CHAPTER 1

Introduction & Literature Review

This chapter presents the introduction of the work and a detailed relevant review of this particular study and provides a brief overview of the similar type of work that had taken place in different corners of the world, including India. The importance of atmospheric aerosols, their properties, their sources, and their effects on the atmosphere, and human health have discussed here.

1.1 Introduction

Rapid urbanization has led to an increasing number of large population agglomerations. Industrialization and transportation have become vital components of modern human life. Increasing air pollution is one of the adverse outcomes of modernization on human beings and the environment **[1,2]**. Air pollution refers to an atmospheric condition in which certain substances are present in such concentrations and duration that might produce detrimental effects on human beings and the ecosystem. Air quality has degraded when undesirable chemicals or different materials are discharged into the environment of urban and industrial areas in sufficient amounts to harm the living and non-living things. The discharge of waste materials into the atmosphere is called air pollutants what is air pollution. The physical, natural, or synthetic changes of air in the climate can be called pollution.

Air pollution is of prime concern globally because of its anthropogenic impacts on both biotic and abiotic life. Urbanization, industrialization, vehicular traffic, biomass burning, and populace development are the fundamental air pollutants supporters. The air quality relies upon the measure of contaminations, the rate at which they have discharged from different sources, and how rapidly it scatters or disperses. Air pollution, in this manner, demonstrates temporal, spatial, and seasonal variations.

The airborne particulate matter, an air-suspended mixture of both stable and fluid particles, is one of the six criteria air pollutants **[3,4]** in the climate because of its unfriendly consequences for human wellbeing, creatures, and plants and to the earth. Particulate matter (PM) sizes run more than several sizes from linear dimensions of a few nanometres (nm) to several micrometers (µm), which impact molecule lifetime in the environment and thus the spatial extent of their impact. The particles' shape and morphology appear spherical, crystalline, or unpredictable sections, needles, agglomerates, and dendritic elements. These heterogeneities are the result of the differing wellsprings of surrounding particulate matter **[5,6]**. Particulate matters are delivered either by various natural processes or due to several anthropogenic activities, and the impact of current anthropogenic activities have increased atmospheric aerosol concentrations **[7-9]**.

Mining has been an actor since old times to meet our limited requirements. With the advent of the industrial revolution, coal mining has become an important industry in many developed and developing countries. Impact on the environment cannot ignore, but it is obligatory to a small extent **[10,11]**. A significant number of mining activities are contributing to air pollution **[10,12]**. As mining is always associated with pollution due to particulate matter emissions, it results in air pollution. Large quantities of dust have been produced and released in the working atmosphere during mining and handling of materials **[7]**. Environmental degradation starts with excavating materials, resulting in land degradation followed by their fine particles in the atmosphere **[12,13]**. Dust is continuously generating at every stage of coal handling **[8,14]**. The particulate matter discharged into the atmosphere has typical characteristics and environmental impact, as generalized in the summary presented in **Fig. 1.1** **[10]**. Although numerous natural and anthropogenic atmospheric particulates sources, mining operations pose the most significant potential risk to human health and the environment **(Fig 1.2) [15,16]**.

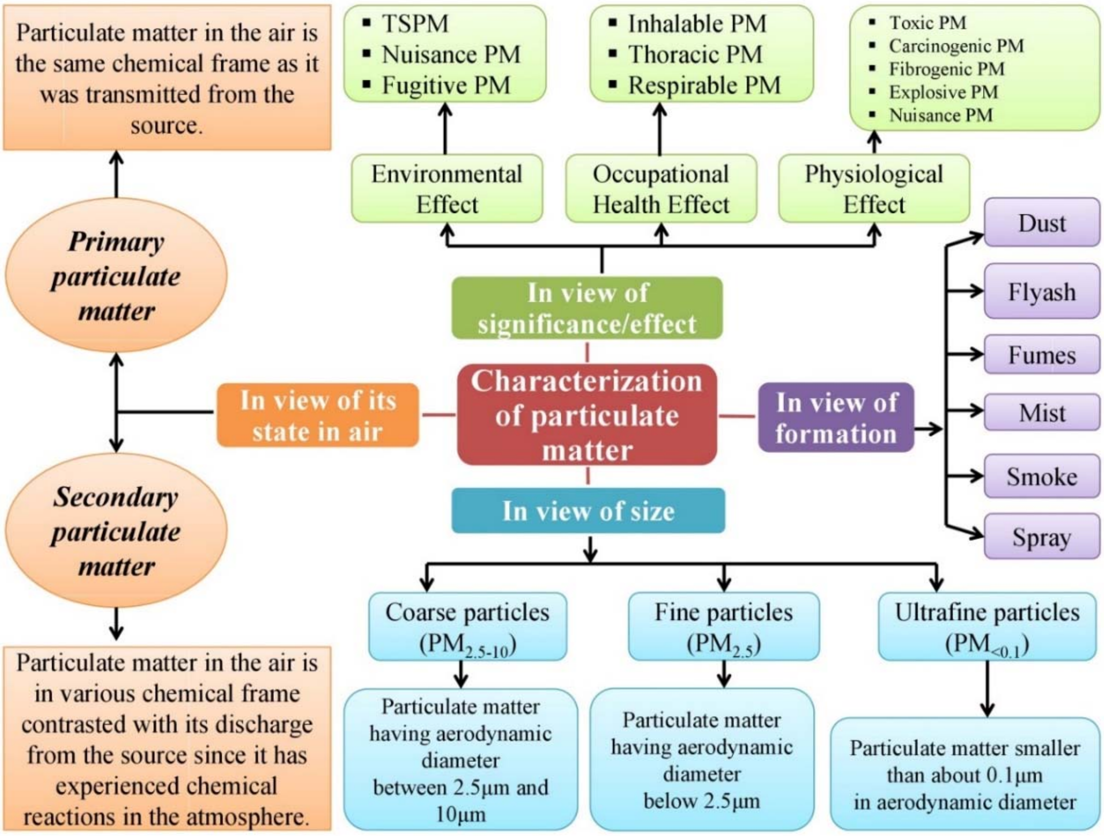

Fig. 1.1: Variables influencing the toxicity of airborne particulate matter (reprinted from Yadav and Jamal **[10]**, with permission from Environmental Quality Management)

In a recent comprehensive assessment of the worst environmental pollution problems, activities associated with mining operations, including artisanal gold mining, metal smelting and processing; industrial mining; and uranium mining, were identified as four of the world's top ten pollution problems **[6,9,17]**. Air pollutants can be natural or anthropogenic in origin. Natural sources include volcanic eruptions, forest fires, soil erosion, etc., whereas industrialization, vehicular emissions, and commercial activities are the primary anthropogenic sources.

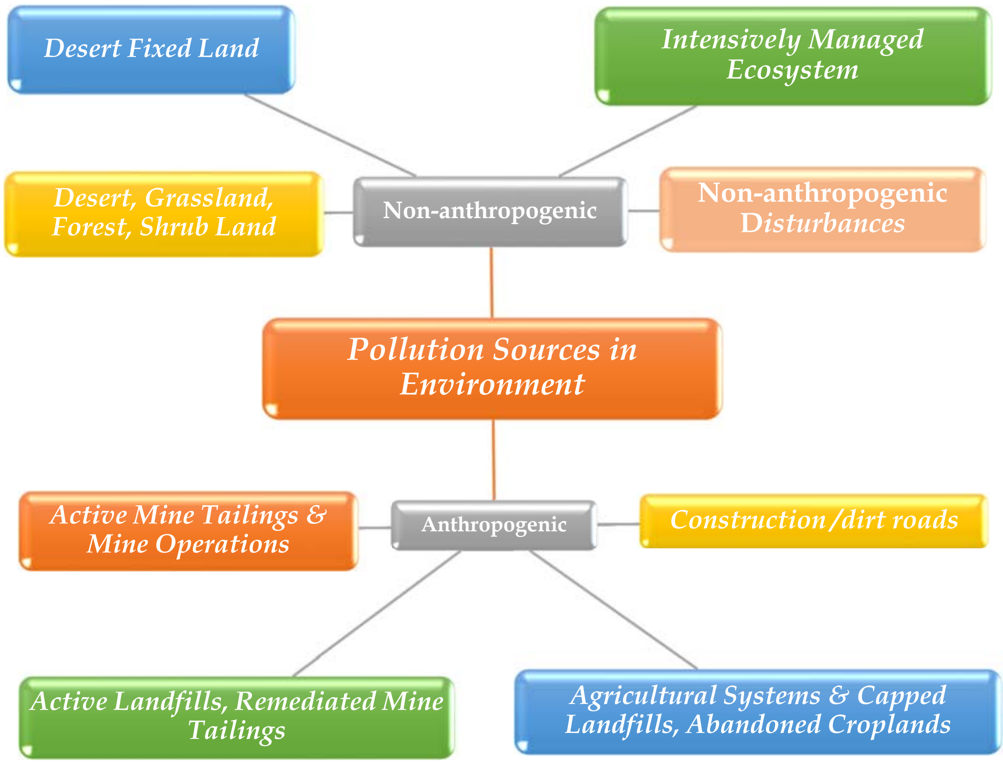

Fig. 1.2: Pollution sources in the environment through anthropogenic and non-anthropogenic dust associated with relative amounts of contaminant concentration, emission (reprinted from Yadav et al. **[15]**, with permission from Environmental Quality Management)

Apart from the natural processes, several anthropogenic activities also contribute metals in the environment. Human activities may profoundly alter the distribution of metals in the atmosphere by introducing minerals into sensitive ecosystems. The development of modern science and technology has translated into the growth of commercial use of metals, and industrial processes generate wastes that have discharged into the environment. Industrial releases constitute many pollutants, especially metals, that have posed a threat of unprecedented magnitude to human life.

1.2 Aerosols and particulate matter

Aerosols and particulate matter are two terms that refer to liquid and solid particles suspended in the atmosphere except for cloud droplets. The term particulate matter relates to the suspended particle alone, while aerosol includes the suspending gas. In practice, aerosol usually refers to the suspended matter as well **[14]**, so throughout this thesis, both terms will be used, referring to the same type of particles in the atmosphere. To be classified as an aerosol, the particle has to be small enough not to settle down from the atmosphere immediately. It can only be achieved by very small particles affected by weak gravitational effects from the earth. However, this can be balanced by winds and turbulent flow, forcing the air pressure to follow the wind speed. In general, the range of aerosols varies with a diameter from 10^{-4} μm to 10 μm **[4,18]**.

1.2.1 Particulate matter size categorization

Particulate matter (PM) consists of discrete particles categorized by sizes spanning several orders of magnitude. Total suspended particulates (TSP) denote all particles referring to less than 100 μm; particulate matter less than 10 μm (PM_{10}) is defined as all particles smaller than 10 μm in aerodynamic diameter; particulate matter less than 2.5 μm ($PM_{2.5}$) is defined as particles smaller than 2.5 μm aerodynamic diameter, and $PM_{10-2.5}$ as the particles with sizes between 2.5 and 10 μm. The coarse and fine particulate matter is identified as those with sizes between 2.5 and 10 μm and smaller than 2.5 μm, respectively (although the terms are sometimes synonymous with $PM_{10-2.5}$ and $PM_{2.5}$, respectively). The ultrafine particles (UFP) have been defined as those smaller than 0.1 μm. Such microscopic particles are particularly important because they are most easily transported into the alveoli of the lungs. They are likely to be more hazardous components such as enriched heavy metals such as lead and arsenic **[19,20]**. To get a better size perspective and understand how tiny those particles size comparison was suggested and shown in **Fig. 1.3 [4]**.

Three different modes typically characterize the distribution of ambient particles as a function of particle size. The importance of each individual is emphasized in **Fig. 1.4**. The distribution has been plotted as particle number, particle surface area, and particle volume concentration. These modes reflect the dominant processes giving rise to ambient airborne particulate matter **[21]**.

Particles smaller than 50nm are termed the nucleation mode and are a newly-formed component of the particle distribution produced by homogenous, heterogeneous, or reactive condensation within the atmosphere or exhaust emissions from combustion processes. Nucleation mode particles are short-lived (minutes to hours) and grow by coagulation or vapor adsorption to form the accumulation mode, which comprises particles of size from 50nm to 1μm. Particles in this latter size range can remain suspended for several days since further growth is inefficient, and gravitational settling and deposition is slow. The coarse mode particles, size >1 μm, are usually primary particles generated by mechanical abrasion processes but may contain other constituents due to coagulation and condensation processes.

Particulate matter (PM) has been classified based on its equivalent aerodynamic diameters. Particulate matter of the same size and equal aerodynamic diameters tend to exhibit the same settling velocities. Furthermore, most researchers have traditionally subdivided particles of the same size as per their equivalent aerodynamic diameter fractions based on their deposition in human airways. The subdivisions include particles with diameters of <10 micrometers (μm), <2.5 μm, and <0.1 μm, which has referred to as PM_{10}, $PM_{2.5}$, and $PM_{0.1}$, respectively. Particles with aerodynamic diameters greater than or equal to 10 μm have relatively short suspension half-lives, and particles of this size tend to be filtered out of the human body by the upper airway of the nose. Particulate matter with aerodynamic diameters between 2.5 and 10μm ($PM_{10-2.5}$) has been defined as coarse particles. PM with aerodynamic diameters of 2.5 μm but greater than 0.1 μm have defined as fine particles, and PM with aerodynamic diameters of less than 0.1 μm have been defined as ultra-fine particles. The total numbers and total surface areas of these particles increase exponentially as the particles' diameters decrease. Thus, the total particulate mass of a substance generally decreases exponentially with decreasing particle diameter **(Fig. 1.5)**.

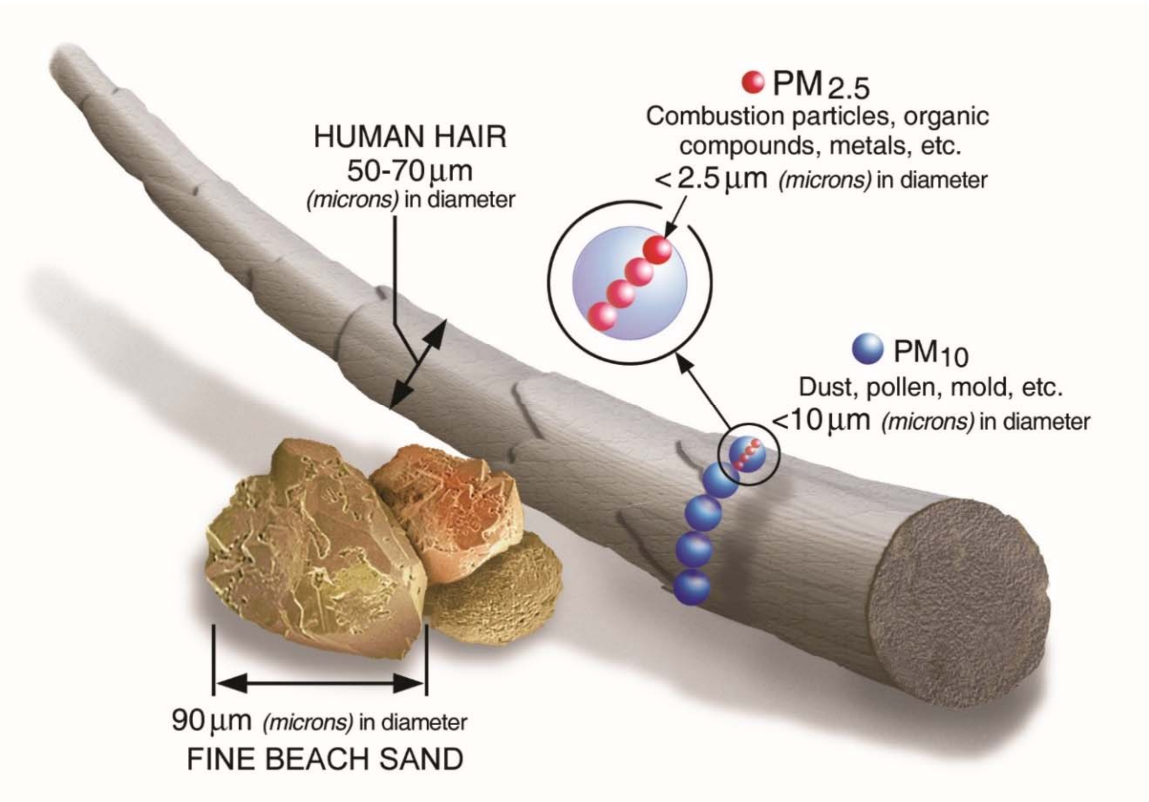

Fig. 1.3: Size comparison of particulate matter (reprinted from USEPA **[4]** with permission from the United States Environmental Protection Agency)

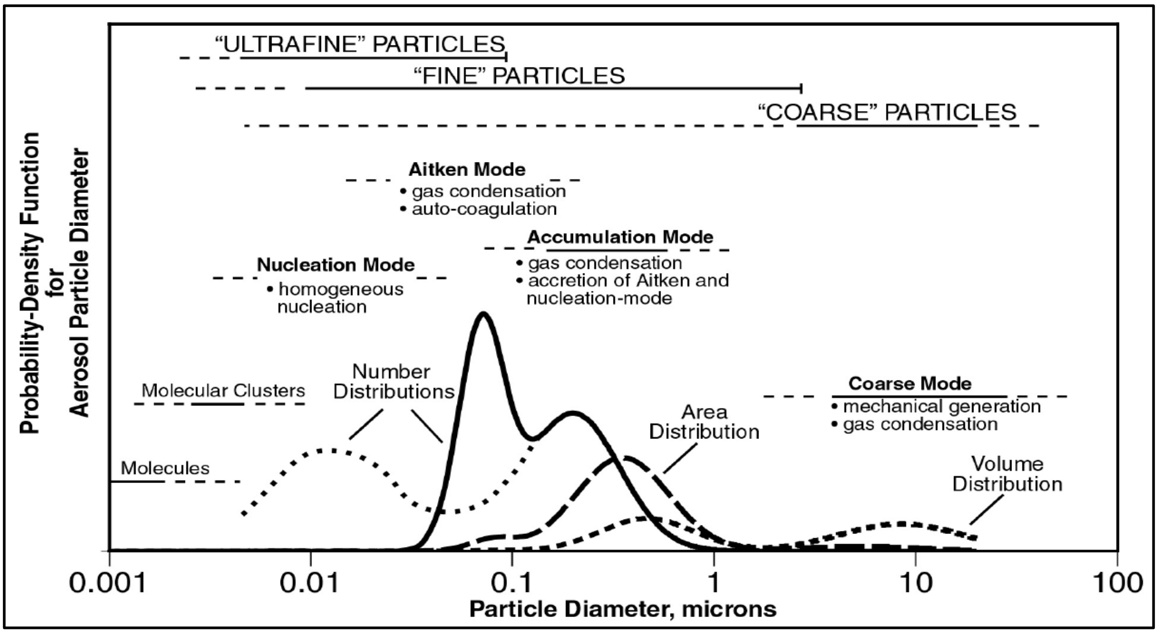

Fig. 1.4: Size distributions of particle numbers along with the mode of formation **[21]**

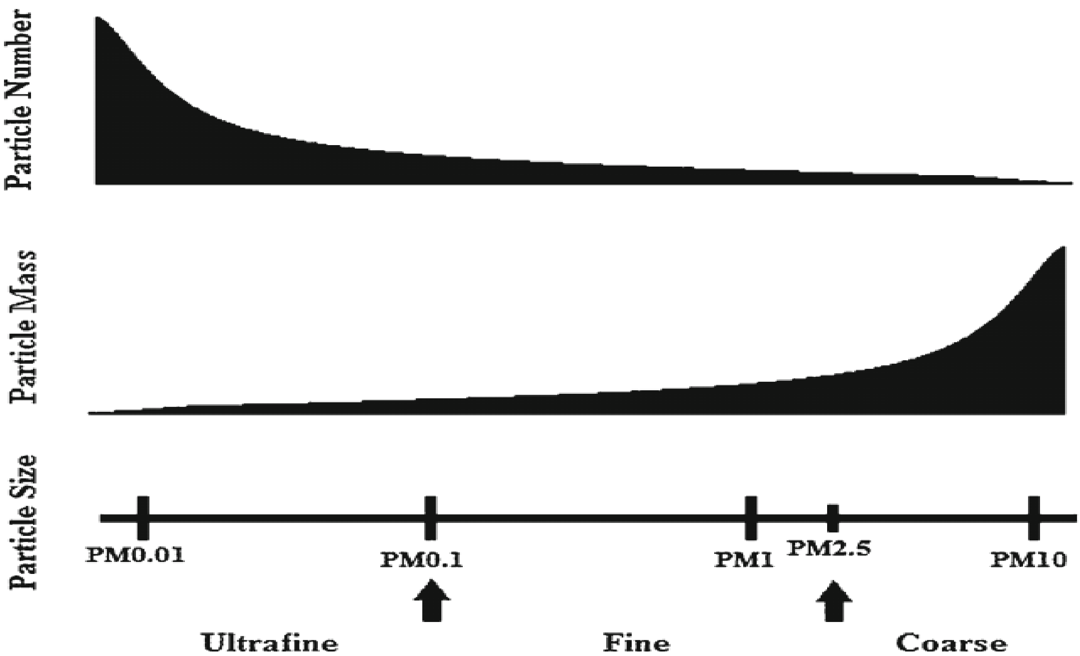

Fig. 1.5: Hypothetical mixed particle distribution (reprinted from Anderson **[22]**, with permission from the Journal of Medical Toxicology

1.2.2 Global pollutant levels in ambient air

In developed countries, modernization trends and cities' associated growth have begun to reverse due to severe congestion levels. In the United Kingdom, motorized road transport has been categorizing as one of the largest single pollution sources in 92% of the areas declared by the national environmental regulatory agency as air quality management areas for having air quality below national standards. Motorized road transport accounts for 33% of oxides of nitrogen (NOx) emissions and 21% of PM_{10} emissions in these areas, leading to frequent violations of the national ambient air quality standards **[23]**. In other European countries, emissions reductions from vehicular exhausts from 1990 to 2009 are approximately 16% for PM_{10} and 21% for $PM_{2.5}$. Despite these efforts, it has been observed that 18 to 49% of the populations in these countries have still exposed to PM_{10} concentrations exceeding the ambient standards **[24]**.

Global satellite imagery of fine particulate matter in different locations worldwide has allowed the review of the spatial variations shown in **Fig. 1.6**. **Fig. 1.6** shows the satellite images of average $PM_{2.5}$ concentrations over the six years from 2001 to 2006 **[25,26]**.

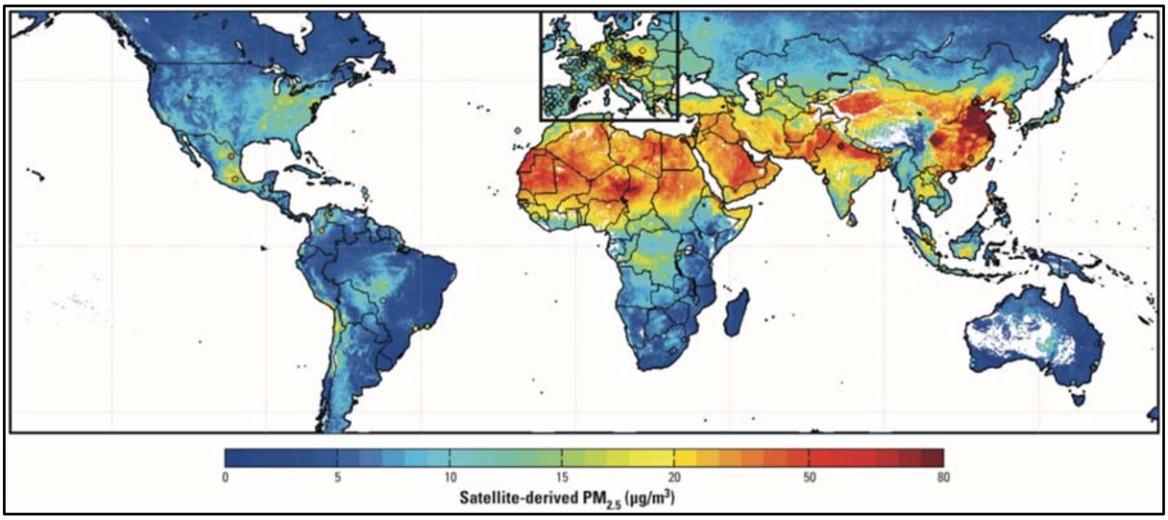

Fig. 1.6: Global satellite-derived concentration of $PM_{2.5}$ (micrograms per cubic meter [μg m^{-3}]; reprinted from Donkelaar **[25]**, with permission from Environmental Health Perspectives)

The satellite imagery shows $PM_{2.5}$ concentrations varying spatially from 0 to 80 micrograms per cubic meter (μg m^{-3}) with an average value of 20 μg m^{-3} based on the best available data on $PM_{2.5}$. As the figure shows, many countries, including the United States, Canada, Russia, Brazil, New Zealand, and Australia, have $PM_{2.5}$ values that are near or less than the WHO permissible range of 10 μg m^{-3} (annual), whereas $PM_{2.5}$ concentrations over India, China, central and northern Africa, and Saudi Arabia exceed the prescribed guidelines **[27,28]**. When compared to maximum world concentrations for $PM_{2.5}$, as well as for general air pollution, Asian countries are known to have the most polluted cities **[28]**. According to the United Nations' Department of Economic and Social Affairs' World Urbanization Prospects report, a staggering 66% of the global population will be living in urban locations by 2050. It increases from 30% of the world's population living in urban areas in 1950 and 54% in 2014 **[29]**.

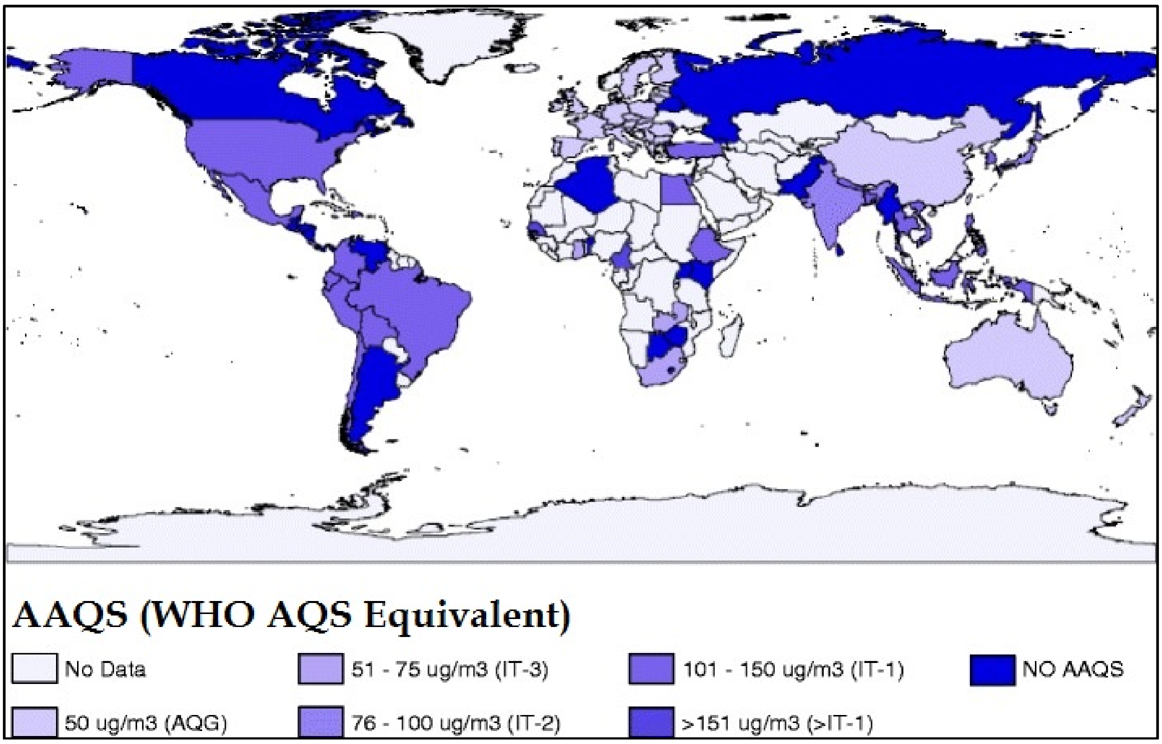

Fig. 1.7: Range of national ambient air quality standards for 24-hr PM_{10} (reprinted from Vahlsing and Smith **[30]**, with permission Air Quality, Atmosphere & Health)

Measurement of air quality in real-time was introduced in 2014 for the National Air Quality Index by the Indian government. The introduction of the Air Quality Index not only notifies the public about the levels of air pollution they are breathing, but it can also be used to protect public health and build awareness of air quality **[31]**. Therefore, these indices' availability helps compare air quality status across the world and design policies for different countries that would support global environmental improvements. Air quality monitoring networks have been designed and are operated in most developing countries to ensure effective regulatory compliance and guidelines. As of June 2017, the Indian National Ambient Air Quality Monitoring network includes 683 operating online air monitoring stations covering 300 cities and towns in 26 states and four Union Territories **[32]**. Worldwide comparison of these results with the national ambient air quality standard used by most countries demonstrated that most countries have a standard for PM_{10}, as shown in **Fig. 1.7**, and the average 24-h PM_{10}, the standard is found to be 95 μg m^{-3}, which is 63% of the United States Environmental Protection Agency's Air Quality Guideline value **[30,33]**.

1.3 Sources of the particulate matter

Atmospheric aerosols result from two distinct formation mechanisms:

(1) Direct injection of particles into the atmosphere, often by dispersion processes, resulting in so-called primary aerosols, and

(2) Transformation of gaseous precursors (through nucleation and condensation processes) into liquid or solid secondary aerosol particles.

Atmospheric aerosols originate from either natural or anthropogenic (human-made) emissions through either primary or secondary processes. The main categories of primary/secondary and natural/anthropogenic sources have presented in **Table 1.1**. The primary sources and associated aerosol components (species) have been fully discussed in the subsequent sections. The primary natural components are soil dust, sea salt, natural sulphate, volcanic aerosols, and those generated by natural forest fires. Natural aerosols are of particular importance because they provide a base level for the aerosol effects, and there is no effective way of controlling them. On a global scale, the abundance of natural aerosols is several times greater than that of the significant anthropogenic. Consequently, natural emissions must be considered when considering air pollutants and their sources **[34,35]**. As can be seen in **Table 1.1,** a substantial fraction of today's tropospheric aerosols is anthropogenic.

Table 1.1: Sources of the particulate matter along with their sizes

Source			**Particle Size (µm)**
Natural	**Primary**	Soil dust (mineral aerosols)	D <1
			D = 1-2
		Sea to air flux of sea salt	D <1
			D =1-16
		Biogenic organic matter	Coarse
		Volcanic ash	Fine
	Secondary	Sulphate aerosols from marine biogenic gases (mainly DMS)	Fine
		Sulphate aerosols from terrestrial biogenic gases	Fine
		Nitrate aerosols from NOx (lightning, soil microbes)	Coarse
		Organic matter from biogenic gases	Fine
		Sulphate aerosols from volcanic SO_2	Fine
Anthropogenic	**Primary**	Aerosols from all kinds of fossil fuel burning, cement manufacturing, metallurgy, waste incineration, etc.,	Coarse and fine
		Soot (black carbon) from fossil fuel burning (coal, oil)	Fine
		Soot from biomass burning	Fine
		Biomass burning without soot	Fine
	Secondary	Sulphate from SO_2 (mainly from coal & oil burning)	Fine
		Nitrate aerosol from NO_x (fossil fuel and biomass combustion)	Fine
		Organic matter from anthropogenic gases	Mainly coarse
		Organic matter from biomass burning	Fine
		Organic matter from fossil fuel burning	Fine

Anthropogenic aerosols' contribution to the total aerosol burden is more significant in industrial and urban environments than in rural and remote areas. Anthropogenic aerosols typically dominate in the sub-micrometer size range, and they are composed of a variety of inorganic and organic species **[36-38]**.

1.3.1 Sources of particulate matters due to mining activity

Air pollution has been defined as all destructive effects of any sources which contribute to the pollution of the atmosphere and deterioration of the ecosystem. Air pollution has caused by both human interventions and natural phenomena. It comprises many kinds of pollutants, including materials in solid, liquid, and gas phases. The surface mining of large-scale mechanization has resulted in widespread concern about environmental quality deterioration, especially the SPM concentration increases within and around the mining area. The haul road of mechanized opencast mines through vehicular traffic has to identify as the most profile source of fugitive dust emitted from the surface coal mines **[39,40]**. According to researchers **[41,42]**, surface coal mining estimated that about 50% of the total dust is released during the movement time of dumper on an unpaved haul road, while 25% for loading and unloading dumper both sites. Coal is lost as fugitive dust during loading for transport, and a similar percentage is lost during unloading. The haul road dust is formed of a spectrum of sizes from submicronic particles to large pieces of a few centimeters in diameter, while dumpers moving at high speed crush the large pieces to more exceptional size fugitive dust. Spillage from these vehicles (Shovel, Dumper, etc.) adds to the haul roads' dust load; thus, the haul roads often show 4-6 inches thick or more accumulated dust on the surface. The road dust contains 3–4% or more of the respirable dust particles, which could quickly get airborne during adverse conditions **[43-45]**. A brief review of particulate matter characterization has summarised in **Table 1.1**.

Dust is the primary air pollutant in opencast mining areas **[46,47]**. Mandal **[44]** has reported haul roads to produce 0.25–0.70 kg of dust per kilometer travel of a dumper. Ghose and Majee **[5]** report that a total generation of 9.4 tonnes of dust per day as a result of whole mining operation in an opencast mine of Jharia Coalfields, of which 7.8 tonnes of dust has generated due to various activities (topsoil removal, overburden removal, extraction of coal, size reduction), and 1.6 tonnes of dust per day was contributed by wind erosion. Maximum concentrations of total suspended particulate matter and respirable particulate matter are found in mining areas, and concentrations gradually decline with increased distance due to transportation, deposition, and dispersion of particles **[48,49]**.

Several authors **[50,51]** studying coal dust generation have observed that particulate matter's maximum concentration generally occurred during winter and minimum in the rainy season. According to the analysis carried out by Amponsah-Dacosta **[52]** using the US Environmental Protection Agency **[53]** guidelines, 93.3% of the total emissions from coal mines were attributable to dust generated from haul roads of South African coal mine. The second-largest source was topsoil handling (2.7%), followed by overburden stripping (1.6%), coal removal (0.8%), coal handling (stockpiles; 0.1%), drilling and blasting (0.4%), and miscellaneous (1.1%). However, emission rates in Indian mines are different from those in the USA due to the differences in mining, site practices, mitigation measures, and geological and climatic conditions. It was reported that 80.2% of total dust emission is from the transport road of Indian mines **[50]**. The screening plant is the next more significant dust emission source, which contributes 8.1% of dust while 2.8% is released from overburden removal. Topsoil handling releases 2.6% of total dust, followed by coal extraction (2.2%), drilling and blasting (1.3%), coal handling or stockpile (1.1%) of dust, and 1.7% is from miscellaneous work.

At present, various techniques are using for controlling road dust, namely,

a) spraying of water on roads at a regular interval; but due to its high surface tension, it is not significantly potential as a wetting agent. Surfactants are added to water to increase the wetting and to capture capacity by affecting the surface tension of the liquid and its interfacial tension against dust,
b) Application of binding materials with water on the haul road. Kost et al. **[54]** and Foley **[55]** have reported a reduction of 27% and 36% in respirable dust and total airborne dust concentrations after the addition of surfactant to water, respectively,
c) Converting unpaved road to a blacktop road,
d) Dust collector also plays a vital role in dust reduction from mines by capturing the airborne materials from the air stream and discharge cleaned air into the atmosphere back, and
e) Development of a green belt on both sides of a transport road. Trees with small branches and tightly arranged broad leaves, hairy with shiny or waxy leaves with high proline content, are preferred to inhibit or minimize dust level **[56,57]**.

Therefore, all these techniques are ineffective because they cannot wholly remove dust (i.e., the sources) from the road surface. For effective control measures, dust must be collected from the road surface, and It can be converted into a solid form, which has been used as domestic fuel.

1.3.2 Source identification and apportionment techniques of particulate matter

Mathematical and statistical methods for source identification and apportionment studies of air pollutants have presented in **Table 1.2**. From **Table 1.2**, the statistical models that can be employed in a variety of air pollution studies to characterize the spatial variability of pollutants. Various studies have reported morbidity and mortality linked with PM exposure; however, there is an urgent need to understand air pollutant actions' mechanisms in an integrated manner.

Hierarchical models have been used effectively to pool health risk evaluations across multiple time-course measurements in several spatial locations to determine the overall associations between daily variations in exposure and health outcomes by accounting for time-varying confounders and variability across areas. The model has to allow multiple levels of information regarding spatial accumulation from different locations and estimate differences within a location, across locations within a region, and regions. The model must also allow for probable consequence changes at every level **[58]**.

Interestingly, employing the pooling strength of data across locations can provide estimates of location-specific risks. The longitudinal complexities of the problems are another reason why the powerful statistical model is required to identify long-term effects. For example, air pollution may adversely impact human health and the future biosecurity and food security of a country. Land use regression models have been applied to model annual mean concentrations of different pollutants varying over time and space. As such, land-use regression models are encouraged for use in Asian countries **[59]**.

Principal components analysis can isolate or identify the most substantial variations in a data set. A combination of principal components analysis and cluster analysis can also be used to classify synoptic metrological conditions. This model can be used for source apportionment studies, as well **[60,61]**.

Table 1.2: Mathematical and statistical techniques for source identification and apportionment studies in air pollution

Statistical method	Application	Comment	Reference
Artificial neural network	For air quality forecasting, modeling, and prediction	Using air pollution and meteorological data for future ambient climate can be easily predicted with Artificial neural network models	**[62]**
Cluster analysis	It can be used for evaluation aerometric data and to analyze air quality	Spatial and Trends distribution of atmospheric pollutants can be studied	**[63,64]**
Empirical orthogonal function analysis	For dimension reduction method and most widely used Empirical orthogonal function analysis in environmental sciences	It can isolate or identify the strongest variations in the data set. Empirical orthogonal function analysis can be used to classify synoptic metrological conditions. It can also be used for source apportionment studies	**[65]**
Environmental benefits mapping and analysis program Model developed by the USEPA	It is a GIS-based software tool for the creation of community-level ambient pollution exposure maps. It systematically analyses the impacts of changes in environmental quality in a suitable trend and effectively addresses uncertainty and unpredictability	This tool used for estimation and assessment of health impacts and associated economic benefits with a change in air quality	**[66,67]**
Fine resolution atmospheric multi-pollutant exchange model	To study spatial patterns of air pollutants through the Fine resolution atmospheric multi-pollutant exchange model and It is based on the Lagrangian atmospheric transport model	It can be used to derive spatial information of the different type of air pollutants	**[68]**
Hierarchical models	It can be allowing the multiple levels of spatial aggregation of available multisite information along with their estimation of variations within site, across sites, within a region, and across the regions, and potential effect modifiers at each level	As such, a hierarchical model has been used for pooling information across locations for estimating an overall association between daily variations in exposure and health outcomes	**[58]**

Independent component analysis	It is an exploratory tool for data analysis to identify main sources of variability	Independent component analysis can also be used to observe the existence of spatial and temporal activity in the climate and weather	**[69]**
Land use regression models	Land use regression models were used to model small-scale variations in air pollution and, nowadays, initially. It is used to assess the spatial variation of different air pollutants or ambient air pollution that areas	It can be applied to model annual mean concentrations of the different pollutants varying with time and space. As such, Land use regression models are encouraged for use in Asian countries	**[59]**
Multiple or multivariate linear regression model	It is used for air pollution predictions (both quantitative and qualitative forecasts). Estimation of spatial interpolation, spatiotemporal air pollution analysis, and identifying emission sources	Such models can be applied to the time-series analysis of data to develop a relationship between pollutant concentrations and other environmental (meteorological) variables. Also, for mapping long-term air pollution concentrations to support policy decisions	**[70]**
Principal components analysis	It is the dimension reduction method and the most widely used multivariate statistical technique in atmospheric sciences	It can isolate or identify the strongest variations in the data set. Combined Principal components analysis and Cluster analysis can be used to classify synoptic metrological conditions. The model can also be used for source apportionment studies	**[61,71]**
Semiparametric models, including generalized additive models	To predict exposures' outcomes, they mix parametric and smooth nonparametric terms in the same model for different predictors. They are particularly useful in the presence of confounding effects, measured or otherwise	As such, modeling has seen widespread applications in recent years	**[72]**
Stochastic models	It is being used to study air pollution resulting from highway and road traffic	As such proposed stochastic traffic flow model can be employed to predict pollutant concentrations	**[73]**

GIS: geographic information system

1.4 Exposure inhalation of particulate matter

Air pollution is a multifaceted mix consisting of particulate matter and gaseous pollutants. Globally, air pollution continues to be a significant environmental problem that has been recognized as an essential public health risk. The increase in the human population, industrialization, urbanization, and modernization, and its attendant increase in vehicular emissions and activities are the major contributors to the rising urban air quality problems. The minerals that are mined and the methodology used in mining affect particulate matter generation and human exposure. Health hazards associated with adverse effects may be acute, intermittent, or chronic particulate matter exposures. Among the common hazardous substances present in mined minerals are arsenic, beryllium, lead, mercury, and radon. Particulate matter inhalation in and around opencast coal mining and coal-based power plant activities lead to many common diseases, such as asthma, black lung, silicosis, asbestosis, bauxite fibrosis, and siderosis **[74]**. Several studies have shown that particulate matter generated through mining operations and coal burning in power plants is associated with increased disease rates in living beings and the environment's degradation. Small quantities of some metals are essential for human health **[75]**. However, high levels of exposure to metal dust are hazardous to human health. The adverse health effects of inhalation of metallic dust depend on the nature, composition, exposure duration, and quantity of dust **[19,37]**.

A particulate matter from coal mining operations affects the respiratory system and causes various respiratory diseases **[8,76]**. Black lung disease is common among coal mine workers, and the inhalation of coal dust causes it and its deposition in the lungs **[58,77]**, while the occurrence of respiratory conditions, including asthma and bronchitis, is caused by the inhalation of organic dust in coal mining operations **[78,79]**.

1.5 Health effects due to ambient air pollutants

Air pollution is a significant problem in recent decades, which has a serious toxicological impact on human health and the environment. The pollution sources vary from small units of cigarettes and natural sources such as volcanic activities to large volumes of automobiles and industrial activities. Air pollution's long-term effects on the onset of diseases such as respiratory infections and inflammations, cardiovascular dysfunctions, and cancer are widely accepted. However, air pollution is linked to millions of deaths globally each year. A recent study has revealed the association between male infertility and air pollution **[80]**. Increasing particulate matter significantly affects air quality and human health due to toxic metals in atmospheric particulate matter. Therefore, air pollution has emerged as a significant public health issue **[61,81]**.

Emissions from motor vehicles are the primary source of particulate matter, volatile organic compounds, oxides of nitrogen (NO_x), and carbon monoxide (CO), all of which have adverse effects on the exposed community **[82,83]**. Differences in air pollutant composition, dosage, and exposure time, along with the fact that humans have generally been exposed to polluting mixtures rather than single substances., can lead to diverse effects on human health. The human health effects can range from nausea, difficulty breathing, or skin irritation to cancer. Health effects can also include congenital disabilities, severe developmental delays in children, and reduced immune system activity, leading to several diseases.

Moreover, several susceptibility factors exist, such as a person's age, nutritional status, and predisposing conditions. Numerous studies have estimated the impacts of these air pollutants on the respiratory system, including pneumonitis, bronchitis, pulmonary edema, shortness of breath, coughing, and the immune system and the cardiovascular system **[14,84]**.

1.6 Recent investigations on ambient air pollutants

The literature survey on the study of particulate matter in ambient air, its chemical composition, and apportioning the sources is exhaustive. Dust is the single most environmental concern for any mining activities, and the problem is more severe in the case of mines. Monitoring has been carried out by different researchers at different sources of dust emission in mines. Pneumoconiosis is a significant health problem among the workers of mine for their continuous exposure to dust.

Extensive studies have been carried out to assess the personal exposure level of dust and silica content in the respirable range vis-a-vis regulatory limits. Dust content with a large amount of silica is a carcinogen. The monitoring of dust exposure levels among the workers is essential. Finally, the prediction of concentration levels of dust around the mine due to the dust released from the mining activities is necessary to have an overall environmental impact assessment for any quarry. Local meteorological conditions play an essential role in the dispersion of dust.

Various mathematical models have been developed for this purpose. Researchers have often validated these models for different meteorological conditions and develop the most appropriate model for a particular meteorological situation. The research work done are summarised below:

Aneja et al. [12] In developed countries, in the difference between the mass concentrations of PM_{10} related to the surface coal mining in two areas in Appalachia, USA, PM_{10} is typically composed of a complex mixture of chemicals that strongly depends on source characteristics.

Balasubramanian et al. [85] carried out a study to determine the particulate matter in the region of the Indian Ocean and surrounding countries of air pollution. Airborne particulate matter concentrations of selected metals and water–soluble ions were measured. In general, particulate matter concentrations were influenced by the proximity of sampling locations to land and air mass origins. The enrichment of metals in the particulate matter was very high relative to those in crustal material. Metal samples were significantly higher in particulate matter samples that were affected by volcanic emissions from Indonesian landowners. The volcanic plume was traced using backward air mass trajectories and chemical trailers, and the Southern Hemisphere of the Indian Ocean was identified as a major particle pollution source. NO^{3-}, NH_4^+, and SO_4^{2-} were low in aerosols collected over the open ocean, but a linear relationship between NH_4^+ and SO_4^{2-} indicates their importance in forming cloud condensation nuclei. No significant differences in the concentration of ions, extracts, and metals were observed between the NE and SW monsoon and the inter-monsoon period.

Behera et al. [86] carried out the gaseous toxic air pollutants usually associated with acute short–and long–term health effects. Therefore, a measurement of these pollutants daily is necessary to understand the science of these events. The gaseous O_3, SO_2, NO_2, NH_3, HNO_2, HNO_3, and HCl and water-soluble inorganic ions (Na^+, K^+, Ca^{2+}, Mg^{2+}, NH_4^+, NO_3^-, SO_4^{2-}, and Cl^-) in $PM_{2.5}$ in Kanpur, India were measured using an annular denuder technique at twelve–hour time resolution during summer. The SO_2, NO_2, Na^+, HCl, NH_4^+, and Cl^- did not show any significant fluctuations. Ion balance revealed that an abundant quantity of NH_3 was present in the samples and neutralized to H_2SO_4, HNO_3, and HCl form $(NH_4)_2SO_4$, NH_4NO_3, and NH_4Cl, and thermodynamics for the formation of NH_4NO_3 was adapt to more humid conditions.

Cai et al. [87] In exposure estimates for indoor exposure to air pollutants with outdoor origin can be improved using the necessary personal information collected with questionnaires. However, we could confirm that the health-relevant outdoor air pollutants evaluated in this study remain important determinants of residential indoor exposure, except for the coarse particle fraction. We cannot conclude the prediction of indoor levels based on outdoor data not possible. The highest fraction of outdoor concentrations contributing to indoor levels were observed for particulate matter absorbance, which may qualify as a prime candidate for use in health studies about the relevance of ambient air pollution. If information about windows is available, models for the ultrafine fraction of particles' median level are rather promising, indicating that ambient particle number concentration's long-term health effects have been investigated.

Chaulya et al. [88] carried out a study to determine the emission rate for SPM to calculate the emission rate for various opencast mining activities. For validation, Fugitive Dust Modelling (FDM) and Point, Area, and Line source model (PAL2) were used. Both models run separately for each mine's same input data to get predicted concentrations at three receptor locations. FDM was found to be more suitable for Indian mining conditions. It was observed that coal handling plants, haul roads, and transport roads were the major sources of dust emission. The average accuracy between observed and predicted values for SPM at certain locations for PAL2 and FDM model was 60-71% and 68-80%, respectively.

Chaulya [82] assessed air quality around the Lakhanpur area of Ib valley. TSP, PM_{10}, SO_2, NOx was monitored at 13 locations for one year. 24 hour and annual average TSP and PM_{10} exceeded NAAQS standards, whereas SO_2 and NOx remained within the limit. 31.94% of TSP was found to be within PM_{10}. Green belts were prescribed as a mitigation measure.

George et al. [18] Estimating fine airborne particle ($PM_{2.5}$) concentrations is possible through rigorous empirical correlations based on monitored PM_{10} samples. From this study, the twenty–six locations spread over three different environments, a relatively clean coastal area, two coal mining areas and a highly urbanized area in Delhi were used. The use of regression analysis for estimating the percentage of $PM_{2.5}$ in PM_{10} in different environments to identify the source. A relatively low percentage of $PM_{2.5}$ concentrations

(21, 28, and 32%) in PM_{10} were found in the clean coastal and two mining areas, respectively. The percentage of $PM_{2.5}$ concentrations in PM_{10} in the highly urbanized area of Delhi was 51%, indicating a very high percentage of fine particles due to the combustion of vehicles in Delhi. The source identification of particles because differences in the percentage of concentrations of $PM_{2.5}$ in PM_{10} can be attributed to the characteristics of sources in different ambient environments.

Ghosh and Majee [7,43] investigated airborne dust created by opencast mines at Jharia coalfield. Particles were more respirable with a median diameter of 20µm. Work zone air was found to contain more TSP, RPM and benzene soluble matter than ambient air. The highest concentration of SPM was found at the Dragline section and the next lower concentration at haul road. At the feeder, TSP was found to be the highest. Respirable particulate matter was found to be highest in summer. TSP concentration at daytime was highest compared to the other two periods as most of the works were done during general shifts (from 0800hrs to 1700hrs). At almost all locations, TSP concentrations exceed the permissible limits by CPCB during winter, summer and monsoon period. The weight percentage of the respirable fraction in haul road TSP was more than that of feeder breaker TSP.

Gianini et al. [89] Used PMF Models to provides a detailed update of the chemical composition of PM_{10} at different site types in Switzerland. It is evident from this work that the emission reduction strategies for PM_{10} and precursors of secondary PM_{10} that have been implemented during the past ten and more years led to a definite improvement of ambient PM_{10} levels. The most noticeable changes are the decreasing concentrations of sulfate, EC, and many trace elements (Pb, Ni, V, Cd). The decreasing concentrations of EC indicate that significant reductions of exhaust emissions from road traffic have been achieved. This indication has been confirmed by analyses of the datasets from 2008/2009 and 1998/1999 for source contributions using positive matrix factorization (PMF), which is discussed in detail.

Gonzalez et al. [90] SEM studies show that the quartz grains in the residential areas are mostly sub-rounded and sub-angular in the respirable dust. The other mineral grains like feldspar, plagioclase, and clay are mostly tabular and acicular in shape. The presence of coal, silica, and other rock constituents in the SPM of residential and working areas shows that persons working in the mines and residing in the nearby areas are also continuously explored to such harmful constituents of the dust. Air quality perception analysis reveals that the levels of awareness regarding air pollution are more among the mining industry persons than persons engaged in some other occupations. It seems to be perhaps owing to their perception of air pollution while at work in the mining area and their seriousness towards the problem.

Gurjar et al. [81] evaluated the health risks in megacities in terms of mortality and morbidity due to air pollution. The risk of the spreadsheet's mortality and morbidity model has been used to estimate the excess numbers of deaths and illnesses. The World Health Organization guideline concentrations for the air pollutants SO_2, NO_2 and total suspended particles, concentration-response relationships, and a population attributable-risk proportion concept are employed by this adopting method. This study's outcomes suggest that some megacities (Los Angeles, New York, Osaka Kobe, Sao Paulo, and Tokyo) have very low excess cases in total mortality from these pollutants. Risk estimates derived from the risk of mortality and morbidity present a realistic baseline assessment for ambient air pollution outcomes compared to simple air quality indices and extend and improve this in parallel with the development of air pollution monitoring networks.

Jamal [91] In this investigation, the environment's quality will be degraded due to the release of various by-products and the destruction of the earth–system during mining activities in general and opencast mining in particular. It comes to realize that there is a need for environmental protection for future healthy survival in and around an opencast coal mine. The opencast mining degrades the air quality significantly, which depends on the level of activities. SPM for air quality is the main threat to environmental quality and its degradation. In the coal mining area, the free quartz percentage in SPM is found to range from 45 – 55 %, while in residential areas, it is found to be between 10 – 20 %. The SPM in the mining areas 90 % of it is in the size range of 0 – 60 μ, and amongst this, the percentage of the inhalable size of 10 μ is around 30 while the percentage of the respirable–size of 3.5 μ is around 15 %. The drilling dust is found to contain 68 and 37 % of inhalable and respirable dust size. Haulage is the main source of dust in opencast mines but has the least inhalable (28%) and respirable dust (17%).

Kulshrestha et al. [92] carried out the metal concentration of $PM_{2.5}$ and PM_{10} particulate and seasonal variations in the urban and rural environment of Agra, India. The annual mean concentration is usually larger urban sites than the rural site.

Kumar et al. [93] Very high concentration of suspended particulate matter (SPM) is observed at India's traffic junctions. Factor analysis-multiple regression (FA-MR), a receptor modeling technique, has been used for quantitative apportionment of the sources contributing to the SPM at two traffic junctions (Sakinaka and Gandhinagar) in Mumbai, India. Varimax rotated factor analysis identified (qualitative) five possible sources; road dust, vehicular emissions, marine aerosols, metal industries, and coal combustion. A quantitative estimation by the FA-MR model indicated that road dust contributed to 41%, vehicular emissions to 15%, marine aerosols to 15%, metal industries to 6%, and coal combustion to 6% of the SPM observed at Sakinaka traffic junction. The corresponding figures for Gandhinagar traffic junction are 33%, 18%, 15%, 8%, and 11%. Due to limitations in source marker elements analyzed, about 16% of the remaining SPM at these two traffic junctions could not be apportioned to any possible sources by this technique. Of the observed lead in the SPM, FA-MR apportioned 62% to vehicular emissions, 17% to road dust, 11% to metal industries, 7% to coal combustion and 3% to marine aerosols at Gandhinagar traffic junction and about a similar apportionment for lead in SPM at Sakinaka traffic junction.

Kumar et al., 2004 [94] Used the FA-MR model to identify the sources of SPM at two traffic junctions in Mumbai. In this technique, the absolute factor scores were regressed on the observed SPM concentration to apportion the SPM to each sample. At one junction, five factors were identified for the 24-hour average SPM concentration 41.4% was contributed by road dust, 14.3% from vehicular emissions, 15.2% marine aerosols, 6% from coal combustion, 6.2% from metal industries, and 16.9% remained unexplained contribution.

Kumar et al. [2] have investigated a significant fraction of daily personal exposure to air pollutants during transport into the microenvironments. The systematic mobile monitoring on a pre-defined route assess personal exposure levels of particulate matter in four transport into the microenvironments, i.e., bus, car, cycle and walk. This investigation has been found during the morning peak, afternoon off-peak, and evening peak at UK town, Guildford. The study aimed to determine the quantity of real-time exposure to fine and coarse particles and identify the factors affecting their Spatio-temporal variation and estimate the respiratory deposition dose.

Kumari et al. [95] carried out a study to determine quartz content in airborne respirable dust (ARD) using the FTIR spectrometer. Personal dust samplers were used to collect airborne respirable dust at different mine locations using GLA-500 PVC membrane filters. The quartz percentage was found to be less than 1% in almost all workings at Jharia coalfield. The maximum Exposure Limit (MEL) was equal to 3mg/m3 in most workplaces.

However, in metal mines, quartz content was more than 5% in many workings. It has been found that good ventilation and wet drilling control the dust problem at some locations, whereas workers' rotations are required in some other locations.

Mishra et al. [83] carried out the observed traffic-induced gaseous emission dispersion characteristics from urban roadside in Delhi, India. The density of pollutants. CO, NO_2, and SO_2 were measured at five selected local urban road sites with simultaneous traffic and ambient atmospheric conditions. It has also been established that the developed model demonstrates the ability to reasonably estimate the characteristics of the dispersion of gaseous pollutants from on-road vehicles to the urban city air quality.

Ozden et al. [96], under the national and international legislation and implementations, air pollution in Eskisehir has decreased significantly, particularly during the last10 years. The use of natural gas for industry (since 1994) and residential heating (since 1996) has been effective in the significant decrease (75%) in SO_2 levels. Partly switching to public transportation by the railway system at the end of 2004 played an important role in decreasing NO_2 concentrations (45%) within the city's central part. Thus, the methodology applied is expected to be useful for future air pollution control applications in other urban areas and improve monitoring and evaluation systems, building air quality management strategies, and preparing new clean air plans.

Pascal et al. [97] Aphekom performed health impact assessments of urban air pollution in Europe. Improving air quality would result in significant health and monetary gains. $PM_{2.5}$ annual mean to 10 μg m^{-3} could add more than six months of life expectancy at age 30 in half of the cities. The associated costs would reach 30 billion Euros annually. European citizens are still exposed to concentrations exceeding the WHO recommendations. Aphekom provided robust estimates confirming that reducing urban air pollution would result in significant health and monetary gains in Europe. This work is particularly relevant now when the current EU legislation is being revised for an update in 2013.

Prusty [98] This investigation is based on the ambient air quality monitoring for SPM, RPM, SO_2, NOx, and CO at eight strategic locations in and around two major lignite mining sites in western Kachchh. He got all these air quality parameters well within the permissible limits prescribed by CPCB for residential and industrial areas. In certain locations, the CO level was below the detectable levels. The investigation threw light upon ambient air quality in and around selected mine areas in the Kachchh region. Increased mining of lignite from Matana Madh, the operationalization of several new major cement industries, and increasing limestone mining in the region necessitate a comprehensive assessment of the ambient air in the whole region comprising other industrial locations, such as thermal power plants, cement plants, ports, and jetties.

Srimuruganandam and Nagendra [99] in the developing city, the mass concentration between PM_{10} and $PM_{2.5}$ is usually larger than the winter season followed by the monsoon and summer season originating mainly a long–range of marine aerosol and vehicular origin of air pollution.

Trivedi et al. [57] examined different dust generation sources and calculated dust emissions from different point, line and area sources in an opencast coal mine. They have carried out air quality modeling using the Fugitive Dust Model. Dust produced by different mining activities doesn’t add to ambient air quality beyond 500m. A modified Pasquill and Gifford formula was used to determine the level emission rate. The predicted value of the suspended particulate matter was 68-92% of the observed value. An exponential fall in TSPM concentration with distance from source had been observed. Dust generation due to mining activity didn’t contribute to ambient air beyond 500m. The main sources of dust emission were loading and unloading of coal, overburden and haul road.

Wang et al. [100] used PMF models to identified potential sources of PAHs in Dalian, China soil in summer was the emission from coal combustion average (46%), diesel engine (30%) and gasoline engine (24%), and in winter the main sources were the emission from the coal-fired bailer 72%, traffic average 20% and gasoline engine 8%.

There are coal-based industries in a mining complex (coal washing, power plant, chemicals, etc.), which also significantly contribute to air quality deterioration. In the Singrauli coal mining complex, there are 11 mines and power plants along with many social and market setup. All these units are wide apart but emit air pollutants into the atmosphere, depending upon their activity level. To fix the accommodability and responsibility, it was felt that a study must be conducted to estimate the contribution of various industries in polluting the air quality of Singrauli town. The thesis work has been planned accordingly.

1.7 Research gap and relevance of study work

The global state of research studies on the ambient atmospheric particulate matter showed that many studies were done on monitoring, characterization, and modeling. Monitoring of particulate matter is a statutory requirement for all types of industries. Monitoring stations often do not represent the true state of particulate matter concentration due to insufficient monitoring stations or improper selection of sampling stations. In this study, all monitoring station has been selected by considering the metrological condition and total affected area, as per the national standard prescribed guideline by The Central Pollution Control Board, Ministry of Environment, Forest and Climate Change, Government of India.

In atmospheric environments, a wide range of sources contributes to pollutant levels. These sources usually vary from place to place. Also, the mixing and dispersion of pollutants vary with meteorological factors in a specific region. It is necessary to properly carry out source distortion studies to identify sources in the area under consideration. It was evident from the literature and characterization of particulate matter that a very limited study was being carried out on metal analysis in India's opencast coal mines. This study was mainly confined to the Jharia and Raniganj coalfields in India, where some elements (Pb, As, Ni, Fe, Cr, Cd, Zn, Cu) were generally considered analysis. However, it is clear from these studies that Hg, Se, and K^+ are produced from coal burning.

Therefore, in the present study, an attempt has been made to analyze Hg, Se, and K^+ concentration have been carried to identify and apportionment the possible generation sources and calculation of human health risk due to elements and radioactive elements.

In this study, functional group analysis metrological studies and elemental studies have been carried out to understand better sources contributing, sources, and behavior of particulate matter in three seasons. This type of study is very limited in the opencast coal mine and around thermal power plants.

In this study, an attempt has been made toward the monitoring and characterizing particulate matter in the ambient air of Singrauli coalfield for three different seasons of two consecutive years. An attempt has also been made to access health due to particulate matter, element, and radioactivity and finally, a methodology has been developed to suppress the particulate matter.

Keeping all the above aspects in view, it has been observed through the literature survey that the characterization of particulate matter plays a crucial role in deciding the virulency of particulate matter as far as impact on the environment, including the health of the population is concerned. It is also important to develop and design particulate matter suppression devices for point and non-point air pollution sources. Air quality, particularly in opencast mines, is important not only for mine workers and professionals but also for the nearby population. There is a continuous addition of activities and fluctuation in production year after year.

The work is done, and needs for air quality status and important research work envisages the following objective:

1) to assess air quality status in and around coal mining complex and thermal power plants,
2) to assess the variation in concentration of particulate matter of various sizes along with nitrogen dioxide and sulphur dioxide,
3) chemical characterization of particulate matter of various sizes in terms of major, trace, and radioactive elements,
4) determination of health risk assessment in and around the mining complex,
5) to quantify the contribution of various sources of particulate matter for air quality deterioration, and
6) mitigation of particulate matter.