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A review on status of particulate matter pollution in India -

G. Kaushik[1*] and A. L. Chel[2]

[1,2] MGM's Jawaharlal Nehru Engineering College, Aurangabad
Mahatma Gandhi Mission (MGM), N-6, CIDCO, Aurangabad -431003, Maharashtra, INDIA
***Corresponding author:** geetanjaliac@gmail.com, Tel: +91 240 2482893, Fax: 91 240 2482232

ABSTRACT

Particulate matter has been implicated in various respiratory, cardio-pulmonary diseases and even cancer. Many Indian cities find place among the world's worst polluted cities. Rapidly growing Indian cities have high concentration of particulates which is attributed to automobiles, industries, biomass burning and re-suspension of road dust. In most cases this concentration even exceeds the permissible limits set up by the regulatory agencies. High Particulate concentration would make particularly the urban population vulnerable to various forms of respiratory diseases. The problem of particulate pollution is more complicated by location meteorology and seasonal variation making some locations like Delhi a pollution chamber. Therefore, cleaner air should be India's focus for economic growth with regard to benefits of longer lives and fewer incidences of PM related sickness. Better pollutant monitoring systems, public awareness regarding the adverse effects of PM, efficient vehicle engines, use of cleaner fuels etc would go a long way in mitigating the harmful effects of particulates.

Keywords: *Particulate, pollution, respiratory diseases, monitoring, SPM, RSPM*

1. Particulate Matter Pollution- Status in India:

World over air pollution is a public health problem. In 2012 air pollution was declared as the largest environmental health risk with almost seven million deaths globally attributed to it (WHO, 2014). According to the Global Burden of Disease 2010 report it was estimated that particulate matter (PM) air pollution was responsible for about 6% of deaths on a global basis (IHME 2013; Lim et al 2012). India is an important country in South Asia with a rapidly growing economy and a large but young workforce. However, rapid industrialization, and urbanization in the country have resulted in a significant deterioration in urban air quality (Kulshrestha et al, 2009). Data from the country's major regulator the Central Pollution Control Board (CPCB), showed that 77% of Indian urban clusters clearly exceeded the National Ambient Air Quality Standard (NAAQS) for respirable suspended particulate matter (RSPM or PM_{10}) in 2010 (CPCB, 2012). The non-respirable portion of particulate matter is suspended particulate matter (SPM) and together RSPM and SPM constitute the TSPM (total suspended particulate matter). Another key estimate from WHO pointed that out of 20 world's worst particulate air polluted cities around 13 are in India including the capital Delhi, which is the worst ranked city in terms of air pollution (WHO, 2014). It is quite alarming to note that the satellite measures of fine particulates created for the entire India reveal that our populations living both in urban and rural areas are exposed to hazardously high levels of particulates. Almost 670 million people comprising 54.5% of the population reside in regions that do not meet the Indian NAAQS for fine particulate matter (GreenStone et al, 2015; Dey, 2012). Numerous studies have revealed a consistent correlation for particulate matter concentration with health than any other air pollutant. Studies show a statistically significant correlation between mortality and ambient particulate matter concentration (Lee et al, 2006). Therefore, it is necessary to understand particulate matter, its sources and health impacts.

2. Particulate Matter – sources and health impacts:

The term "Particulate Matter" (PM) refers to tiny particles which remain suspended in air, in the form of either solid or liquid droplets which originate from various sources that pollute the ambient air. Particulate matter comprises of various organic and inorganic components; the major components include acids, ammonia, sodium chloride, black carbon, water and mineral dust. The respirable particulates having aerodynamic diameter d" 10µm (PM 10) are an important part of the atmosphere.

Six main sources of ambient particulate matter include: traffic, industry, domestic fuel burning, natural sources including soil dust (re-suspended) and sea salt and unspecified sources of pollution of anthropogenic origin. Traffic includes various types of vehicles which in addition to primary PM emissions from exhaust and emissions of organic and inorganic PM precursors from fuel and lubricants combustion, considerable amounts of particles are emitted through the wear of brake linings, clutch, and tyres (Amato et al., 2009; Belis et al., 2013).These are deposited onto the road and are then re-suspended by vehicle traffic along with crustal dust particles. Industry is a heterogeneous category including emissions from oil combustion, coal burning in power plants and emissions from different industries (petrochemical, metallurgic, ceramic, pharmaceutical, IT hardware etc.) and from harbor-related activities (Belis et al., 2013). Domestic fuel burning includes wood, coal and gas fuel for cooking or heating. Natural sources include soil dust and sea salt. Soil dust is resuspended from fields or bare soils by local winds. Sea salt particles in the air can be found close to the coast (Seinfeld and Pandis, 2006). Unspecified sources of human origin mainly include secondary particles formed from unspecified pollution sources of human origin. Primary particle emissions include mechanically generated particles and primary carbonaceous particles. Primary particles also include carbonaceous fly-ash particles produced from high temperature combustion of fossil fuels in coal power plants. Secondary particles are formed in the atmosphere through reactions of primary gaseous pollutants (nitrogen dioxide NO2, ammonia NH3, sulfur dioxide SO2, non-methane volatile organic compounds NMVOCs) (Belis et al., 2013).

A total of 419 source apportionment records from studies conducted in cities of 51 countries were used to calculate regional averages of sources of ambient particulate matter. Based on the available information, globally 25% of urban ambient air pollution from PM2.5 is contributed by traffic, 15% by industrial activities, 20% by domestic fuel burning, 22% from unspecified sources of human origin, and 18% from natural dust and salt (Karagulian et al, 2015).

PM is widespread and affects more people than any other ambient air pollutant. These particles have a high probability of deposition deeper into the respiratory tract and are likely to trigger respiratory diseases such as asthma, bronchitis, cardio-pulmonary infections (GreenStone et al, 2015, WHO, 2014). Epidemiological evidence has even attributed PM_{10} in cancer and in some cases even premature death. The relative strength of association of air pollutants with mortality were reported as follows: $PM_{2.5}$ e" PM_{10} e" SO_2 e" H^+ e" O_3 e" NO_x (Dockery et al., 1992; Das et al, 2006). Further it has been found that for each 10 ìg/m^3 increase in PM_{10} concentration there is an estimated increase in mortality by almost 1 per cent (Dockery and Pope, 1994; Ostro, 1996; Das et al, 2006). Each 10ìg/m^3 elevations in fine particulate air pollution has been associated with approximately with 4, 6 and 8% increased risk of all cause, cardio pulmonary and lung cancer mortality respectively (Pope, 2000).

These particles have also been implicated as carriers of toxic air pollutants including heavy metals and organic compounds (Satsangi et al, 2011). According to

'National Ambient Air Quality Standards- 2009' when PM_{10} particles are present in excess of 60μg/m^3 (annual basis) these are known to adversely affect human health. In view of the air quality status, some of the Indian cities are considered to be among the most polluted cities in the world (Mitra and Sharma, 2002). It is well known that PM_{10} is a better indicator of total suspended particulate matter (Das et al, 2006).

From the above discussion it is evident that the presence of particulate matter in the air is associated with various adverse effects on human health, other living and non-living components. It is therefore of significance to conduct monitoring studies to estimate the concentration of PM in the ambient air so that public is aware and can reduce its exposure. In addition the government agencies and institutions can undertake arrangements to protect the population from such adverse effects of PM pollution (Kaushik & Borah, 2016). In this regard this paper reviews the status of PM pollution across India. It is expected this paper would provide key insights into locations with high PM concentrations, need for mitigation and policy measures for the government.

3. Particulate matter pollution – studies from India:

Table 1 summarizes the results of PM monitoring studies conducted across India. For ease of understanding India has been divided into North, West, Central, East and South India and the literature is summarized accordingly (Figure 1).

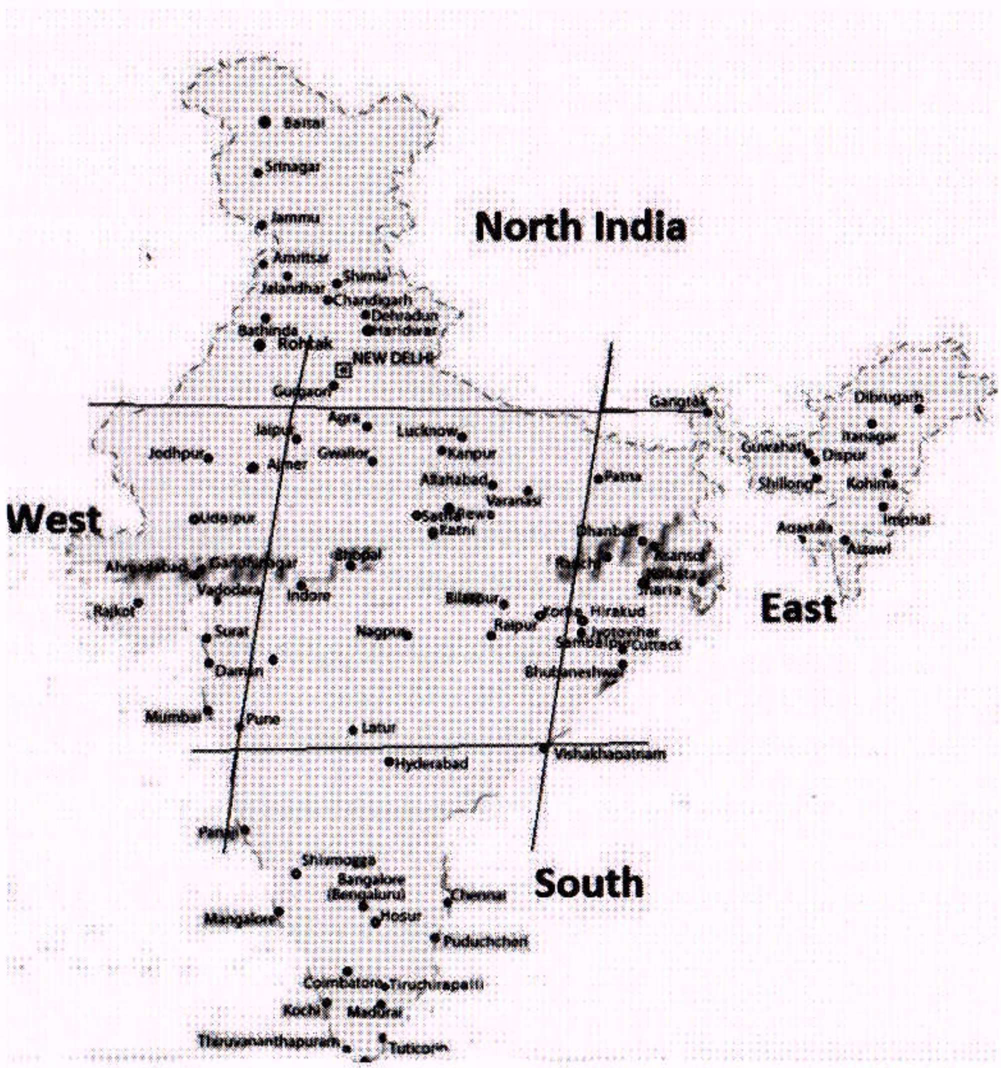

Figure 1: India's map with major monitoring locations

Table. 1. Summary of PM monitoring studies across India

Sr. No.	Site	Typology	PM class & Concentration	Reference
North India				
1.	Rohini, Delhi	Residential	SPM 111-222 μg/m^3	Kannan and Rajola, 2004
2.	7 locations, Delhi	Residential Industrial sites	SPM -280–420 μg/m^3 300-450μg/m^3	Goyal et al, 2006
3.	India Gate, Delhi	Open space	SPM decreased from 470 to 275 μg/m^3 and RSPM from 390 to 220 μg/m^3	Devi et al, 2007
West India				
4.	Ajmer, Rajasthan	industrial, traffic, residential sensitive locations	RSPM -488.0 μg/m^3 in Dec. and June at industrial site	Chalka et al, 2006
5.	Worli, Mumbai Maharashtra	ambient and kerbsite	PM2.5, and PM10 were 43, and 61 μg/m^3 at ambient site and at Kerbsite it was 69 and 90 μg/m^3	Kumar and Joseph, 2006
6.	Pune, Maharashtra		average PM10 was 120.35 μg/m^3	Gidde, 2007
Central India				
7.	Indore, Madhya Pradesh	11 locations, mostly at outer city areas	average RSPM range 39.78-649.92 μg/m^3	Joshi and Jain, 2000
8.	Taj Mahal, Agra, Uttar Pradesh		PM10 115 to 233, 155 to 321 and 33 to 178 μg/m^3,	Singh et al, 2010
9.	Nagpur, Maharashtra		annual concentration of SPM was 270μg/m3 and of RPM was 150μg/m3	Anjikar et al, 2015
10.	Aurangabad, Maharashtra	traffic intersection industrial residential commercial	PM 10 353.98 μg/m3 303.77 μg/m3 208.86 μg/m3 255.66 μg/m3	Kaushik et al, 2016
East India				
11.	Tantra-Raikela-Bandhal iron ore mines, Orissa		SPM ranged between 91.9 to 338.9 μg/m^3	Das et al, 2003
12.	Kolkata West Bengal		PM10 was 304 μg/m^3 PM2.5 -179 μg/m^3 PM10-2.5 -126 μg/m^3	Das et al, 2006
South India				
13.	Bangalore, Karnataka	10 congested areas	SPM values exceeded prescribed limits in 6 of the 10 congested areas	Dayal & Nandini, 2000
14.	Coimbatore, Tamil Nadu	8 sites were residential and rural mixed zone, one industrial and one sensitive zone	SPM higher than threshold limits in main traffic routes and commercial localities	Meenambal and Akil, 2000
15.	Hyderabad, Andhra Pradesh		40.9 to 499.5 μg/m^3 for PM10 and 31.1 to 285.5 μg/m^3 for PM2.5	Gummeneni et al, 2011

4. Discussion:

From the above background on particulate matter concentration from various locations across India it is clear that barring few almost all locations have high PM 10 and PM 2.5 not only in commercial and industrial areas but also the residential areas which has been attributed to automobiles, construction activities, industries and suspension of road dust. PM concentrations clearly exceed the National standards. Hence, urgent steps to reduce particulate matter concentration are warranted to safeguard the health of consumers in particularly high PM concentration areas. It is also evident that the four metropolitan cities are the focus of PM monitoring studies particularly Delhi which has the maximum number of studies followed by Kolkata, Chennai and Mumbai. Next to follow are the studies on state capitals. East part of India seems to be underrepresented in terms of monitoring studies. Particulate matter pollution has not received due attention in the country which is responsible for this grave situation. If we observe the CPCB data for Indian cities it is evident that almost 85 Indian cities fall in the category of Critical with regard to PM pollution (CPCB, 2014).

When the CPCB, 2014 data trends in air quality for states and union territories (UT) are examined out of 31 states and UTs for four namely Dadra & Nagar Haveli, Daman & Diu, Manipur and Sikkim there was no data available. Out of the remaining 27 a whooping 24 states and UTs exceeded the standards. This clearly highlights the grave situation the country is facing and urgent steps are warranted for its mitigation.

From the above background it is quite evident that PM concentrations are greater due to greater emissions from various pollutant sources however, the particulate concentrations may be elevated due to other reasons such as meteorology. The meteorology of the location plays an important in determining the pollutant load. Numerous studies have assessed the influence of wind speed, wind direction, rainfall, relative humidity and temperature on particulate matter pollution. The measured PM pollution generally showed inverse relationship with wind speed, relative humidity and temperature (Karar et al, 2005). Therefore, it is possible that on account of unfavorable topography and meteorological conditions some locations are more prone to particulate pollution. This needs to be carefully considered while planning an industrial area or a residential township. The second dimension to be considered here is the seasonal variation of particulates, in India summer season of the year (April to June) is associated with strong winds, low humidity that can substantially reduce the level of ambient pollutants. In contrast, the monsoon of the year (July to September) is associated with low wind speeds and medium to heavy precipitation, which reduces the air pollution potential. The winter (October to December) and spring (January to March) seasons of the year are associated with low wind speeds and negligible rainfall resulting in buildup of pollutants which increase the air pollution level of the studied location (Kavuri and Paul, 2013). Further, the lower solar insulation rates during the winter months lead to lower atmospheric inversion layers where pollutants become trapped close to the ground, further increasing fine particle concentrations (Gummeneni et al, 2011). PM2.5 data confirms the pronounced seasonal peaks coinciding with lower mixing heights of the winter months. It has been concluded that the measured PM pollution in the winter is at least double the concentrations measured during the rest of the season (Guttikunda, 2009). Hence, in locations with topography and meteorological conditions favoring atmospheric inversion layers traffic load may be reduced by odd-even car number plying on alternate days, industrial production on alternate days and other steps which can reduce public exposure to high PM concentration.

Another key point to be considered here is that mortality and morbidity effects due to air pollution are not solely linked to ambient level concentration. Human exposure to pollutants is affected by the amount of time spent outdoors and by the amount of outdoor air that enters buildings and homes. So, reducing the exposure is the key to reduce harmful effects of air pollution. Also, population density affects the number of people exposed in a given area. Dose response to pollutant exposure may vary for different people depending on their age, health status, exposures to other stressors such as tobacco and indoor air pollution from cook stoves, and other factors.

Therefore, study should be carried out for various population subgroups with time spent in different environments and the results should then be aggregated (Joseph et al, 2003). Previous studies (Apte et al, 2011) have highlighted a very important fact that the concentrations of air pollutants from vehicles are elevated along roadways, indicating that human exposure in transportation microenvironments may not be adequately characterized by centrally located monitors. Therefore, the actual pollutant levels to which public are exposed may be several times greater than the concentration measured by the pollutant monitors.

5. Control Measures:

In this regard it is evident that PM pollution is a significant cause of mortality and morbidity, Indian cities particularly the urban areas have a high PM concentration making the population prone to its adverse effects. Therefore, it is urgent to undertake suitable strategies for reducing it particulate matter in ambient air could be controlled by adopting the following measures:

1) Improvement of road conditions including repair of roads, widening of roads and construction of flyover.

2) Vehicular emission check, compliance and imposition of fine for non-compliance

3) Mass awareness campaigns to educate public about health effects of particulates.

4) Vehicles older than 15 years should be taken off from roads, strict implementation is the key.

5) Implementation of road cleaning (at least weekly) to check the resuspension of road dust

6) Encourage use of cleaner fuels like CNG in 3 and 4 wheelers and focus on better mass transportation systems.

7) Industry needs to control its PM emissions and also ensure safety for its workers

8) Better air monitoring systems in terms of accuracy and coverage a as well as the data accessibility to the public would play an important role as a health advisory system and increase the pressure on polluters to comply with regulatory standards.

9) Planting trees (such as *Azadirachta indica*, *Ficus bengalensis*, *Mangifera indica*) near roadsides which are known to be absorbers of particulate matter from vehicles. Then they can be used effectively by planners and green belt developers in managing the urban air pollution (Mate and Deshmukh, 2015).

10) Control of emissions from source is important but it is even more important to reduce the exposure to particulates by wearing masks especially for those exposed like traffic policemen and industrial workers.

11) Citing of residential townships and industrial zones based on the site meteorology to reduce buildup of particulate load to which population is exposed.

12) Implementing odd even car days, rotation work days for industry to reduce the particulate concentration particularly during the winter.

13) Highlighting air quality status especially during days classified as critical for particulate pollution so that public is able to reduce exposure by wearing masks and staying indoors.

6. Conclusion:

In the last few decades growing population, industrialization and a tremendous growth in vehicles has resulted in air pollution becoming a serious issue in developing countries such as India. The situation is alarming as the population of over a billion is exposed to harmful particulate matter which is associated with severe form of health effects such as asthma, cardio-vascular disorders and even cancers. This review critically examined the status of PM pollution in India and it is evident that majority of cities exceed the national standards for PM. Almost 85 cities have been classified as critical with regard to PM 10 levels. 24 states and UTs have high PM concentrations way above the standards. In addition to greater emission from pollutant sources high PM loads may be due to site location and meteorology, seasonal variation etc. Therefore, careful planning of industrial zone must be done to minimize exposure to residential areas. Proper monitoring of PM levels and highlighting hot spots would also reduce public exposure to particulates. In addition better pollutant monitoring systems, public awareness regarding the adverse effects of PM, efficient vehicle engines, use of cleaner fuels etc would go a long way in mitigating the harmful effects of particulates.

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