CHAPTER 2
REVIEW OF LITERATURE

2.1. Particulate matter

Focused on atmospheric particulate research is gaining importance for its tremendous implications on human health, atmospheric chemistry, climate system and hydrology.

As per a joint report of U.N. Environment Program and WHO, PM is estimated to kill more than 500,000 people each year [1]. According to recent WHO update ambient (outdoor air pollution) was estimated to cause 3.7 million premature deaths worldwide in 2012 of which 88% occurred in low- and middle-income countries, and the greatest number in the WHO Western Pacific and South-East Asia regions [2]. The Organization for Economic Co-operation and Development (OECD) in its Environmental Outlook 2050 report, warns that urban air pollution could become the biggest environmental cause of premature death by 2050 with the number of premature deaths doubling if no actions to improve air quality are implemented [3]. The majority of the additional deaths are expected to be in China and India, making urban air quality very much an Asian problem. In a recent study, Park et al. [4] found a significant positive association between PM\textsubscript{10} exposure and non-accidental mortality among Asian populations.

Particulates affect the climate system both directly and indirectly. Interestingly, they are engaged in both positive and negative radiative forcing and so, particulates are of a ‘newer found’ interest to the climate scientists. Again, climate change impacts the particulate levels which is difficult to predict [5], emphasizing the need of continuous monitoring and research on this pollutant.

Reports on particulate concentration, today, are available from all corners of the world including many such reports from the South Asian countries. The trend in developing countries differs greatly than the trend in the developed countries. This is because the pattern of energy use and fuel type, which are so different in these two worlds. For instance biomass burning is a common source of energy in the developing nations especially the South Asian countries. So, this region has a characteristic emission.

In a program study under the Regional Co-operation Agreement (RCA), Hopke et al. [6] reported that most of the participating countries exceed the WHO guidelines.
characteristics of a receptor site: a study at a rural institutional area of Assam

[7] and the US NAAQS standards. They reiterated that China, Pakistan, Bangladesh and Sri Lanka are a cause of concern. Increases in coal combustion, increased population, and heavy traffic in urban centres might be a major factor for high pollution in India and China. Researchers pointed out use of more motor vehicles and dense population as the chief contributors of pollution in Pakistan and Bangladesh.

It is worthy to mention here that most of the studies from the South Asian countries are from urban centres. For instance, in Bangladesh reported studies are mostly from cities. In a study, Mahmud et al. [8] attributed 15000 premature death and several million cases of illness every year in Dhaka City to be from air pollution. They reported average mass of TSP and PM$_{10}$ of 68 µgm$^{-3}$ and 43 µgm$^{-3}$ respectively for the period of August and September, 2005. In another study, Begum et al. [9] reported PM$_{10}$ concentration of 140±114 µgm$^{-3}$ at a locality in Dhaka and considered it as PM hotspot area. Researchers attributed motor vehicle and brick kilns as the major source of PM emission in Dhaka city [10,11].

Very high loadings of PM were reported by researchers in Pakistan [12,13,14]. Colbeck et al. [15] reported that the 24-hr mean levels in cities are at least 3-5 times higher than the WHO guidelines of 50 µgm$^{-3}$. They concluded that higher levels of PM are generally found in the summer rather than the winter and the monsoon. Ghauri et al. [16] reported the levels of TSP and PM$_{10}$ in the range of 292-577 µgm$^{-3}$ and 189-251 µgm$^{-3}$ respectively in a baseline study conducted in 33 sites of six major cities of Pakistan. However, Hopke et al [6] conducted an experiment for duration of 4 years at Nilore (Islamabad), a residential campus away from major emission sources and reported mean PM$_{10}$ concentration of 68±50 µgm$^{-3}$.

There are a few reported studies from the Himalayan Republic of Nepal as well. Giri et al. [17] reported daily PM$_{10}$ concentrations from six representative sites of Kathmandu valley in the range of 7 µgm$^{-3}$-633 µgm$^{-3}$. The lowest and highest average annual concentration during the study period was found to be 47.78 µgm$^{-3}$ and 199.80 µgm$^{-3}$ respectively. They had found much variation in daily PM$_{10}$ concentration in the inner city areas and concluded that the reasons of such variation to be diverse land-use, activities and consequent sources of emission.

Vahlsing and Smith [18] had conducted a study on National Ambient Air Quality Standards (NAAQSs) for PM$_{10}$ and SO$_2$ (24-h) and identified 96 countries having NAAQSs. Eighty three percent of the 96 countries have 24-h AAQSs for PM$_{10}$ and SO$_2$ and slightly more countries have 24-h Ambient Air Quality Standards
(AAQSs) for SO$_2$ (76 countries) then PM$_{10}$ (69 countries). The average AAQSs for PM$_{10}$ and SO$_2$ are subsequently higher than the WHO guideline values.

As per the Article 48A of the Indian constitution, the onus of protecting the environment from degradation lies with the Government. The Central Pollution Control Board (CPCB), Government of India (GoI) is engaged in routine monitoring of Suspended Particulate Matter (SPM) and Respirable Suspended Particulate Matter (RSPM) at 342 operating stations covering 127 cities and towns in 26 States and 4 Union Territories of Indian State and has also taken-up a project for setting up of Continuous Real Time Air Quality Monitoring Stations in 16 cities. Recently CPCB had also conducted a source apportionment study in six cities of India [19]. Several studies have been carried out at various urban centres spread over the whole of India [20-25]. India is a vast country where most of the population (~70%) lives in rural areas, yet systematic studies on particulate pollution in these areas have not been initiated in a major scale.

In the northeastern region of India, despite being ecologically sensitive and a biodiversity hotspot, studies on air pollution is not attaining pace. There are a few reported studies on Aerosol Optical Depth (AOD) characteristics [26-28], and on carbonaceous properties of aerosols [29,30]. Biomass burning is a common sight in the rural areas of Northeast India in the form of household burning for cooking and heating, agricultural residue burning, shifting agriculture and forest fire which are few major contributors of atmospheric PM$_{10}$ load in the region. Festive biomass burning is an important source of particulates in the Brahmaputra valley [31,32], which could also have regional implications.

2.2. Particulate concentration and atmospheric condition

Atmospheric conditions that comprise the state of the atmosphere in terms of temperature, wind, precipitation and clouds affect the particulate loading in the atmosphere. During winters temperature inversions are more frequent leading to higher PM concentration [32,33]. Also the winter mixing layer height lowers than other seasons of the year which influences atmospheric PM concentration. Lowering of mixing layer height results in increase PM levels in the atmosphere [32,34,35]. Amodio et al. [36] reported very high PM$_{10}$ concentrations during poor atmospheric dispersion condition in Apulia of South Italy.

However, during monsoon season, rain washout results in low pollutant concentration in the atmosphere [20,37]. Secondary particulate formations are high
during the winter and the monsoon due to moderate temperature and high relative humidity [38]. During the summer increased solar insolation favours resuspension of crustal dust while wind speeds are conducive to medium- and long-range atmospheric dust transport [39,40]. The long range transport of pollutants to a particular region has been addressed by back trajectory analysis by several researchers [32,36,41-43].

2.3. Monitoring methods of PM

Simple to advanced sampling devices are used for PM monitoring. High volume samplers [20,32,38,44,45], medium volume samplers [46,47] and low volume samplers [48-50] were very common for PM$_{2.5}$ and PM$_{10}$ measurements and were used from very early days. The most commonly used size-fractionating equipment is the cascade impactor [51-55]. This works on the same principle as the regular PM samplers, but has a series of impactors and collection surfaces which allow the classification of different sizes. One of the advanced PM sampler is the Micro-Orifice Uniform Deposition Impactors (MOUDI) sampler [56]. Beta Attenuation Monitor [35,57], is also used for continuous monitoring of PM$_{2.5}$ and PM$_{10}$.

A very popular technique of PM measurement is using an optical method of laser scattering like Aerosol Spectrometer [35,58,59]. These instruments can be operated in a mode to collect a single particle size or multiple size ranges continuously. Scanning mobility particle sizer (SMPS) [60], Differential mobility particle sizer (DMPS) [61-63] are commonly used for ultra fine particles. A Wide-range Particle Spectrometer (WPS) was used to measure aerosol size distributions in the range of 10 nm-10 µm. The instrument is a high-resolution aerosol spectrometer which combines the principles of Differential Mobility Analysis (DMA), Condensation Particle Counting (CPC) and Laser Light Scattering (LPS) [43].

2.4. Source apportionment of PM

Source apportionment (SA) describes techniques used to quantify the contribution of different sources to atmospheric PM concentrations [64]. There are mainly three groups of SA models viz., methods based on monitoring data, emission or dispersion model and receptor model. Principal component/factor analysis are commonly used for SA because of that detailed prior knowledge of the sources and source profiles is not required [65]. The fundamental principle of receptor modelling is that mass and species conservation can be assumed and a mass balance analysis can be
used to identify and apportion sources of airborne PM in the atmosphere [66]. Receptor modelling was also used in epidemiological and health related studies [67,68]. Researchers from different parts of the world were using different receptor models like Principal Component Analysis-Multiple Linear Regression (PCA-MLR) [24,69,70], Principal Component Analysis- Absolute Principal Component Scores (PCA-APCS) [71-73], Positive Matrix Factorization (PMF) [56,74,75], UNMIX [70,71], Chemical Mass Balance (CMB) [21,76] etc. for SA. In Indian context, source apportionment by CMB is limited and factor analysis is widely used [21].

2.5. Festivities and PM emission

Festivals emit large volume of particulates into the atmosphere. Earlier studies [46,77,78] reported that festivals often emit huge bulk of air pollutants in the Asian cities that pose serious implications to air quality. Diwali and meji burning of North east India are two major emitters of air pollutants in India.

2.5.1. Diwali fireworks

Fireworks are generally associated with celebrations worldwide. Such celebrations range from smaller local events like birthday parties, wedding ceremony, and victory in a sports event to huge nationwide celebrations. In India, Diwali is one such festival marked with lighting of lamps and celebrations with major fireworks all over the country. The main fascinating characteristic of Diwali is the participation of almost every household in bursting firecrackers, leading to emission of huge volume of aerosols into the atmosphere in one single day.

There are reports of many fold rise of PM$_{10}$ loadings and elevated levels of harmful gases and elements in the atmosphere during fireworks [79-83]. Increase in the carbonaceous materials [46,83,84], ionic components of particulates are also reported from India and elsewhere in the world during fireworks [46,81,85,86]. However, organic emission is reported to be less when compared with other chemical species from fireworks [80,81,83]. Nishanth et al. [78] reported increase in PM$_{10}$, O$_3$, NO$_2$, NO along with various hazardous organics in the atmosphere which are released from burning of firecrackers during traditional Vishu festival of Kerala, India. There are also studies on effects of Diwali celebrations on high ground or surface ozone concentration [87,88]. Deka and Hoque [89] had studied Diwali fireworks in rural Brahmaputra Valley and reported marginal incremental effect of Diwali as compared to the events in the ‘mainland India’.
2.5.2. Festive biomass burning

Previous studies [90,91] have reported that biomass burning emits large volume of particulates and chemical oxidants into the atmosphere. Festive biomass burning, the traditional *meji* burning, is a unique feature of the Brahmaputra Valley during winter time, which releases significant volume of particulates posing regional implications [31]. Deka and Hoque [32] had found incremental effects of PM$_{10}$ load during *meji* burning in the Brahmaputra Valley atmosphere which in turn has implications on the characteristic of PM$_{10}$ of this region. They reported that PM$_{10}$ of being extremely carbonaceous and enriched with Br and other metallic species.

2.6. Biomass burning in rural kitchens

Biomass burning as fuel in kitchen is a concern as large volume of air pollutants and particulates mainly in the submicron size could affect indoor air quality. It is the primary energy source in rural India [92].

Cooking practice has several adverse impacts on indoor air quality. Household solid fuels use in developing countries produces exposures to smoke components that are remarkably high by the standards set for outdoor air in developed countries [93]. It emits hazardous chemicals and gases which not only affect human health, but also contribute to regional and global air pollution and climate forcing [94-96]. Women and children pass several hours of a day inside the home, who may get exposed to this unknown types and loads of air pollutants. Indoor air pollution has caused 400000-550000 premature deaths, annually in India, of children under five and adult women [97]. Globally, 4.3 million premature deaths were attributable to household air pollution as of 2012 [2]. Women exposed to biomass smoke are 3-times as likely to suffer from chronic obstructive pulmonary disease (COPD), than women who cook with cleaner fuels such as electricity, gas etc. [98]. Mondal et al. [99] reported 3-times more PM$_{10}$ and PM$_{2.5}$ in indoor air of biomass using households than LPG-using families. Chronic inhalation of biomass smoke elicits oxidative stress and extensive DNA damage.

It has been estimated that 39% of the global population use biomass fuels for cooking and heating, and large amounts of biomass fuels are consumed in developing countries [100]. It had been estimated that approximately 76% of all global particulate matter air pollution occurs indoors in developing world [101]. Biomass in the form of wood, crop residues and animal dung is used in more than two fifths of the world’s household as the principal fuel [93]. In India, about 80% of rural households still use unprocessed solid biomass like wood, dung and agricultural refuges for cooking and
heating [102]. Biomass accounts for more than 80% of domestic energy in India [103] and about 90% biomass using households of the country use wood or animal dung as their primary cooking fuel [104].

Carbon, H, N, S, Cl, and O are the elementary biomass composition. Potassium, Na, Mg, Ca, P, and some heavy metals such as As, Cd, Cr, Cu, Hg, Ni, Pb and Zn are present in a lower proportion [105]. Five major ions including K\(^+\), NH\(_4\)\(^+\), Cl\(^-\), NO\(_3\)\(^-\) and SO\(_4^{2-}\) are emitted by all types of biomass burning [106]. Emission of these ions were also reported by other researchers from biomass burning [63,107-109].

At the global scale, the major source of primary carbonaceous aerosols is biomass burning and its widespread use as fuel for cooking and heating homes [110-112]. Venkataraman et al. [113] had estimated biofuel burning as the largest single source of black carbon in India. Biomass burning in kitchens also emits high concentration of PAHs. It contributed more than 90% and 60% of total PAHs emissions in India and China, respectively [114].

2.7. Soil and atmospheric PM\(_{10}\)

Soil, the upper surface of earth is a receptor site of atmospheric particulate matter and, therefore, signature of PM\(_{10}\) characteristics may be found in the topsoil. Atmospheric particles get deposited on soil by wet or dry deposition. Sampling and analysis of wet and dry atmospheric deposition can provide a clear picture of the environmental quality of an ecosystem and can lead to actions aimed at reducing pollutant emissions in the atmosphere. Atmospheric deposition is measured as a part of ecosystem studies and regional pollutant monitoring networks [115].

Most studies on heavy metal levels in urban soils have usually been carried out in large cities with dense traffic or a high degree of industrialization and few studies have addressed this issue in smaller cities [116]. There are a few studies on heavy metal and its impact on agricultural soil reported from India. Different studies suggests that if the present trend of atmospheric deposition is continued, it will lead to a destabilizing effect on the sustainable agricultural practice and will increase the dietary intake of toxic metal leading to long term health implications [117,118].

2.8. References


