	1043.49	
900-1100	RtBl	1037.70	Silicate ion
	AdBl	1035.77	
	AcBl	1043.49	

Table-4.8: Common group frequencies for thiols and thio-substituted compounds

Group frequency, Wave number(cm^{-1})	Sampling site	Peaks observed	Functional group/ assignment
670-715	RtBl	682.80	Aryl thioethers,Ø-S (C-S stretch)
	AdBl	682.80	
	AcBl	677.01	
570-705	RtBl	682.80	Disulfides (C-S stretch)
	AdBl	682.80	
	AcBl	596.00,677.01	
430-500	RtBl	470.63	Aryl disulfides (S-S stretch)

	AdBl	468.70	
	AcBl	470.63	
470-500	RtBl	470.63	Polysulfides (S-S stretch)
	AdBl	468.70	
	AcBl	470.63	

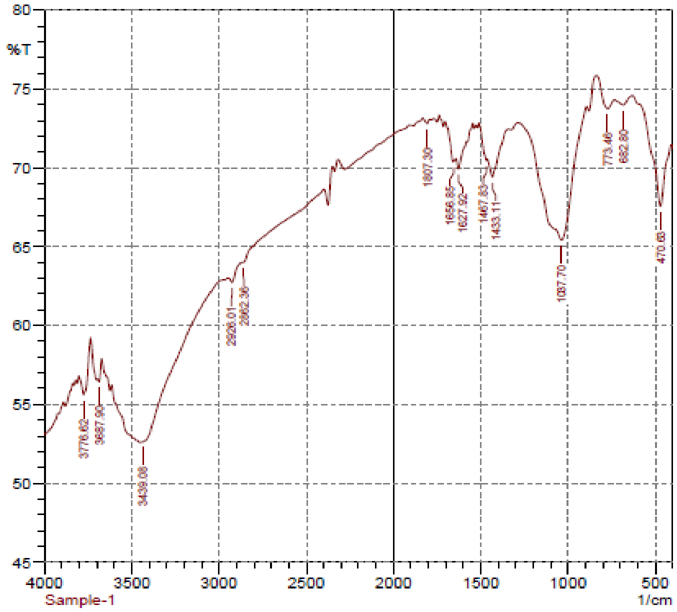
Table-4.9: Functional group assignment of observed frequencies

Name of Building	FTIR spectra at peak	Functional group/Assignment
10-storied residential tower	470.63	Aryl disulfides (S-S stretch)/ Polysulfides (S-S stretch)
	682.80	Alcohol, OH out-of-plane bend/Aliphatic bromo compounds, C-Br stretch/Aromatic C-H out-of-plane bend
	773.46	Skeletal C-C vibrations/ Aromatic C-H out-of-plane bend
	1037.70	Cyclohexane ring vibrations/ Aromatic C-H in-plane bend
	1433.11	C-H bending
	1467.83	Methyl C-H asymmetric bend Aromatic ring stretch
	1627.92	Alkenyl C=C stretch/ Open-chain azo (-N=N-)
	1656.85	Alkenyl C=C stretch
	1807.30	Transition metal carbonyls
	2862.36	Methyl C-H symmetric stretch
	2926.01	C-H stretching of alkanes
	3439.08	Hydroxy group, H-bonded OH stretch/ Heterocyclic amine, NH stretch
	3687.90	Stretching vibration of O-H(alcohol)
	3776.62	O-H Stretching mode
Administrative Building	468.70	Aryl disulfides (S-S stretch)
	682.80	Alcohol, OH out-of-plane bend/ Aliphatic bromo compounds, C-Br stretch/ Aromatic C-H out-of-plane bend
	771.53	Skeletal C-C vibrations/ Aromatic C-H out-of-plane bend
	1035.77	Cyclohexane ring vibrations
	1382.96	Phenol or tertiary alcohol, OH bend/ organic sulfates
	1433.11	C-H bending
	1625.99	Alkenyl C=C stretch/Open-chain azo (-N=N-)
	2854.65	Methylene C-H symmetric stretch
	2924.09	Methylene C-H asymmetric stretch
	3421.72	Hydroxy group, H-bonded OH stretch/ Heterocyclic amine, NH stretch
	3693.68	Stretching vibration of O-H(alcohol)
	3774.69	O-H Stretching mode
	3876.92	O-H Stretching mode
Academic Building	470.63	Aryl disulfides (S-S stretch)/ Polysulfides (S-S stretch)
	596.00	Alcohol, OH out-of-plane bend
	677.01	Alcohol, OH out-of-plane bend/Aliphatic bromo compounds, C-

		Br stretch/ Aromatic C-H out-of-plane bend
	773.46	Skeletal C-C vibrations/ Aliphatic chloro compounds, C-Cl stretch/ Aromatic C-H out-of-plane bend
	1043.49	Cyclohexane ring vibrations
	1107.14	C-H stretching band/Organic siloxane or silicone (Si-O-C)
	1382.96	Phenol or tertiary alcohol, OH bend/organic sulfates
	1433.11	C-H bending
	1627.92	Alkenyl C=C stretch/Open-chain azo (-N=N-)
	1656.85	Alkenyl C=C stretch
	1807.30	Transition metal carbonyls
	2856.58	Methylene C-H symmetric stretch
	2926.01	C-H stretching of alkanes
	3419.79	Hydroxy group, H-bonded OH stretch/ Heterocyclic amine, NH stretch
	3687.90	Stretching vibration of O-H(alcohol)
	3776.62	O-H Stretching mode

SHIMADZU

CARS, DU



	Peak	Intensit	Corr. In	Base (H	Base (L	Area	Corr. Ar
1	470.63	67.538	4.768	634.58	408.91	32.924	2.078
2	682.8	73.967	0.484	732.95	634.58	12.741	0.135
3	773.46	73.737	1.169	837.11	732.95	13.347	0.377
4	1037.7	65.404	8.103	1286.52	893.04	62.538	9.628
5	1433.11	69.403	1.615	1462.04	1342.46	17.899	0.476
6	1467.83	70.459	0.376	1510.26	1462.04	7.046	0.078
7	1627.92	69.908	0.951	1643.35	1581.63	9.284	0.15
8	1656.85	70.38	0.402	1703.14	1651.07	7.558	0.039
9	1807.3	72.804	0.308	1834.3	1791.87	5.805	0.037
10	2862.36	63.999	0.06	2868.15	2399.45	83.065	-0.628
11	2926.01	62.734	0.561	2949.16	2868.15	16.063	0.089
12	3439.08	52.612	0.139	3444.87	2989.66	107.224	-2.11
13	3687.9	56.432	0.821	3701.4	3674.39	6.629	0.088
14	3776.62	55.589	2.182	3803.63	3736.12	16.622	0.65

Comment;
Sample-1

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Apodization;

Figure-4.1: FTIR analysis of particles of 10-storied residential tower

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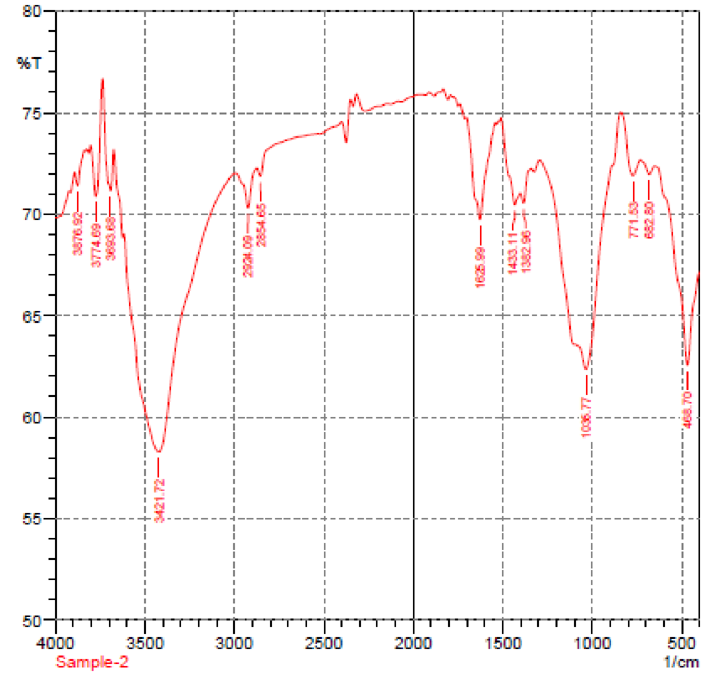
CARS, DU



	Peak	Intensit	Corr. In	Base (H	Base (L	Area	Corr. A
1	468.7	62.571	5.993	651.94	399.26	42.781	3.169
2	682.8	71.959	0.528	732.95	651.94	11.408	0.104
3	771.53	71.898	1.605	840.96	732.95	14.761	0.528
4	1035.77	62.357	4.042	1099.43	840.96	44.211	2.661
5	1382.96	70.548	0.876	1402.25	1342.46	8.753	0.091
6	1433.11	70.456	0.826	1510.26	1421.54	12.591	0.318
7	1625.99	69.727	4.898	1705.07	1543.05	22.9	2.302
8	2854.65	71.868	0.538	2875.86	2640.55	31.775	-0.334
9	2924.09	70.308	1.859	2993.52	2875.86	17.158	0.475
10	3421.72	58.287	11.683	3618.46	2993.52	115.895	21.058
11	3693.68	71.14	0.915	3703.33	3674.39	4.172	0.102
12	3774.69	70.864	3.98	3803.63	3738.05	9.053	0.867
13	3876.92	71.396	1.013	3894.28	3842.2	7.39	0.143

Comment;
Sample-2

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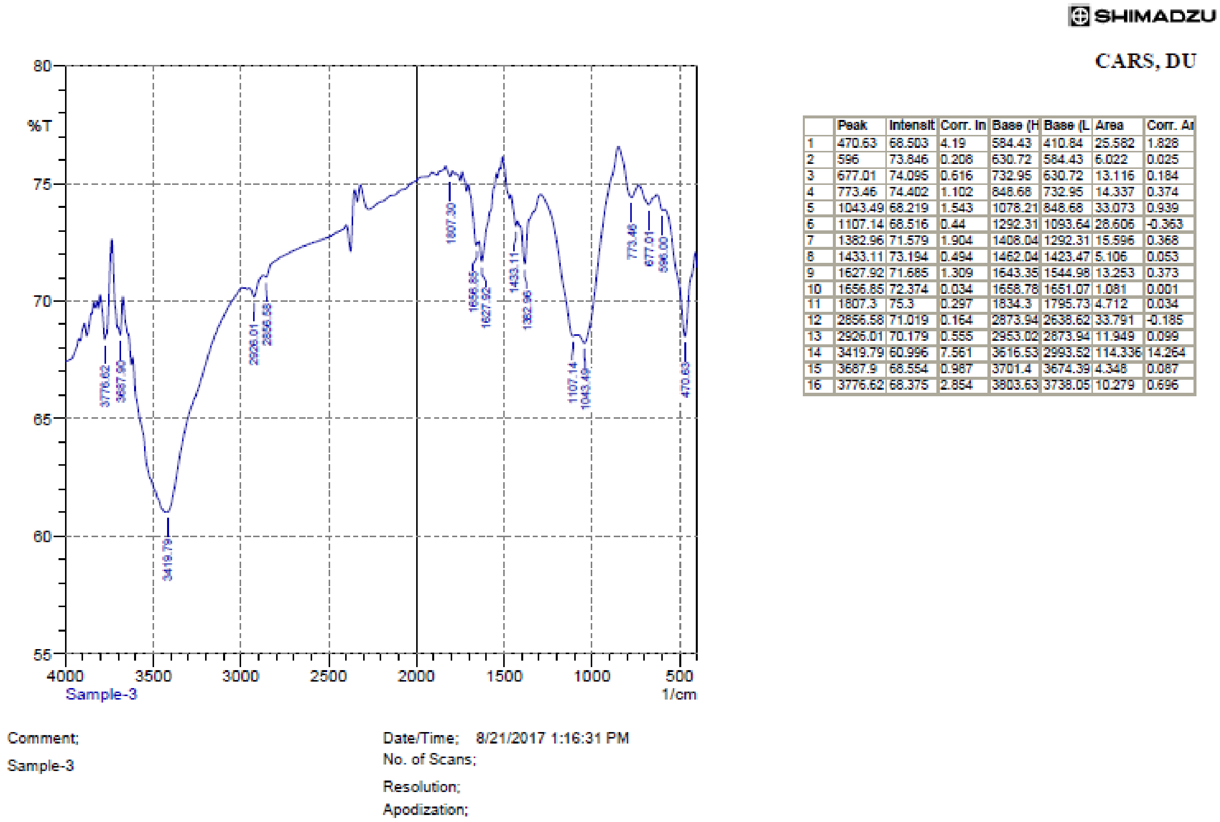
Figure-4.2: FTIR analysis of particles of Administrative building



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CARS, DU

	Peak	Intensit	Corr. In	Base (H	Base (L	Area	Corr. Ar
1	470.63	68.503	4.19	584.43	410.84	25.582	1.828
2	596	73.846	0.208	630.72	584.43	6.022	0.025
3	677.01	74.095	0.616	732.95	630.72	13.116	0.184
4	773.46	74.402	1.102	848.68	732.95	14.337	0.374
5	1043.49	68.219	1.543	1078.21	848.68	33.073	0.939
6	1107.14	68.516	0.44	1292.31	1093.64	28.606	-0.363
7	1382.96	71.579	1.904	1408.04	1292.31	15.596	0.368
8	1433.11	73.194	0.494	1462.04	1423.47	5.106	0.053
9	1627.92	71.685	1.309	1643.35	1544.98	13.253	0.373
10	1656.85	72.374	0.034	1658.78	1651.07	1.081	0.001
11	1807.3	75.3	0.297	1834.3	1795.73	4.712	0.034
12	2856.58	71.019	0.164	2873.94	2638.62	33.791	-0.185
13	2926.01	70.179	0.555	2953.02	2873.94	11.949	0.099
14	3419.79	60.996	7.561	3616.53	2993.52	114.336	14.264
15	3687.9	68.554	0.987	3701.4	3674.39	4.348	0.087
16	3776.62	68.375	2.854	3803.63	3738.05	10.279	0.696

Comment;
Sample-3

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Apodization;

Figure-4.3: FTIR analysis of particles of Academic building

4.6.3 Amino (–NH_2) Group

Amino (–NH_2) group is regarded as an amino substituent derived from ammonia (NH_3), and has similar sp^3 structural features. Amino (–NH_2) group can occur in different vibrations from 3300–3500, 1550–1650 and 660–900 cm^{-1}. It appears that weak N–H bond overlapped and disappeared when the strong O–H bond was identified in 3300–3500 cm^{-1}. The medium to strong bending vibration at 1627.92, 1625.99 and 1627.92 cm^{-1} (Table -4.5, Fig- 4.1, 4.2,4.3) was attributed to the –NH_2 scissoring, and vibration at 677.01,682.80,771.53,773.46, cm^{-1} was assigned to NH_2 wagging, indicating these organic compounds may originate from the primary amino compounds in addition to the IR bands of organonitrates, such as $RONO_2$, which may also absorb around 1631 cm^{-1} (Allen et al., 1994).Organonitrates are expected to contribute for the secondary organic aerosol formation. This group was mainly observed in the particles at all three sampling sites. The bending vibration at 1600– 1660 cm^{-1} was selected for relative quantification of the organic –NH_2 group by subtracting the relative contribution of organonitrates in atmospheric particles (≤ 0.1 μm).

4.6.4 Carbonyl (–CO) Group

The structural features of the carbonyl group can be found in several classes of organic compounds which impose very specific planar geometry associated with sp^2 hybridised carbon and oxygen, such as aldehyde (R–COH), ketone (R–CO–R) and carboxylic acid (R–COOH). This group can blend with other functional groups resulting in properties and reactivities of combined functional groups. Carbonyl group can appear in a broad frequency range of 1640–1850 cm^{-1} (10-storied residential tower, Academic building) with specific peaks from low to high frequencies depending on various functional groups from amide to open-chain acid anhydride. The absorption bands found at 1656.85 cm^{-1} and 1807.30 cm^{-1} match well with the reactive carbonyl compound (acid halide and aryl carbonate), simple carbonyl compound (ketone) and conjugated carbonyl compound (conjugated ketone), respectively, (Coates, 2000) in the particles for 10-storied residential tower and Academic building .

Table-4.10: Assignment of Infrared Absorption frequencies of the collected samples.

Name of samples		FTIR spectra at peak	Tentative Assignment
Quartz (900-1100cm^{-1} and 400-800cm^{-1})	10-storied residential tower building	470.63,682.80,773.46, 1037.70	Si-O symmetric bending, Si-O symmetric stretching.
	Administrative building	468.70,682.80,771.53, 1035.77	
	Academic building	470.63,596.00,677.01, 773.46,1043.49	
Calcite (1400-1450cm^{-1})	10-storied residential tower/Administrative/ Academic building	1433.11	doubly degenerate asymmetric Stretching, CO_3 stretching, C=O stretching,combinational mode, O-H stretching.
Asbestos (900-1200cm^{-1})	10-storied residential tower	1037.70	Si-O stretching mode vibration.
	Administrative building	1035.77	
	Academic building	1043.49,1107.14	

4.7 XRD analysis

The XRD analysis was done for the collected indoor dust sample of three buildings of JUST to determine their mineral constituents. Different figures are showing below the XRD pattern of the collected samples. The predominant presence of alite,belite,quartz, and calcite minerals was found in XRD analysis. The collected samples confirmed their typical mineral existence. It is also revealed the existence of α-quartz i,e crystalline silica in dust sample.

The primary diffraction line for α-quartz is 26.66^0 at 2θ (3.343D) (NIOSH, 2003).The XRD analysis showed peaks at 26.8962^0(10-storied residential tower), 27.1920^0(Administrative building) and 26.8735^0(Academic building) at 2θ which signifies the presence of crystalline silica.

XRD analysis was done in Atomic Energy Centre, Dhaka.

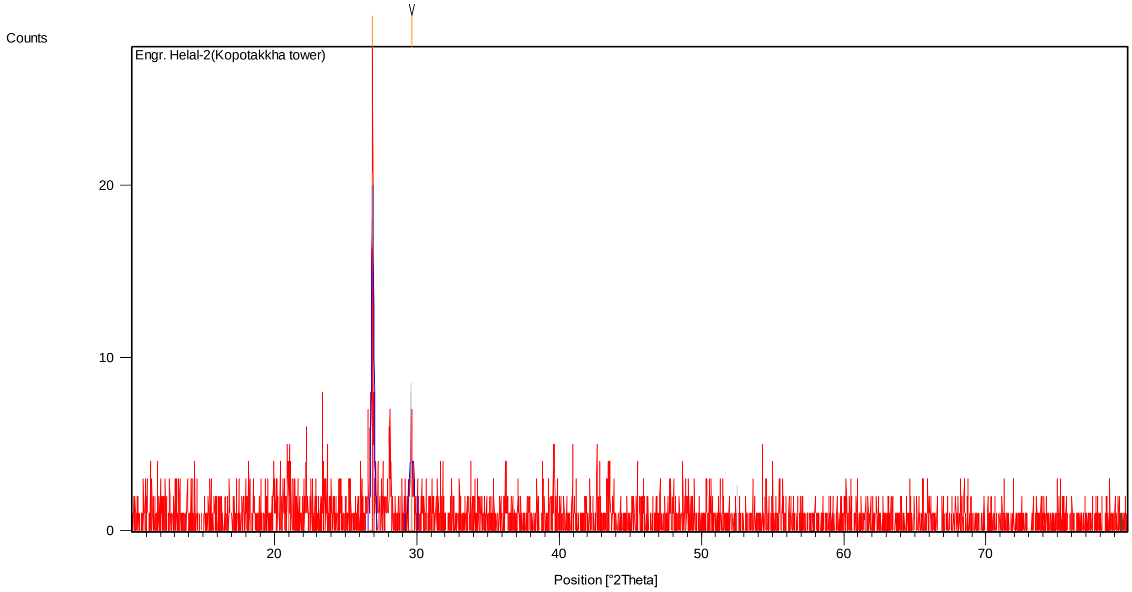

Figure-4.4: XRD analysis of 10-storied residential tower

Peak List:

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing [Å]	Rel. Int. [%]
26.8962	20.69	0.1574	3.31494	100.00
29.6350	3.92	0.4723	3.01452	18.95

Pattern List:

Visible	Ref. Code	Score	Compound Name	Displacement [°2Th.]	Scale Factor	Chemical Formula
*	01-083-2467	26	Quartz, syn	0.000	0.585	SiO_2

The XRD pattern of deposited indoor dust of 10-storied residential tower illustrated the presence of Liottite (code:LIO) (Score:26.8962^0 at 2θ) and Li-ABW(code:ABW) (Score: 29.6350^0 at 2θ)

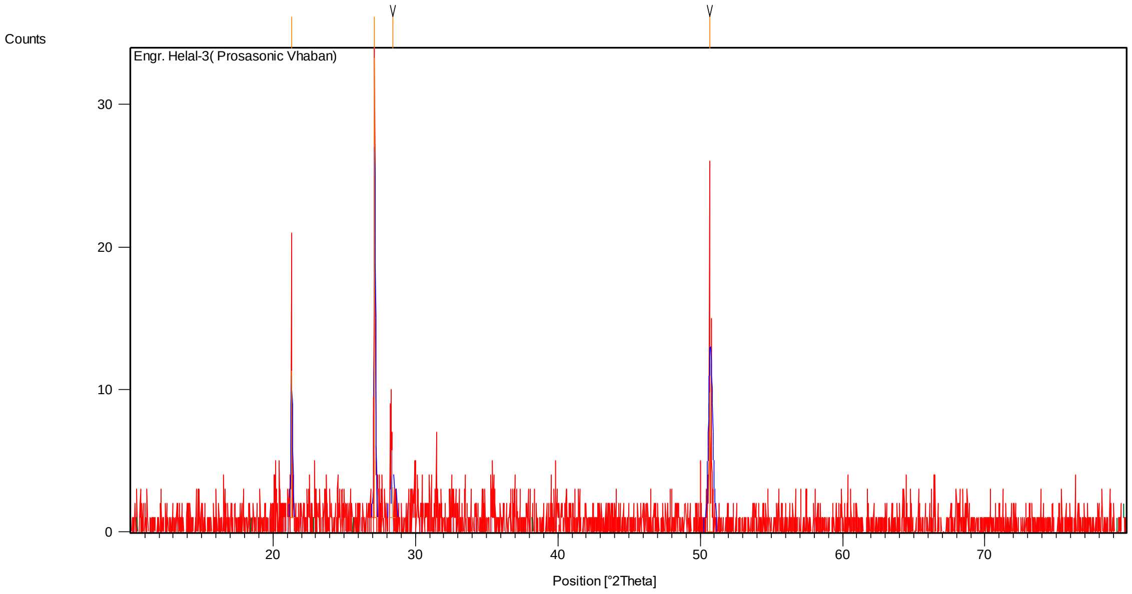

Figure-4.5:XRD analysis of Administrative Building

Peak List:

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing [Å]	Rel. Int. [%]
21.2969	10.33	0.1181	4.17214	31.96
27.1290	32.31	0.0787	3.28702	100.00
28.4151	2.19	0.4723	3.14110	6.76
50.6901	9.84	0.2880	1.79947	30.45

Pattern List:

Visible	Ref. Code	Score	Compound Name	Displacement [°2Th.]	Scale Factor	Chemical Formula
*	01-078-1259	29	Quartz $GA, syn	0.000	0.250	SiO_2

The XRD pattern of deposited indoor dust of administrative building illustrated the presence of Alpo-11,Calcined(code-AEL)(Score:21.2969^0 at 2θ),Rho,Deuterated Berylloarsenate (code-RHO) (Score: 27.1290^0 at 2θ), Afghanite (code:AFG) (Score: 28.4151^0 at 2θ) and Montesommaile (code: MON) (Score: 28.4151^0 at 2θ)

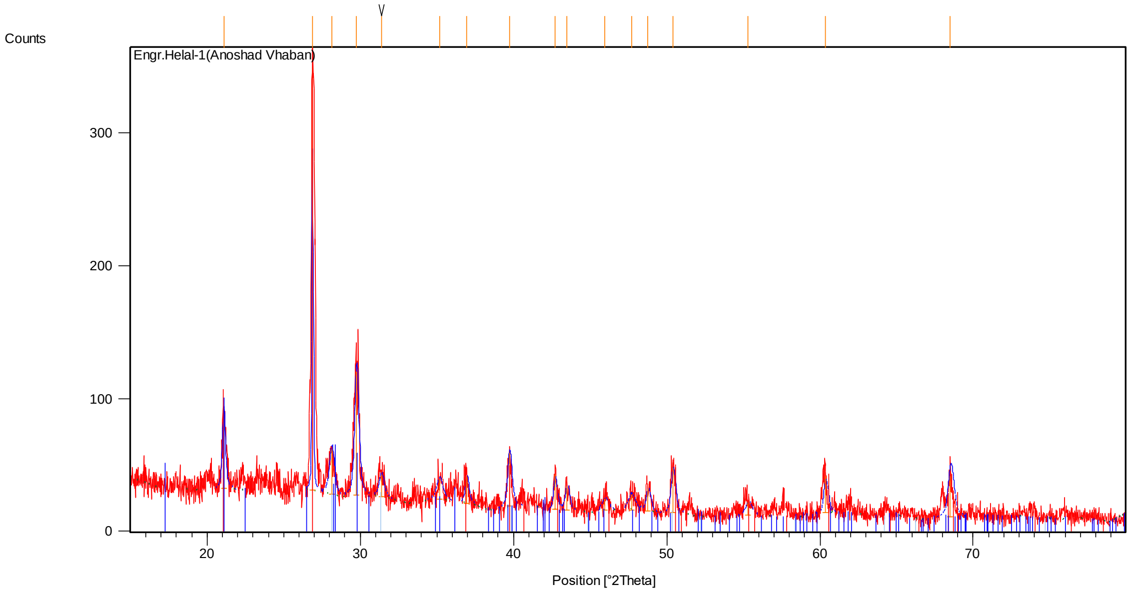

Figure-4.6: XRD analysis of Academic Building

Peak List:

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing [Å]	Rel. Int. [%]
21.0925	56.88	0.2362	4.21209	17.82
26.8735	319.20	0.0787	3.31769	100.00
28.1393	34.02	0.3936	3.17126	10.66
29.7565	93.26	0.3149	3.00249	29.22
31.3701	16.93	0.3936	2.85163	5.30
35.1604	15.14	0.4723	2.55243	4.74
36.9552	20.38	0.2755	2.43248	6.38
39.7336	40.45	0.3149	2.26856	12.67
42.7152	25.91	0.2362	2.11687	8.12
43.4882	18.03	0.3149	2.08101	5.65
45.9667	8.45	0.4723	1.97441	2.65
47.6944	11.60	0.4723	1.90685	3.64

48.7838	17.39	0.3149	1.86679	5.45
50.4087	34.20	0.3149	1.81036	10.71
55.3085	9.86	0.4723	1.66102	3.09
60.3624	27.98	0.2755	1.53348	8.77
68.5119	30.59	0.3840	1.36847	9.58

Pattern List:

Visible	Ref. Code	Score	Compound Name	Displacement [°2Th.]	Scale Factor	Chemical Formula
*	01-083-2467	49	Quartz, syn	0.000	0.988	SiO_2
*	01-082-1561	18	Silicon oxide	0.000	0.447	SiO_2

The XRD pattern of deposited indoor dust of academic building illustrated the presence of Barium Chloroaluminosilicate (code-MER)(Score:21.0925^0 at 2θ), Liottite (code-LIO) (Score: 26.8735^0 at 2θ),Li-ABW(code:ABW) (Score:28.1393^0 at 2θ), Li-ABW(code:ABW) (Score: 29.7565^0 at 2θ), Alpha Cristobalite, (Score:31.3701^0 at 2θ), Tiptopite (code:CAN) (Score: 35.1604^0 at 2θ), Alpha Cristobalite (Score:36.9552^0 at 2θ), Alpha Quartz (code:-) (Score: 39.7336^0 at 2θ) and Bicchulite (code:SOD) (Score: 42.7152^0 and 43.4882^0 at 2θ)

4.8 SEM (Scanning Electron Microscope) analysis

SEM Micrograph of surface morphology of indoor Dust of 10-storied residential tower Building has found the presence of angular (size, 36x19.5µm), flaky (size, 9x19.5µm, 21x7µm) and rounded (size,16.5x16.5µm,7x8µm,7x6µm) shape particles. SEM Micrograph of indoor Dust of Administrative Building has found the presence of flaky (size, 22x16µm, 11x4µm) and rounded (size,13.5x13.5µm,7x6.5 µm) shape particles. SEM Micrograph of indoor Dust of Academic Building has found the presence of flaky (size, 17x14.5µm, 6x4µm) and rounded (size,3.3x3.3µm,7x7µm,10x10µm, 11.5x11.5µm,14x14µm) shape particles.

4.9 Determination of PM_{10} and $PM_{2.5}$ concentration in ambient air by using Tactical Air Sampler (TAS)

Table-4.11: Ambient air pollution Data sheet (Outside of Building):

Name of Building	Time	PM_{10} (µg/m^3)	$PM_{2.5}$ (µg/m^3)
10-storied residential tower Building	04.20pm-7.20pm	51	42
Administrative Building	09.52am-12.52pm	76	56
Academic Building	01.05pm-4.05pm	171	78

Table- 4.12: Indoor air pollution Data sheet (Inside of Building):

Name of Location	Time	PM_{10}(µg/m^3)	$PM_{2.5}$(µg/m^3)
Administrative Building	02.00pm-04.00pm	130	113
Academic Building	04.30pm-06.30pm	170	103

Table- 4.13: WHO Guide line and Bangladesh standard values of PM:

PM	WHO guideline values		Bangladesh Standard values	
	24 hour	1 year	24 hour	1 year
PM_{10} (µg/m^3)	50	20	150	50
$PM_{2.5}$ (µg/m^3)	25	10	65	15

From table-4.11 and 4.12; it is seen that in administrative building PM_{10} and $PM_{2.5}$ concentration is higher in indoor than outdoor. In academic building $PM_{2.5}$ concentration in indoor is higher than outdoor. Both PM_{10} and $PM_{2.5}$ concentration is higher in academic building than other two because academic building is situated near a road and construction work is going on adjacent to this building.

Comparing with table-4.13, it has seen that concentration of PM_{10} in all cases exceeds WHO guideline limit both in outdoor and indoor and in academic building exceeds Bangladesh standard both in outdoor and indoor. Concentration of PM_{10} in administrative building both in outdoor and indoor and 10-storied residential tower building in outdoor is within Bangladesh 24 hour standard but exceeds Bangladesh 1 year standard.

Concentration of $PM_{2.5}$ in all cases exceeds WHO guideline limit both in outdoor and indoor and in academic building exceeds Bangladesh standard both in outdoor and indoor. Concentration of $PM_{2.5}$ in administrative building exceeds Bangladesh standard in indoor but in outdoor within 24 hour standard but exceeds 1 year standard. Concentration in 10-storied residential tower in outdoor within the 24 hour standard but exceeds 1 year standard.

From the above data it is found that people with specially sensitive groups such as the asthmatic, the children and the elderly, while staying in indoor are at greater risk. That is why maintenance of indoor air quality is very important for maintaining good health.

4.10 Air Quality Index (AQI)

Air quality index calculated using the following formula

$AQI_{pollutant}$ = (Pollutant data reading/standard) x100

<u>Air Quality Index (AQI)</u>

Table -4.14: Location: Ambient air outside of Building

Building Name	**AQI** (PM_{10})	**AQI** ($PM_{2.5}$)	**Comments**
10-storied residential tower Building	34	65	AQI for PM_{10} is Good, Little potential to affect public and AQI for $PM_{2.5}$ is Moderate, Unusually sensitive individuals.
Administrative Building	51	86	AQI for PM_{10} is Moderate and Unusually sensitive individuals. Air quality for $PM_{2.5}$ is polluted.
Academic Building	114	120	Air quality for both PM_{10} and $PM_{2.5}$ Heavily polluted. Caution, Identifiable groups at risk-different groups for different pollutants.

Table 4.15: Location: Ambient air inside of Building

Building Name	**AQI** (PM_{10})	**AQI** ($PM_{2.5}$)	**Comments**
Administrative Building	87	174	AQI for PM_{10} is Polluted, Unusually sensitive individuals and AQI for $PM_{2.5}$ is Unhealthy, air quality is severely polluted. General public at risk; sensitive groups at greater risk.
Academic Building	113	158	AQI for PM_{10} is Heavily polluted. Caution, Identifiable groups at risk-different groups for different pollutants and AQI for $PM_{2.5}$ is Unhealthy, air quality is severely polluted. General public at risk; sensitive groups at greater risk.

Chapter 5

Control and management of indoor dust

5.1 General: The Control and management strategies of dust are based on planned activities and anticipated emissions. These determine the precautionary measures that are required. Control and management of construction, renovation and demolition activities, housekeeping are required to maintain good indoor air quality. Construction and renovation projects present a variety of situations which may release contaminants and pollutants that can impact the indoor air quality (IAQ) of a Building. These contaminants may be transported to other areas via the heating, ventilation and air conditioning systems and subsequently affect populations beyond the immediate project area. Advance planning with appropriate contract language, material review and selection processes and effective control strategies combined with proactive communication efforts can successfully control pollutant levels, allay concerns, and maintain occupant comfort during and after construction activities.

Table -5.1: Sources of dust, problem and control strategies

Name of dust and source	Problem	Existing Control facilities	Proposed action/Remedies
Non toxic or nuisance dust and fine particle emissions. **Source:** Construction and other civil engineering activities. Created by cutting, sanding, disturbing dirty areas or the installation of Portland cement, gypsum, limestone, and Plaster of Paris.	This is a common and significant problem. Construction activities may introduce particulate matter such as dusts and fibers into an environment. Cause no long term health effects, but can increase occupant discomfort, irritating to the skin, eyes, and respiratory tract.	Personal protecting are used but not adequate.	Environmental controls and appropriate personal protecting equipment should be implemented. Adequately controlling measures to be taken by construction site operators to minimize this problem such as confinement of source, obstructing the entrance of dust to indoor.

Name of dust and source	Problem	Existing Control facilities	Proposed action/Remedies
Volatile Organic Compounds (VOCs)	VOCs are readily released in the form of a gas from building materials. At high enough levels, VOC exposure can cause central nervous system effects (headaches, drowsiness) and at lower levels, they may cause to be irritants to the eyes, nose and throat. If VOC emitting materials used in more surface area such as floor,wall then more significant impact on the air quality.	Little or no measures.	Low VOC emitting products should be used. Categories of VOC emitters should initiate as control strategies to minimize occupant exposure such as: Coatings, Stains/ Varnishes, Resilient Flooring, Caulks, Fuels, Cleaners, Wall Coverings, Sealants, Adhesives, Composite Wood products Paints, Carpeting, Fabrics, Draperies.
Hazardous Particulates	Particulates which are subject to special regulation include lead paint dust is toxic to the nervous system, and asbestos is a carcinogen.	Little or no measures.	Projects which may disturb lead painted surfaces or asbestos containing materials need close supervision to ensure compliance with all applicable laws. Licensed and certified contractors will be required to perform these types of activities.

Name of dust and source	Problem	Existing Control facilities	Proposed action/Remedies
Combustion products **Source:** Vehicles, generators, and space heaters. May introduce CO, CO_2, NO_X, and SO_2 into a space. Welding can produce these contaminants as well as O_3.	May cause eye, nose, throat, and respiratory system irritation. Some individuals, such as those with asthma, may experience more serious reactions. CO exposure may cause headache, dizziness, rapid heartbeat, and at high levels can be fatal.	Little or no measures.	Personal protecting device should be warned. Generators and other equipments Should be placed away from air intake of building and PM (Particulate matter) trapping system may be adopted.
Biological Materials/ Bio-aerosols **Source:** Demolition of materials and disturbance of previously sealed areas may contribute to the release of Bio-aerosols. Present in the form of pollens, fungal spores, dust mites, insect parts, bacteria, viruses, and any fragments from plants and animals. Bio-aerosols can become airborne when renovations are undertaken, stagnant water is encountered, and bird or animal droppings are disturbed. Chronically wet or damp areas may be reservoirs of gross contamination.	Potential health hazards of indoor bio-aerosols to humans, with a special focus on allergenic or toxigenic fungi and their association with indoor air quality. Douwes et al. (2003) concluded that the potential health effects of bio-aerosol exposures are diverse including infectious diseases, acute toxic effects, allergies and cancer.	Personal protecting are used but not adequate.	Engineering controls to minimize worker and occupant exposure, personal protective equipment, and proper decontamination techniques must be considered. There is also a growing body of scientific literature examining the relationship between dampness and mould in buildings and associated health effects (Bornehag et al. 2001; IOM 2004; Mudarri and Fisk 2007).

Name of dust and source	Problem	Existing Control facilities	Proposed action/Remedies
PM from construction, renovation, and demolition activities	Create occupant discomfort, irritating to the skin, eyes, and respiratory tract. Some particles such as crystalline silica are carcinogenic.	Insufficient Measures are taking	The area around the site, the adjacent road, should be regularly and adequately swept. Covering vehicles, Watering of rubble chutes shall be undertaken. Besides the following measures should be taken. **Early identification:** The area to be renovated should be inspected during the project planning stage. Looking for possible asbestos and lead containing materials. Attempting to identify sources of dust and microbial contamination. **Source Removal:**Identifying a source of contamination and relocating it so that it will not impact the IAQ. For example, do not locating a diesel generator or a roofing kettle near a building air intake. **Source Substitution:**Identifying a material likely to impact the IAQ and selecting a similar but less toxic substitute. **Source Encapsulation:** Creating a barrier around the source and isolate it from other areas of the building. **Ventilation:**Dilution ventilation increases the amount of outside air passing through an area to dilute and flush out low levels of contaminants. **Housekeeping:** Good housekeeping practices allows adequate confidence to building occupants. Vacuum cleaner can be used to minimize recirculation of contaminants. Suppressing dust with wet methods. Quickly cleaning up spilled materials.

Name of dust and source	Problem	Existing Control facilities	Proposed action/Remedies
PM from painting activities.	Irritating to the skin, eyes, and respiratory tract. Some particles such as crystalline silica are carcinogenic.	Using mask.	Low VOC emitting paint should be selected that is free of Pb and Hg. Interior painting to be done during off hours, isolating the space, and ventilating the area well both during and after the painting is completed.
PM from flooring activities.	Create occupant discomfort, irritating to the skin, eyes, and respiratory tract.	No measures are taking.	Grinding, surfacing, sanding, abrading, breaking or removing asbestos containing materials (ACM) flooring may only be done by a licensed asbestos contractor.
Dust and aerosols at construction sites., digging, preparation and transfer of materials, windblown dust, etc.	Create occupant discomfort, irritating to the skin, eyes, and respiratory tract. Some particles such as crystalline silica are carcinogenic.	Insufficient/ Poor measures are taking to minimize these PM. Sweeping are done manually by using broom.	Adequate prevention at the source. Binding dust from unpaved trails with compaction or water sprinklers. Limiting speed on vehicles to 30 km/h. Dismantling demolition objects in large pieces. Greening unpaved surfaces and all surfaces should be either paved or green. Washing/ wetting adjacent areas/road at regular interval. Other measures may be (i) Exposure Control: Carefully scheduling the work during holidays, evenings and weekends. (ii) Setting a Code of Practice for demolition and construction works on building sites. (iii) Publicity and Communication. (iv)Monitoring and testing. (v)Air quality management and policy.

Name of dust and source	Problem	Existing Control facilities	Proposed action/Remedies
Indoor/outdoor PM of JUST campus	Create occupant discomfort, irritating to the skin, eyes, and respiratory tract. Some particles such as crystalline silica are carcinogenic.	At Present cleaning of dust is done by sweepers manually by using broom. But in this process dust particles disperse the surrounding area. As a result concentration of dust in ambient air increases and people inhale more	All reasonable precautions shall be taken to prevent particulate matter from becoming airborne. Sweeping of indoor by using broom should be replaced by vacuum cleaner. Outdoor sweeping for cleaning dust/dirt and other materials should be done by cleaning vehicle instead of using manual broom. For this sufficient number of cleaning vehicle should be purchased. During vertical extension of existing buildings casting work should be avoided during office hour or class time and notice should be placed at conspicuous position writing the working time, nature of work, telephone number of contractors responsible person . Whole University campus should either be metalled or grassed/greened and there should not be any unveiled ground. If the wheel of vehicles contain mud/earth; should be properly washed/cleaned and then allow to enter into the campus. In dry season when rainfall is scanty there is more chance for dust particle becoming airborne; this time watering should be done in road and outdoor. Sufficient PM deposit on the top of furniture such as almirah, file cabinet,rack etc. and on the top of ceiling fan, AC and others. These

		dust.	should be clean at regular interval by using wet cloth so that dust deposition is minimum. Window sill, grill, railing, tube light etc should be cleaned regularly by using wet paper/cloth. Upholstered furniture, toys, plastic flowers, carpets, curtains etc should be cleaned regularly and care should be taken that dust dispersion is minimal. In case of AC rooms indoor air concentration should be diluted by mixing fresh outdoor air by opening windows. Incineration of plastics and other materials in the campus should be prohibited. Because burning of plastic material produces toxic gases such as Hydrogen chloride, Hydrogen sayanide, Aldehyde etc. There is a environmental committee in JUST campus. They should asked to send plastic materials in the recycling plant and biodegradable substances to dump in a land fill. In construction and demolition activities conducted by contractors; sufficient clause should be provided in tender document for maintaining good air quality. Bidders should be requested for entrepreneurial remedies (equipment, methods, and materials) to curtail emissions. Specific and weighted criteria should be defined in tender document for allaying dust during awarding the contract.

			Construction debris, dusty spills should be clean up immediately. Monitoring and testing of air quality should be done at regular interval and to be incorporated in contractors work schedule.

Chapter 6

Conclusions and Recommendations

6.1 Conclusions:

The summary of the results and discussion of this research work is mentioned below:

- The study has revealed the existence of redundant of heavy metals such as Fe,Cu, Zn,Ti,As,Zr,Pb in the indoor dust of Jashore University of Science & Technology (JUST) Campus.
- The study has confirmed the presence of criteria air pollutant (Pb) in the indoor dust of JUST Campus.
- The study has found the presence of toxic substances such as Rb, Sr, Zr in the indoor dust samples.
- The study has found the presence of poisonous substance such as Arsenic (As) in the indoor dust samples.
- The study concluded that the quality of air found relatively better in other buildings than the building situated near road side which may be due to vehicular traffic and ongoing construction work.
- The study has found that Concentration of $PM_{2.5}$ in exceeded all cases (42,56,78,113,103 $\mu g/m^3$) the Bangladesh 1 year standard value- 15 $\mu g/m^3$ and exceeded three cases (78,113,103 $\mu g/m^3$) the Bangladesh 24 hour standard value- 65 $\mu g/m^3$.
- The study has also revealed the existence of α-quartz i,e crystalline silica in dust sample which is carcinogenic.

6.2 Recommendations for further studies:

The following recommendations can be implied for further studies:

- Determining concentration of indoor Particulate matter in representative educational institute/Universities (area based) all over Bangladesh.
- Determining the effect of surface morphology of indoor Particulate matter.
- Setting out air quality standard during construction/demolition activities in educational institutions all over Bangladesh.
- Assessment of environmental and health risk due to exposure of criteria pollutants generating from construction/demolition activities in educational institutions all over Bangladesh.

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Appendix-A

Calculation

Calculation:

(a) Ambient air outside of Building

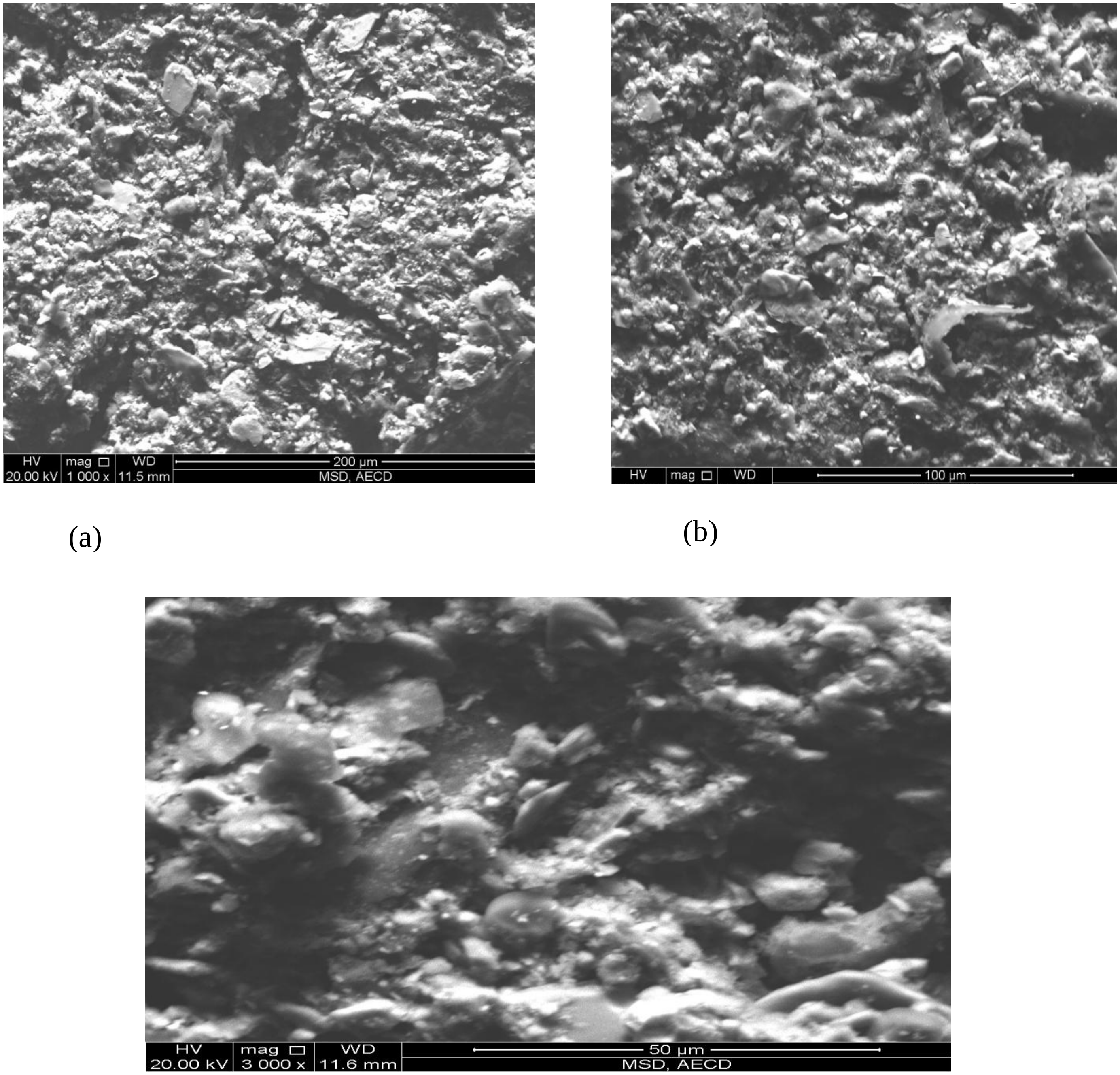
- (i) 10-storied residential tower Building, AQI(PM_{10})=(51/150)*100=34
- (ii) 10-storied residential tower Building, AQI($PM_{2.5}$)=(42/65)*100=65
- (iii) Administrative Building, AQI(PM_{10})=(76/150)*100=51
- (iv) Administrative Building, AQI($PM_{2.5}$)=(56/65)*100=86
- (v) Academic Building, AQI(PM_{10})=(171/150)*100=114
- (vi) Academic Building, AQI($PM_{2.5}$)=(78/65)*100=120

(b) Ambient air inside of Building

- (i) Administrative Building, AQI(PM_{10})=(130/150)*100=87
- (ii) Administrative Building, AQI($PM_{2.5}$)=(113/65)*100=174
- (iii) Academic Building, AQI(PM_{10})=(170/150)*100=113
- (iv) Academic Building, AQI($PM_{2.5}$)=(103/65)*100=158

Appendix-B

Supplementary Figures

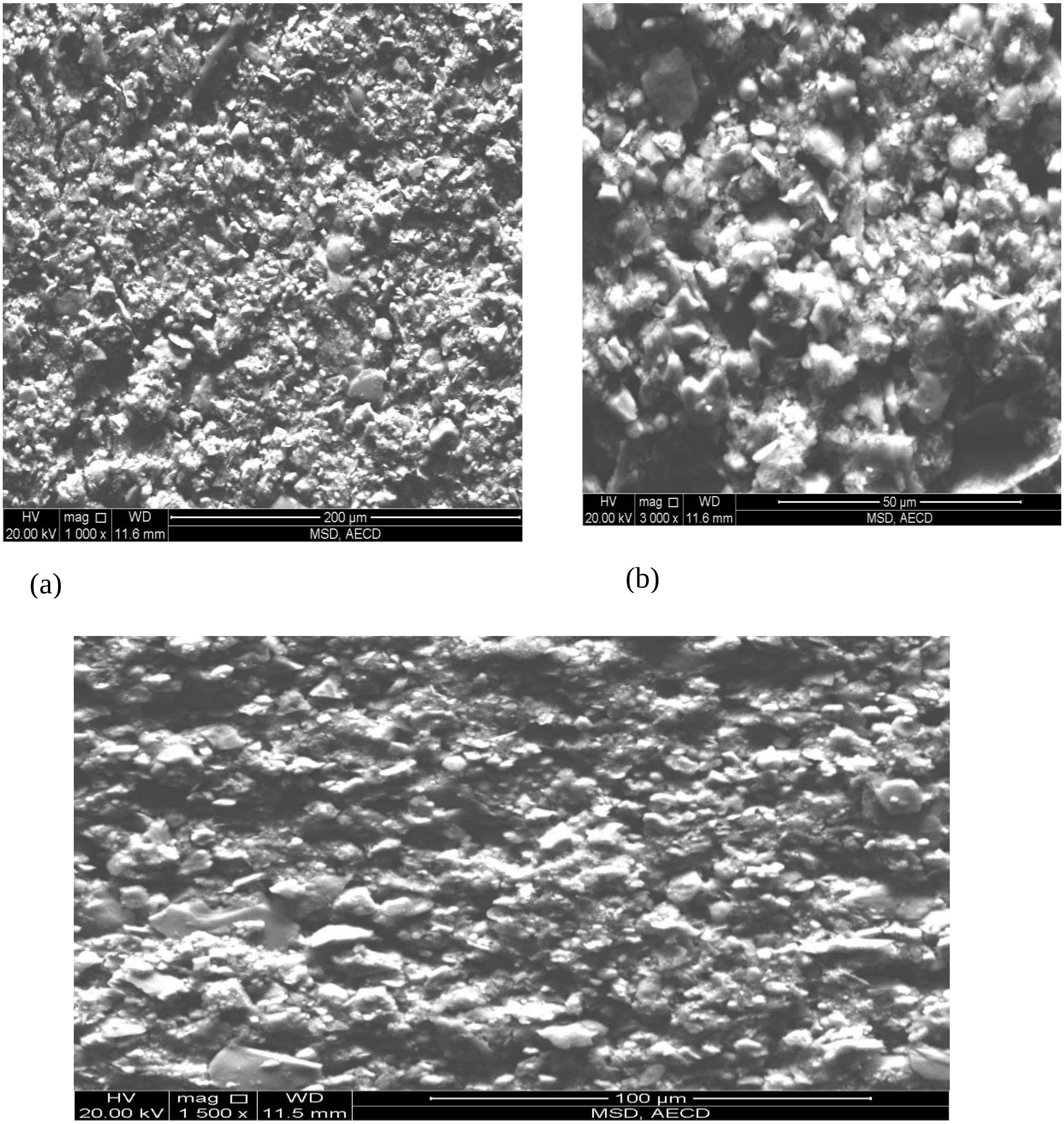


(a)

(b)

(c)

Figure- B-1(a,b,c): SEM Micrograph of indoor Dust-10-storied residential tower Building



(a)

(b)

(c)

Figure- B-2 (a,b,c): SEM Micrograph of indoor Dust of Administrative Building

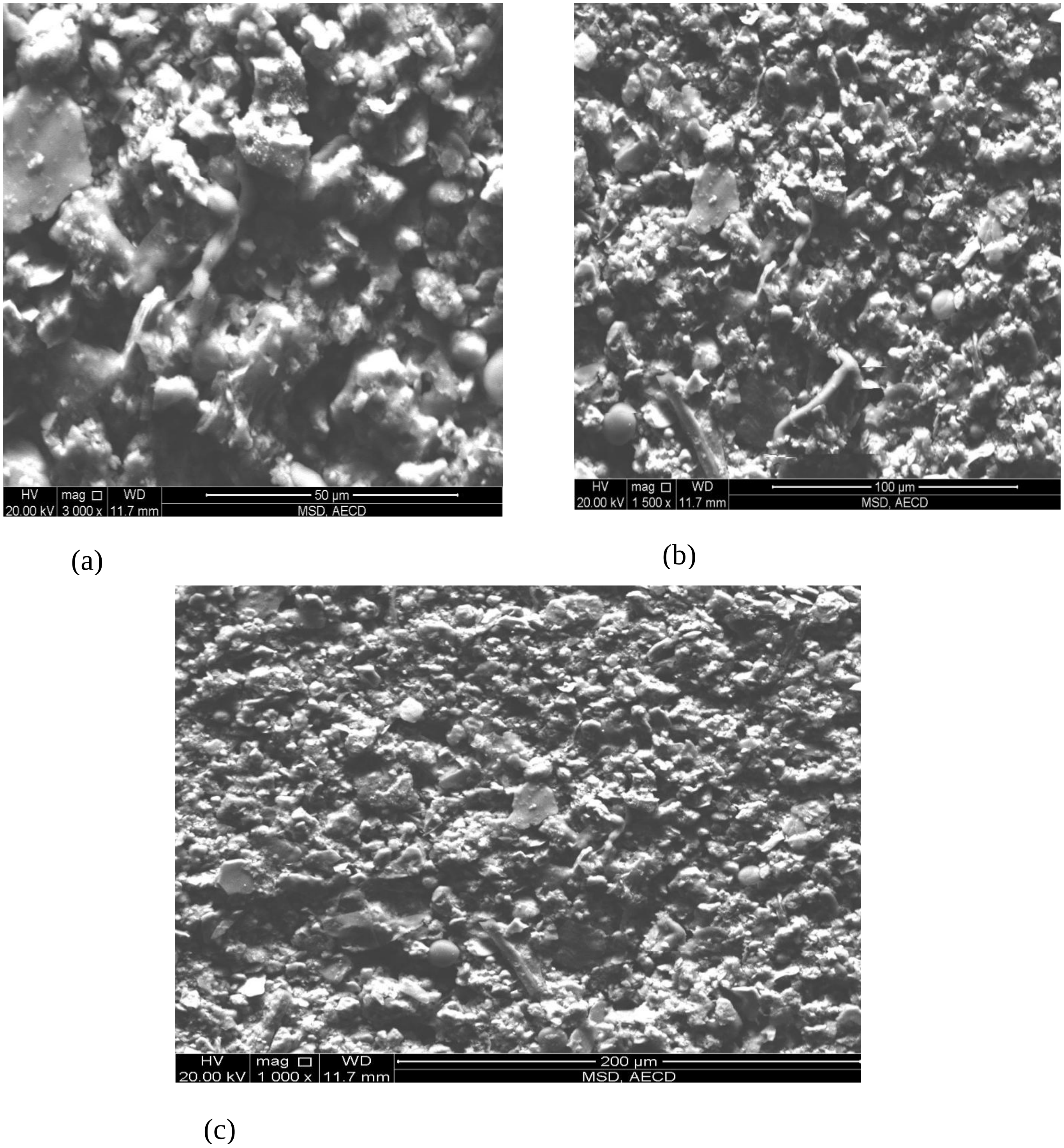


Figure- B-3 (a,b,c): SEM Micrograph of indoor Dust of Academic Building