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Assessment of particulate matter (PM) concentrations at a typical construction site in Bangalore, India

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Abstract

Construction sites pose a major challenge to the environment due to presence of different types of particulate matter (PM). Concentration of particulate matter is a typical indicator for urban air quality. Although it has long been recognised that construction activities are a pertinent source of PM emissions, not much research has gone in this direction. The investigation envisages quantification of the PM emissions at a construction site for particulates having varying aerodynamic diameters–fine particles 2.5 µm ($PM_{2.5}$) and coarse particles10 µm (PM_{10}), based on an exploratory study. Investigation revealed the concentration of fine PM exceeds that of coarse PM and is 4-5 times more than the permissible limits prescribed by the Central Pollution Control Board (CPCB), INDIA. Mitigation of impacts caused by particulate matter is also outlined briefly.

Keywords: Ambient air pollution, Urbanization, Particulate matter, Environmental impacts, Construction sites.

Introduction

Level of ambient air pollution (AAP) in any neighbourhood is influenced by complex interactions amongst various factors including local meteorology, prevailing climatic conditions, wind attributes (direction, velocity), physiographic, urban and social conditions along with air pollution emissions from anthropogenic sources. It is noted that the single most important factor that affects air quality in any localized area is the chemical composition and magnitude of exposure particularly related to concentration of substances hazardous to humans and the environment[1].

Human activities, especially in large metropolitan cities of the developing world have definitely improved the material well-being leading to a higher standard of living for its denizens however the same development has also led to increase in severity of environmental problems like ambient air pollution[2]. Some of the more visible causes of increase in AAP in developing countries include uncontrolled growth in number and type of industries, vehicular emissions, unmitigated waste burning, unbridled construction of houses, demolition of old structures and bio-mass burning besides particulate suspensions from unpaved roads. It is also surprising to note, that urban ambient air is more polluted than overall atmosphere of the country which is attributed to high human population density and anthropogenic activities which lead to release of pollutants at a higher rate compared to less developed areas and natural environment[3]. Twin effect of the same constitutes a grave potential health hazard as they directly influence in increasing mortality rates and serious illnesses[4] so much so that outdoor air pollution is reported to be the sixth leading cause of death after blood pressure, tobacco smoking, indoor air pollution, poor nutrition and diabetes in South East Asia. In India, it is the fifth leading cause, accounting for about 6,27,000 premature deaths every year[5].

Problem of AAP is so severe that in the latest urban air quality database of World Health Organization (WHO), 98% of cities in low- and middle income countries with more than 1,00,000 inhabitants do not meet prescribed air quality guidelines. Amongst various types of atmospheric contaminants, airborne particulate matter (PM) is unique, mainly because of its potential complexity both in terms of chemical composition and physical properties[6]. PM in the ambient affects the immediate environment in a complex manner by way of particles being of different sizes, shapes, and chemical compositions derived from a wide range of sources and formation mechanisms[7]. PM is a major air contaminant which not only leads to visibility degradation but also threatens public health by acting as a toxic component.

Building construction activities affect the environment directly and indirectly resulting in generation of particulate matter, noise, dust, gaseous pollutants and other atmospheric contaminants. Though construction industry is augmenting the current infrastructure of our cities, it at the same time is also responsible for atmospheric pollution due to dust and PM emissions. They are seen to originate from a number of sources predominant being the construction activities besides heavy vehicles associated with construction works and on-site machinery (off-road emissions), thus encompassing static as well as mobile machinery (not restricted to roads)[8]. Use of this varied type of machinery at construction sites can easily be understood to lead to detrimental health impacts of PM emissions that are not just confined to construction site, but also affect health of people living and working in the neighbourhood. Since fine particles (PM < 2.5 µm dia.) are known to travel over long distances, PM also impacts outdoor and indoor air quality in the neighbouring areas. This leakage of PM into the indoor air has been reported to cause cardiovascular diseases (CVD), morbidity and mortality as evidenced by epidemiology literature with stronger associations for $PM_{2.5}$ compared to PM_{10}[9].

Exploitation and manipulation of environment has led to an increase in cases of heart attacks, respiratory diseases, and lung cancer and that is noted to be significantly higher in people who get exposed to dirty air compared to matching groups in cleaner environments[10].

Bangalore, the IT capital of India has been in the thick of construction activity for several years now and the dust deposits at construction sites have taken a toll on the air quality. The present research measured the ground and above ground concentrations of $PM_{2.5}$ and PM_{10} in an upcoming residential complex in a plush area of Bangalore. The foremost aim of this investigation was to determine the level of exposure to particulate matter which the residents and workers are subjected to all day long and to identify and characterize the PM with different aerodynamic data. Further correlate this exposure to the environmental impacts resulting from these construction sites. Three different towers (at different distances from the actual construction site) were selected to gauge the variation in exposure to PM.

Methodology

The Study: Round the clock construction activities in the residential complex elevated the levels of dust and noise owing to machinery, vehicles ferrying goods, fittings, marble cutting, mixing materials, masonry etc. In the current study, concentration of particulate matter (both coarse and fine) during construction was monitored for one month (24 h; at 6 h intervals in August 2016), at three different sites (three different towers at different distances) in the vicinity of construction activities (Table-1) in a residential complex.

The construction site studied is located at Hosur Road in Bangalore, Karnataka, INDIA. The latitude and longitude of study site is 12.9014E and 77.6289N respectively with an altitude of 920 m above sea level. It has a total area of 11 acres with 8 residential towers (6 of which are complete and occupied), each with 21 floors. On each floor, there are 8 units in one tower, totaling 1008 residential units. The site is a gated community which has been beautifully developed and landscaped with sufficient open spaces, greenery, water bodies etc. Out of 8, two units are still under construction where an array of activities goes on throughout the day and night. Primarily, the activities include manual excavation, construction and razing of auger piles, different types of masonry, cutting and polishing of granite and tiles, carpentry, water proofing, plumbing, electrical fittings, execution of reinforced concrete (columns, beams and slabs), lift masonry, mortar execution, masonry shaft, transport of materials by vehicles and trolleys etc.

To measure the extent of particulates present at and in the vicinity of construction site, an Air quality monitor- DYLOS 1700 was used. DYLOS 1700, USA is a true portable LASER particle counter with air quality monitoring capabilities in 2 particle size ranges (0.5 – 2.5 µm or $PM_{2.5}$ and 2.5 - 10 µm or PM_{10}). DYLOS 1700 is battery powered with a LCD screen readout showing small (> 0.5 µm) and large (> 2.5 µm) particle concentrations in real-time. The Air Quality Monitor (AQM) has the ability to display in its alphanumeric readout two different counts, wherein the first is for particles in the range of 0.5 to 2.5 ($PM_{2.5}$) microns in size per 0.01 cubic foot whereas second part shows particle count for particles larger than 2.5 microns but smaller than 10 microns (PM_{10}). The unit is versatile in the sense that it is able to log particle counts in multiple modes of operation including minute, hour and day while monitoring air quality. In the study $PM_{2.5}$ and PM_{10} readings on the DYLOS 1700 AQM were averaged over a minute at a particular position. Though the readings obtained were expressed per 0.01 cubic feet, these were properly converted to concentrations per cubic meter to match the universal standards. The AQM is light weight and portable with a small built-in ‘CPU’ fan at the end to pull in ambient air loaded with particulate matter into the unit. The ‘polluted’ air is made to pass between a narrow beam of the LASER and a photo detector. Scattering of light by the particulate matter is the basic principle of measurement employed by AQM.

Results and discussion

In the current study the investigation clearly establishes a differentiation between a polluted and non-polluted surrounding. Obtained results from the study indicate that air quality concentrations prevailing in the vicinity of the construction far outstrip acceptable threshold of air quality till which are known not to affect health and safety of the population (primary standard), as well as result in damage to the flora, fauna, material and environment as a whole[8].

The World Health Organization[11] has prescribed the following limits for Particulate Matter (PM) in its Air Quality Guidelines in the year 2005.
$PM_{2.5}$: 10 µg/m^3 annual mean; 25 µg/m^3 24-hour mean.
PM_{10}: 20 µg/m^3 annual mean; 50 µg/m^3 24-hour mean.

In our country, the Central Pollution Control Board (CPCB) has a different set of prescribed limits which have been published in the Gazette of India under National Ambient Air Quality

Guidelines[12]. The permissible values of particulate matter for industrial, residential and other areas are:
$PM_{2.5}$: 40 µg/m^3 annual mean; 60 µg/m^3 24-hour mean.
PM_{10}: 60 µg/m^3 annual mean; 100 µg/m^3 24-hour mean.

The guidelines vary from country to country depending on the population and the stage of development the country is in.

For the current investigation, the concentrations of $PM_{2.5}$ and PM_{10} were recorded meticulously. Though the concentrations of PM10 are generally within the permissible limits prescribed by CPCB, the concentrations of fine $PM_{2.5}$ are alarming. The air (especially $PM_{2.5}$) that a resident inhales is 4-5 times more polluted than the threshold prescribed by the Central pollution control board and nearly 10 times the limits given by the World Health Organization. Compared to fine particulate matter, the congregation of coarse PM is not that frightening. But at the same time, these values also are in the hazardous category and can have an adverse affect on the well being of residents of this tower.

Literature indicates that in a typical ambient the life time of $PM_{2.5}$ varies from several days to many months as these fine particles have a negligible sedimentation rate leading to their excessive concentrations. On the contrary, PM_{10} particles being heavy settle quickly and are unable to travel long distances. All the above mentioned construction activities are responsible for enhanced levels of PM in and around the construction site. Worldwide researchers have reported silica (basic constituent matter in any construction) as one of the most harmful elements since it is prone to bypass human body's filter mechanism undetected and make humans susceptible to all kinds of pulmonary infections by detrimentally reducing the lung capacity.

With concentration at 90 - 120µ/m^3 of $PM_{2.5}$, people with respiratory issues start feeling the strain of the polluted air and at 120 - 250µ/m^{3,} which is categorised as "very poor", the risk of developing respiratory illness on prolonged exposure increases. Such huge exposures can lead to escalation in hospital admissions resulting from respiratory and cardiac symptoms. Even a healthy person with prolonged exposure to air of 'severe' category will start experiencing breathlessness, wheezing and chest constrictions. $PM_{2.5}$ can easily enter the human respiratory system and cause serious health impacts, while larger particles are not able to penetrate as deeply and therefore cause less damage[13]. It is a well known fact that $PM_{2.5}$ is able to easily penetrate human lungs causing irreparable cardiovascular problems besides damaging the inner walls of the arteries. The group most susceptible to $PM_{2.5}$ poisoning include the very young, the infirm and the old besides those employed in hazardous occupations.

Table-1: Monthly mean concentrations of $PM_{2.5}$ and PM_{10} (24 h mean) observed at different levels (floors) of Towers I, II and III at different distances in the vicinity of construction site.

S. No.	Level	Tower I - 50 metres		Tower II - 200 metres		Tower III – 500 metres	
		$PM_{2.5}$ (µg/m^3)	PM_{10} (µg/m^3)	$PM_{2.5}$ (µg/m^3)	PM_{10} (µg/m^3)	$PM_{2.5}$ (µg/m^3)	PM_{10} (µg/m^3)
1.	Level 21	190	44	103	15	116	13
2	Level 18	186	44	104	15	101	12
3.	Level 15	247	74	105	15	101	11
4.	Level 12	286	99	115	16	99	11
5.	Level 09	274	95	116	17	101	11
6.	Level 06	252	82	132	18	99	12
7.	Level 03	296	106	108	15	106	11
8.	Level Ground	128	23	115	20	99	11
9.	Permissible NAAQS India values	60	100	60	100	60	100
10.	Permissible WHO values	25	50	25	50	25	50

The mean concentrations at a distance of 200 meters from the construction site are almost half or even less of what we recorded at a distance of 50 meters. The values of $PM_{2.5}$ here too are way above the permissible limits but PM_{10} concentrations are within the prescribed limits. This result is very disheartening since $PM_{2.5}$ is known to be more harmful because of it having a relatively larger reactive surface area, its ability to diffuse deeper, enhanced ability to get deposited especially in the alveoli and having a poisonous chemical composition. $PM_{2.5}$ is also known for extensive translocation into the systemic circulation by being very small in size and hence their ability to cross the lung alveolar-capillary interface. Cardiovascular diseases result directly from their mixing with blood as they tend to toxify the system.

If we move a little farther from the construction site, say at a distance of 500 meters, the values of PM_{10} are further reduced (Table-1). Sadly, the concentration of fine particulate matter is excessive here too; manifesting that $PM_{2.5}$ can travel longer distance than PM_{10}. A very peculiar trend of PM being more in the middle levels (above ground and below top levels) is also reflected in the observation tables. It is indicative of wind carrying the particulates above ground. But it is not strong enough to fly them to greater heights.

The current investigation confirms adverse environmental impacts of airborne PM and clearly establishes their influence on the public health which urban populations in both developed and developing countries currently endure. Some of the ill-effects of the enhanced PM concentrations in ambient are known to be aggravated bronchitis, premature death in people with heart or lung disease, non-fatal heart attacks, irregular heartbeat, decreased lung function, and increased bronchial symptoms such as irritation of airways, coughing, or difficulty in breathing[14]. The main problem with PM as an environmental contaminant is understood to be lack of evidence to suggest a threshold below which no adverse health effects are expected to occur.

Although WHO[15] in its report on ‘Health effects of Particulate Matter’ suggests proactive interventions from various policy makers and Governments to adopt regulatory measures to reduce air-pollution by having stricter air quality standards, limits for emissions from various sources, reducing energy consumption, especially that are based on combustion sources, changing modes of transport, land use planning as well as behavioural changes by individuals by using cleaner modes of transport or household energy sources. In a country like ours which tops the list of having most polluted cities of the world, there is an urgent need to implement stricter policies and establish mitigation measures on a war footing. Thousands of laborers and construction workers are exposed to alarming levels of pollutants most often in dangerous conditions without any protective gear. For them to earn their bread and butter is more important than taking care of their health. Sadly enough, the fraudulent builders and contractors still cut corners and show scant regard to the guidelines issued by the Ministry of Environment and Forests to curb pollution at construction sites.

Recently, during a smog outbreak in the National capital, the Delhi Govt. stalled all construction and demolition activities for 5 days, ordered closure of Thermal power plants, banned the transport of Fly ash. To improve the quality of life, such measures need to be taken from time to time. Discussing the impacts of PM on health, wind velocity plays a major role in alleviating the concentration of PM in Bangalore. Since the wind velocity is high (approximately 3-4Km/h), it disperses the particulate matter in the atmosphere and subsequently cuts down the risk of dreaded diseases owing to PM pollution. Though fine PM can travel great distances with the wind but its concentration at a given construction site is diminished.

Conclusion

This work evaluates the emission of particulate matter at construction sites from an environmental perspective, taking into consideration different activities during construction. The quantification and identification of the PM enables one to understand the impact of PM on public health. The values obtained prick our consciousness to minimize pollution and also suggest measures for its mitigation.

The present investigation indicates that PM emission during a typical building construction has contributions from variables including actual construction activities, associated construction site vehicles (both on- and off-road) and on site machinery. Further the PM emissions have no single clearly definable pattern and that they depend on the technology being used and management control methods used by the builder. Finally, the weather condition variables including wind direction and velocity besides other local conditions influence the emission concentration of PM. Dust dispersion methods, plantation of low shrubs and plants (green barriers), covering of construction material or stacking in closed environment must be practiced untiringly. Existing rules and guidelines for construction sites must be enforced stringently to prevent PM and dust from escaping into the ambient.

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