$PM_{2.5}$

10 FREQUENTLY ASKED QUESTIONS ON PARTICULATE MATTER (PM)

URBAN emissions .info

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(UEinfo) was founded in 2007 with the vision to be a repository of information, research, and analysis related to air pollution. There is a need to scale-up research applications to the secondary and the tertiary cities which are following in the footsteps of the expanding mega-cities. Advances in information technology, open-data resources, and networking, offers a tremendous opportunity to establish such tools, to help city managers, regulators, academia, and citizen groups to develop a coordinated approach for integrated air quality management for a city.

UEinfo has four objectives: (1) sharing knowledge on air pollution (2) science-based air quality analysis (3) advocacy and awareness raising on air quality management and (4) building partnerships among local, national, and international airheads.

This report was conceptualized, drafted, and designed by the members of UEinfo.

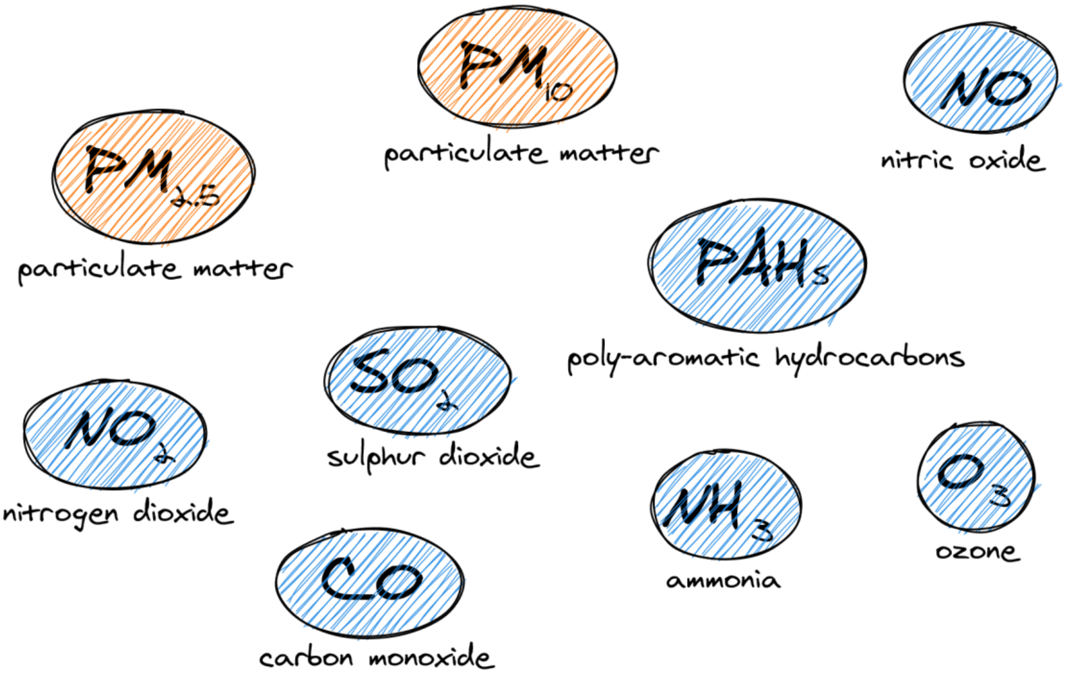
All the working papers and more are accessible @ www.urbanemissions.info/publications

Send your questions and comments to simair@urbanemissions.info

Introduction

I participated in a series of podcast recordings and online lectures during the COVID-induced/isolated-2020 and there were some frequently asked questions. While these questions sound simple, it was not easy to frame technical understanding into simple statements.

This paper is dedicated to answer some of those questions on particulate matter (PM) and go over some basic material.



Among many pollutants, PM is the most talked about and probably the main indicator to human health. Among the other pollutants, noteworthy ones are sulphur dioxide, nitrogen oxides, carbon monoxide, hydrocarbons, especially the polycyclic aromatic hydrocarbons, and ozone.

From a regulatory perspective, PM is studied, measured, and monitored the most for multiple reasons. Such as, being the critical pollutant for health concerns (asthma, breathing troubles, eye irritation, etc), being a critical ingredient to a visual form of pollution (smog) leading to visibility issues, and commonly the most visual pollutant out a chimney (often in the form of black soot).

World Health Organization (WHO) and Institute of Health Metrics Evaluation (IHME) estimated that urban air pollution from PM accounts for ~4 million premature deaths annually and the burden occurs primarily in developing countries.

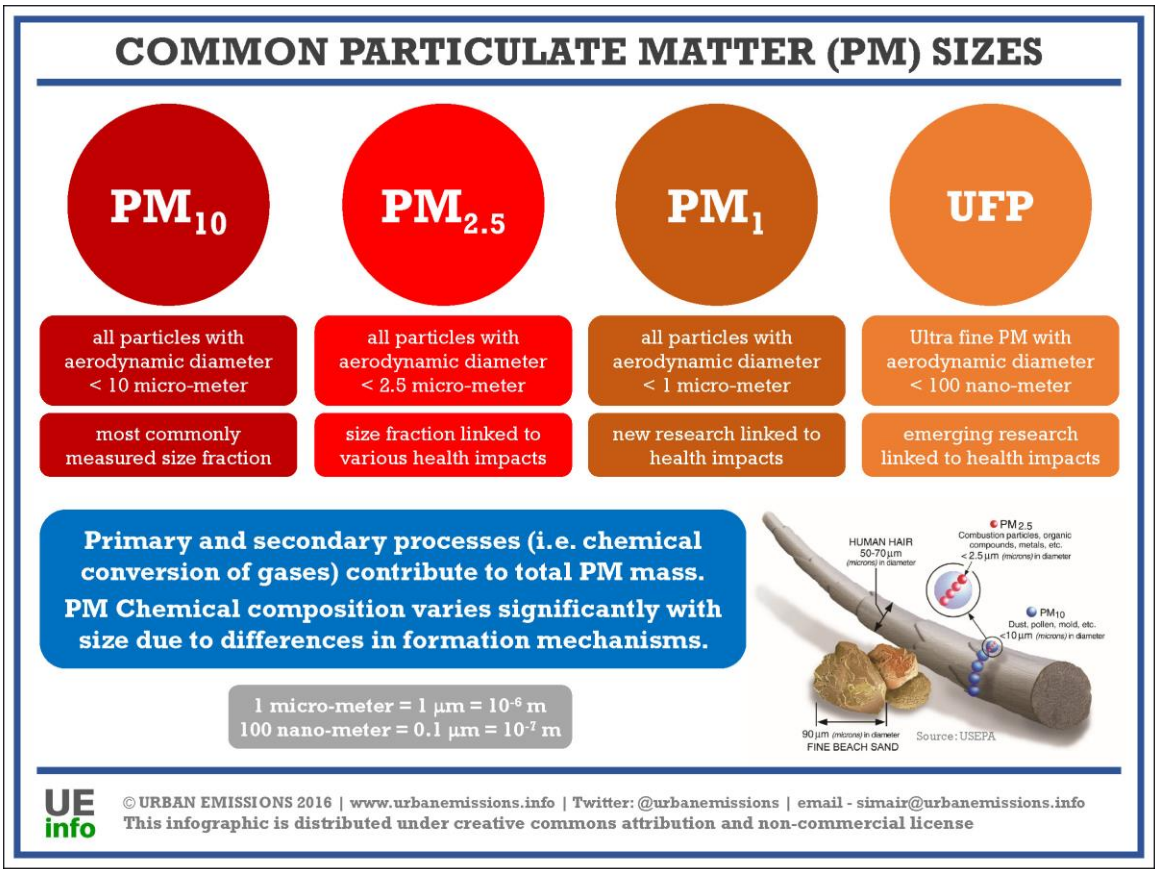
It is important that we understand more about the pollutant that concerns the most (sources, strengths, and weakness) to formulate rational and effective policies and make informed investment decisions related to air quality improvements.

The focus of this paper is to put forward some basic understanding behind particulate matter in the form of ***10 Frequently Asked Questions (FAQs)***

1. Which size fraction of particulate matter is more important?
2. What is the difference between primary and secondary particulate matter?
3. What is the difference between fine and coarse particulate matter?
4. What is pollution source apportionment?
5. Which size fraction of particulate matter should be measured?
6. How many monitors are required to monitor particulate matter in a city?
7. Is road-transport the main culprit of particulate matter pollution in a city?
8. Is $PM_{2.5}$ the most harmful of all air pollutants?
9. Can we vacuum our particulate pollution problem using air purifiers and smog towers?
10. Can we model particulate matter?

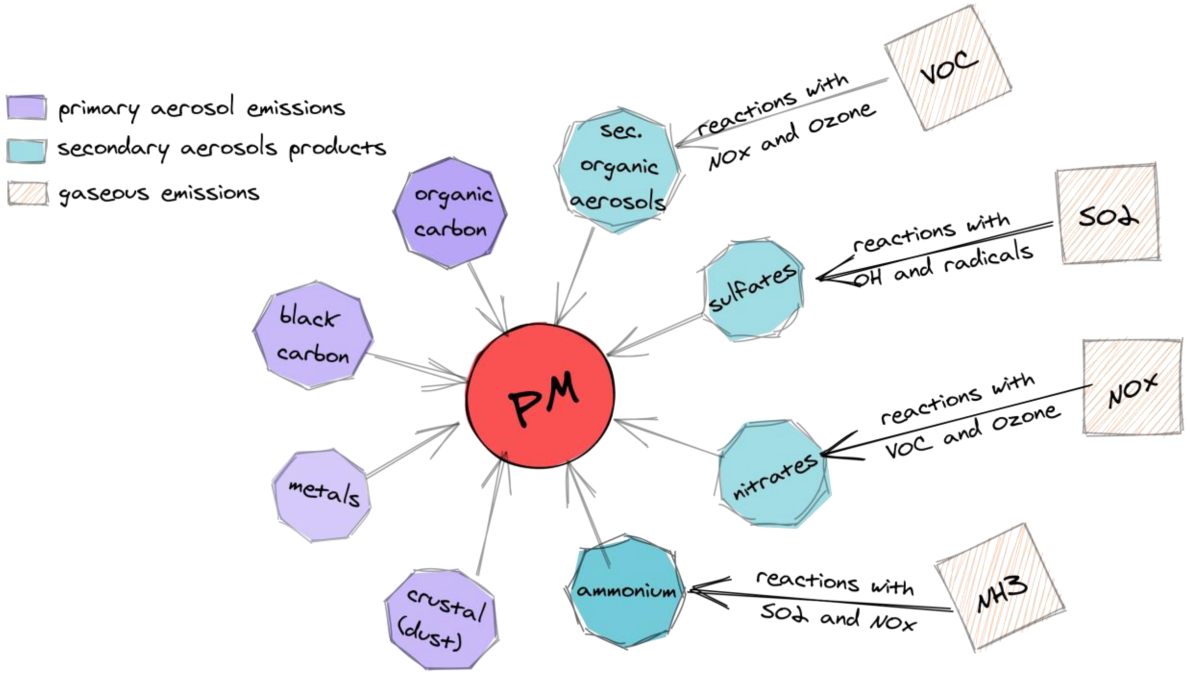
Question # 01 - Which size fraction of particulate matter is more important?

Particulate Matter (PM) is generally measured as mass concentration of particles within certain size classes. These size distinctions are a result of sources and formation mechanisms, which lead to variation in chemical composition and physical properties. The range of sizes also affects their atmospheric lifetime, spatial distribution, indoor-outdoor ratios, temporal variability and associated health impacts.



To date, most measurements are conducted for PM_{10} and most of the developing countries still monitor PM_{10} as a key indicator. Slowly, with the growing knowledge on PM composition and its direct linkage to health impacts, finer fractions are becoming more important. $PM_{2.5}$ is now more critical for health impacts and other policy relevant discussions.

Question # 02 - What is the difference between primary and secondary particulate matter?



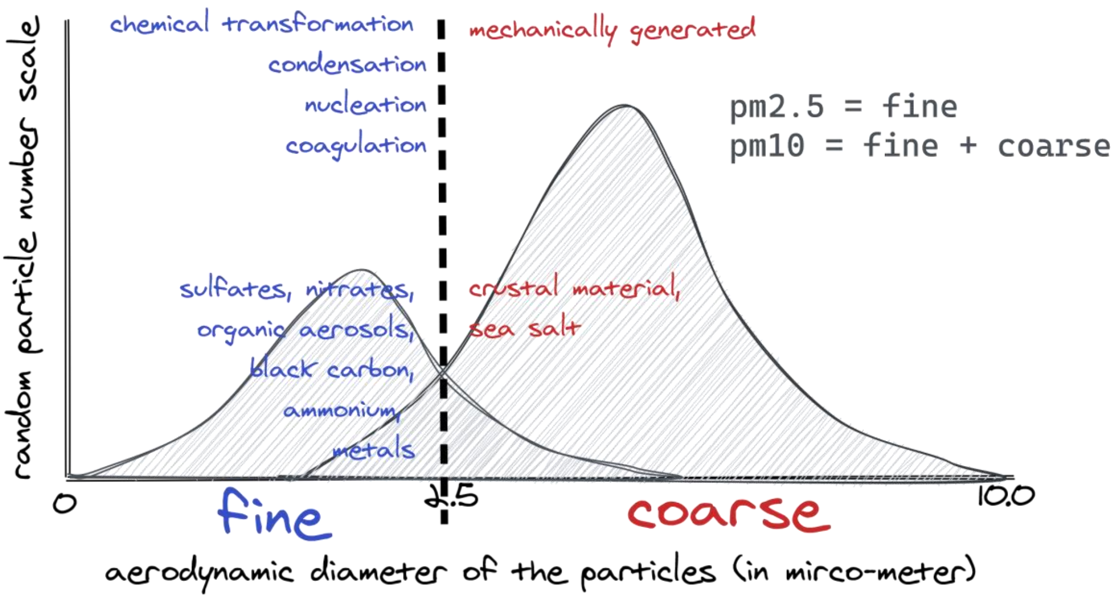
Primary is a direct emission source and forms a significant portion of the PM pollution, comprising of metals, elemental carbon (also known as black carbon), and organic carbon.

Other primary pollutants include sulfur dioxide, nitrogen oxides, volatile hydrocarbons, methane, carbon monoxide, and carbon dioxide.

Secondary is due to chemical transformation of primary gaseous emissions. In PM, the secondary aerosol components include sulfates from sulfur dioxide emissions, nitrates from nitrogen oxide emissions, organic aerosols from hydrocarbon emissions, and ammonium from ammonia emissions. The path and the quantity of chemical transformation depends on the strength of the pollutant emissions and the mix of the emissions. In an atmospheric chemical mechanism, these interlinkages can run into 300 equations.

Other secondary pollutants include ozone – a result of a mix of reactions between nitrogen oxides and hydrocarbon emissions in the presence of sunlight.

Question # 03 - What is the difference between fine and coarse particulate matter?



There is constant confusion between $PM_{2.5}$ vs. PM_{10} and "fine vs. coarse" fractions of particulate matter. The schematic above presents an overview of what is part of each of these fractions and they are broadly defined like this

- $PM_{2.5}$ – this is all the particulate matter under 2.5 μm
- PM_{10} – this is all the particulate matter under 10.0 μm
- Fine PM – this is all the particulate matter under 2.5 μm, which is same of $PM_{2.5}$
- Coarse PM – this is all the particulate matter between 2.5 and 10 μm

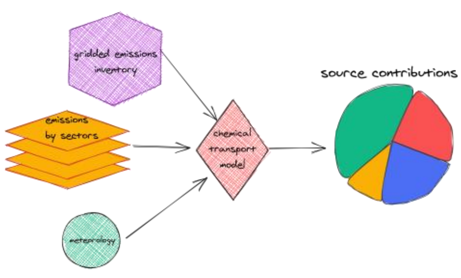
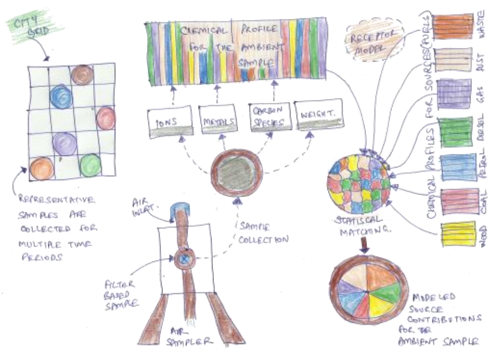
Question # 04 - What is pollution source apportionment?

This is the process of estimating the contribution of various sources to ambient particulate pollution. This is a key input required for prioritizing actions against the most contributing sources.

It is important to keep in mind a common mistake overlapping emissions and pollution

1. The emissions inventory is not pollution source apportionment. While an emission inventory also provides information at the source level, the information critical for policy discussions is the contribution of sources to the pollution we breath in the air.
2. In each city or region, the contributions estimated from emissions at the sources need not be the same as the contributions estimated for ambient pollution. For example, a power plant will contribute significantly to the emissions inventory in a city. However, its pollution travels long distance and contributes less in the immediate vicinity.

There are 2-ways to ascertain source apportionment and the table below presents the pros and the cons of these approaches. While these approaches have their differences, they are complimentary in nature and in an ideal situation, a study to understand the source strengths in a city or a region will include an application of both the approaches.

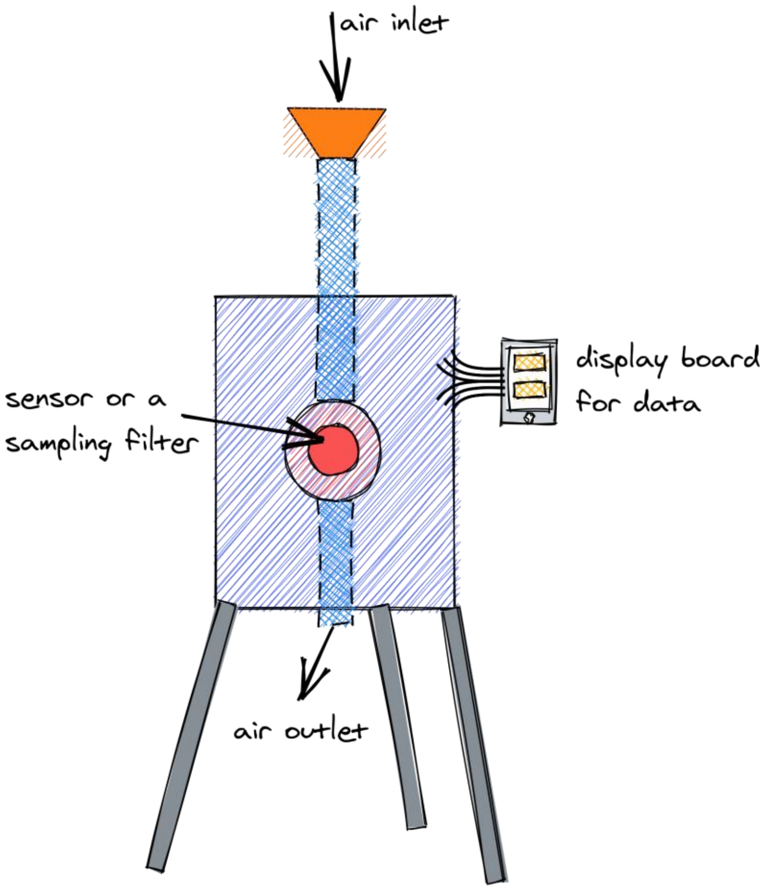
approach	**Bottom-up source modelling**	**Top-down receptor modelling**
		
basic definition	In this approach an emissions inventory is established for all the known sectors (anthropogenic and natural) and processed through a meteorology coupled chemical transport model to ascertain their share of contribution to the select airshed.	In this approach, an ambient sample is analysed for its chemical composition (in the form of ions, metals, and carbon species) and statistically matched with the chemical profiles of different fuels to ascertain their share of contribution to the measured

		ambient sample.
source definition	Typically, source refers to a sector and, in some cases, it can refer to a region.	Typically, source refers to the type of fuel and with some handwaving it can refer to a sector.
Major limitations	The emissions inventory work is heavily dependent on the depth of activity levels, fuel consumption data, and emission factors which vary by region and combustion technology in place.	It is very difficult to differentiative between the sectors burning the same fuels. For example, diesel burnt at a generator set and diesel burnt in a truck will show the same chemical profile; dust from wind erosion and dust from the side of the roads that is resuspended will have the same chemical profile; biomass burnt in an open field and biomass burnt inside the house for cooking will have the same chemical profile.
Spatial representativeness	Analysis results are representative of the entire airshed selected for the emissions and the chemical transport modelling exercise. The grid resolution can provide further details within the airshed.	Analysis results are representative of an area covering 2-km radius of the sampling location. The representativeness of the overall result to a city or a region depends on the number of sampling locations and the number of samples collected in the city or the region.
Temporal representativeness	Analysis results will be available at various temporal scales – by hour, by day, by month, and by season, depending on the granularity of the emissions and the chemical transport modelling exercise.	Analysis results are representative of the day and time of the sample collected. Because of this, multiple samples are required by month and season to ascertain the temporal trends in source contributions.
Financial burden	VARIABLE - depending on the granularity of the modelling exercise; primary data collecting activities; and modelling tools employed.	HIGH - depending on the number of sampling locations in the airshed and number of samples collected per season.
Laboratory needs	HIGH - when primary data collection is carried out to ascertain the emission factors by fuel and by sector.	HIGH - a stringent set of protocols must be followed starting from sampling, storage, chemical analysis, source profiling, QAQC,

		and receptor modelling.
Personnel needs	LOW to MEDIUM - when the emission inventories are available and the chemical transport model setup is operational, personnel needs can be low.	HIGH - Includes personnel to perform field, laboratory and statistical modelling tasks as described below. Advanced, semi-autonomous samplers can reduce personnel time in the field.
Personnel skill needs	HIGH - experienced staff is required to collate/manage/map/analyse the emissions inventory for the airshed; experienced staff is required to operate/calibrate/analyse the meteorology coupled chemical transport models for the airshed to ascertain the source contributions	HIGH - experienced staff is required to collect/store/record the samples during the field experiment; experienced staff is required to operate/calibrate/analyse the samples in the lab; and experienced staff is required to conduct the receptor modelling exercise involving selection and use of relevant source profiles.
Computational needs	HIGH - depending on the chemical transport model of choice, chemical mechanism selected, spatial and temporal resolution of the modelling system, and range of output parameters, computational needs can range from HIGH to VERY HIGH	MINIMUM - only part when computational facilities are required is the receptor modelling exercise, which is a statistical package capable of running on a laptop
Study time scales	Typically, less than one year.	Typically, one year for the sample exercises and 1-2 years for chemical analysis and receptor modelling (which entirely depends on the capacity of the lab)

Question # 05 - Which size fraction of particulate matter should be measured?

What to monitor is a tricky question. Any pollutant with a national standard must be monitored for regulatory and auditory purposes. In case of particulate matter, PM_{10} was most measured for the longest time – partly because of the availability of the equipment. In India, $PM_{2.5}$ was introduced to the criteria pollutants table in 2009 and since then all the cities have started to add this to the list of must measure pollutants. Typically, this list includes PM_{10}, $PM_{2.5}$, SO_2, NO, NO_2, CO, Ozone, Ammonia, and some VOC's like Benzene, Toluene, Xylene, Formaldehyde,



When health impacts are in discussion, $PM_{2.5}$ is the key size fraction with the greatest number of studies. Chronic and acute exposure to other pollutants also lead to some health impacts; however, $PM_{2.5}$ composition has contributions from all the other pollutants via secondary chemical mechanisms, which makes it the most important pollutant of them all.

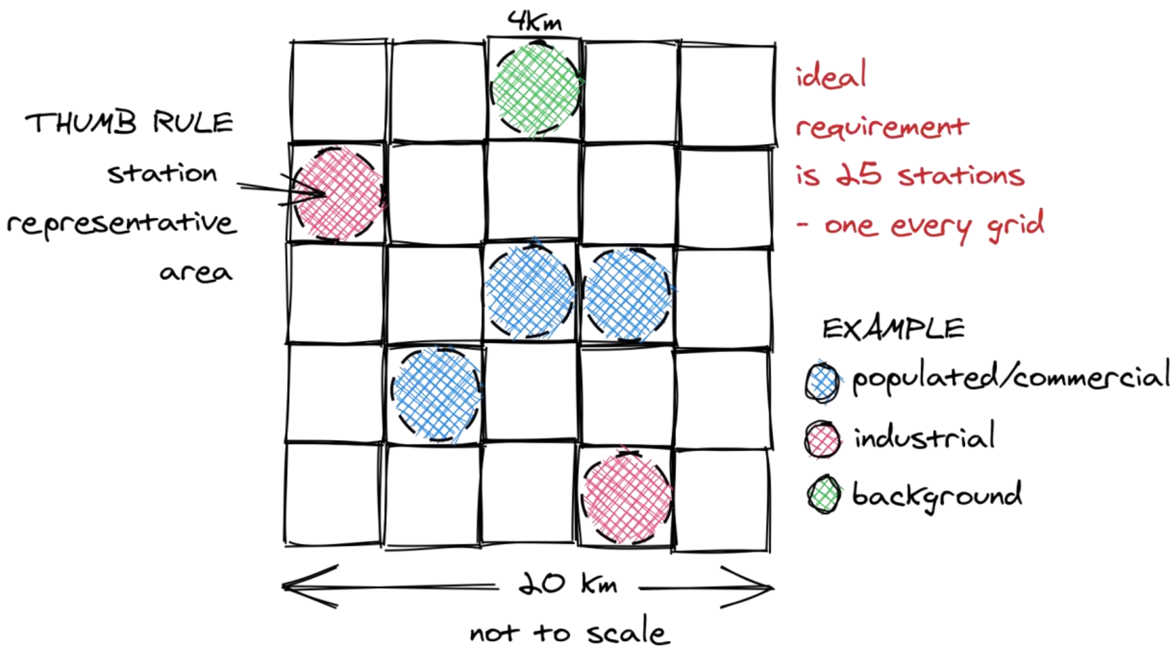
Since the PM pollution is a concern for most of the growing cities, more efforts are necessary to monitor it – both the size fractions (PM_{10} and $PM_{2.5}$). With the growing advances in technology, there is a wide array of monitors, in size, precision, and cost, and with some background checks, a user can take a decision on what is available.

Question # 06 - How many monitors are required to monitor particulate matter in a city?

Unlike the "what to monitor" question, "how much to monitor" primarily depends on the financial status of the city or the concerned institution. It is important that monitoring stations are established as many as possible, to create a representative pollution map the city or the area of interest, and this is dependent on the local institutional capacity, not only for procuring the equipment, but also to operate and maintain the same.

Typically, a thumb rule for representativeness of a continuous monitoring station is 4-km diameter. This could be lesser inside the cities with multiple obstructions like tall buildings and trees or could be more outside the cities which is commonly referred to as "background". Placing a monitor every 9-km^2 is financially and technically prohibitive for any city or country.

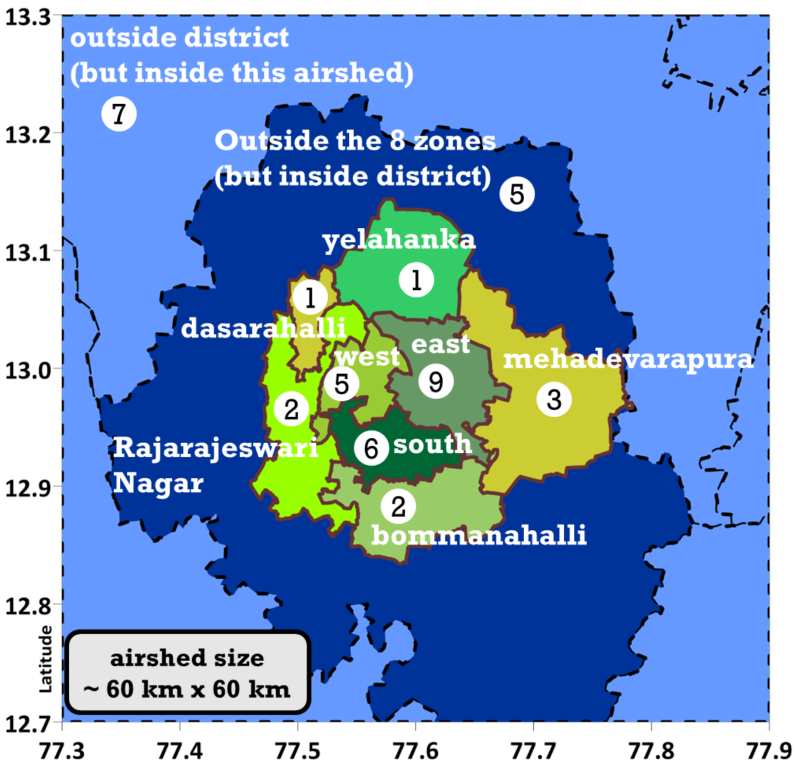
A representative sample set will include many monitors in densely populated and commercially active areas of an airshed and lesser number of stations outside the main urban areas. This is a compromise between technical needs and financial obligations of a buying and operating a network.



Countries have their own thumb rules on the number of recommended monitoring stations to represent the trends spatially and temporally in a city or an area of interest. India's Central Pollution Control Board created some guidelines, summarized below, for estimating recommended number of monitoring stations for total suspended particulate matter (SPM), SO_2, NO_2, and CO (and other oxidants).

Table: Recommended number of ambient air quality monitoring stations based on protocols established by India's Ministry of Environment and Forests

Pollutant	Population in the airshed	Number of stations
Suspended particulate matter (SPM)	< 100,000 100,000 to 1,000,000 1,000,000 to 5,000,000 > 5,000,000	4 4 + 0.6 per 100,000 population 7.5 + 0.25 per 100,000 population 12 + 0.16 per 100,000 population
Sulfur dioxide (SO_2)	< 100,000 100,000 to 1,000,000 1,000,000 to 10,000,000 > 10,000,000	3 2.5 + 0.5 per 100,000 population 6 + 0.15 per 100,000 population 20
Nitrogen dioxide (NO_2)	< 100,000 100,000 to 1,000,000 > 1,000,000	4 4 + 0.6 per 100,000 population 10
Carbon monoxide (CO) and Oxidants	< 100,000 100,000 to 5,000,000 > 5,000,000	1 1 + 0.15 per 100,000 population 6 + 0.05 per 100,000 population



Using these guidelines, an example for the city of Bengaluru is presented in the figure above. This assessment used information on gridded population and gridded urban settlements area to ascertain recommended number of 41 PM monitors in the city's airshed.

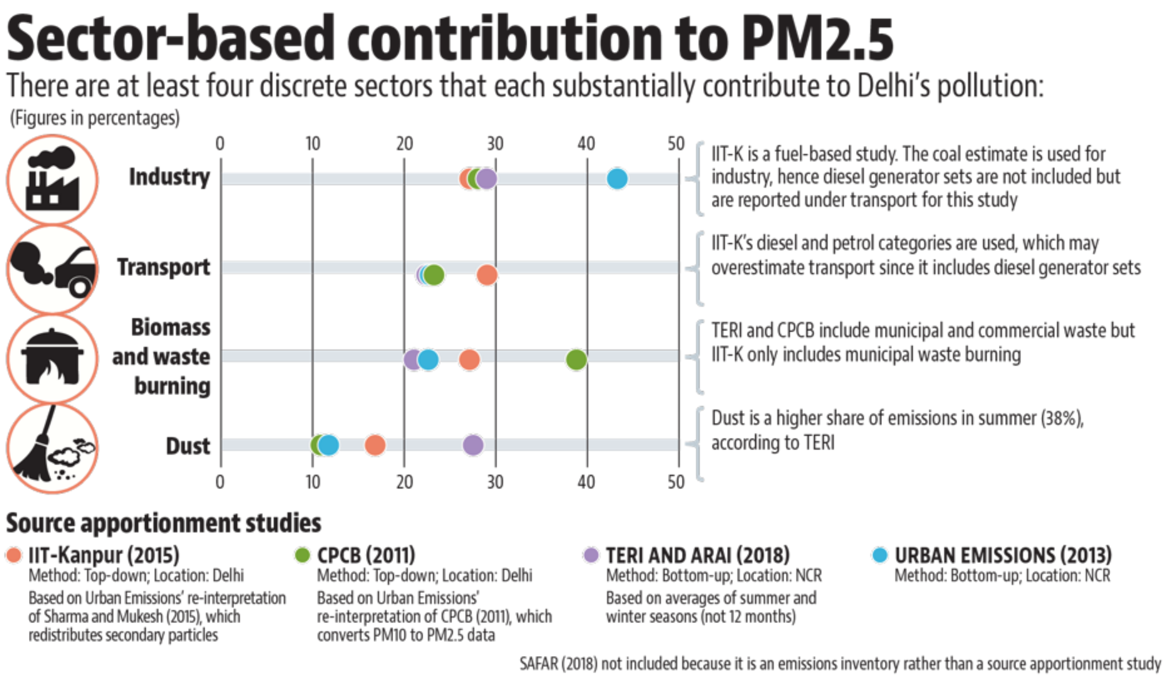
Question # 07 - Is road-transport the main culprit of particulate matter pollution in a city?

A common question with a difficult answer - "it depends". Yes, the road-transport emissions are growing rapidly in most of the developing country cities and its contribution to local and global air pollution problems is also increasing significantly. Yet, the answer lies in the mathematics and knowing the strengths of all the sources that are contributing to the problem.

On one side, the visibility of this growing sector creates a cloud that over-represents its contribution. Since the people spend more time on the roads, either because of traveling or just from spending time idling on busy roads at peak hours, they tend to get exposed to most of the pollution from on-road activities (including resuspension of dust), it is natural to assume that the road-transport is the main culprit of all the air pollution problems.

If we focus all the analysis on the roads, the contribution of the transport sector is the main culprit. However, for a city, it is important that an understanding of all the sources (inside and outside the city boundaries) is established before a decision is made on the contribution of any sector.

For example, Delhi's air pollution, which is the most studied city in India. Summary of contribution results from multiple studies is presented below, suggesting - road-transport emissions are an important culprit, but not necessarily the main culprit always.



Delhi has a complex air pollution problem - at least 4 sectors — industry, transport, biomass and waste burning, and dust — are substantial contributors to pollution in Delhi-NCR. Because all sources have to be addressed, it is pointless to debate which source is more or less at fault. At different times different sources predominate — crop burning in October, dust in the summer, transport year around — but on an annual basis, all are important. As a result, for Delhi's citizens to point accusing fingers at farmers, or transport interests to point fingers at industry, and vice versa, ignores the data — all sources have to be reduced. Also, arguing whether most sources are within-NCR or largely outside NCR is also irrelevant — both must be addressed

Full article is available @ https://www.hindustantimes.com/india-news/delhi-has-a-complex-air-pollution-problem/story-xtLhB9xzNYeRPp0KBf9WGO.html

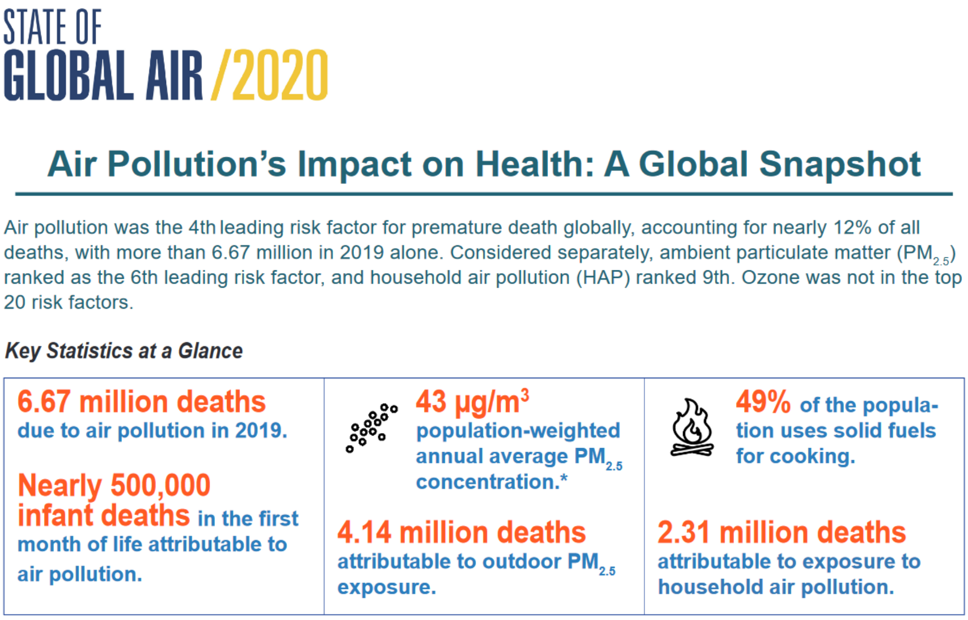
Now, the long-range transport plays a critical role. The transport emissions are ground-based and tend to increase the local concentrations significantly. However, the industrial emissions contribute to farther distances because of their tall chimneys (technical term of this is "advection"). And for pollutants like sulphur dioxide and other gases, the advection is more important as it provides enough hang time for these gases to undergo chemical transformation and eventually contribute to PM fractions downwind of the source regions.

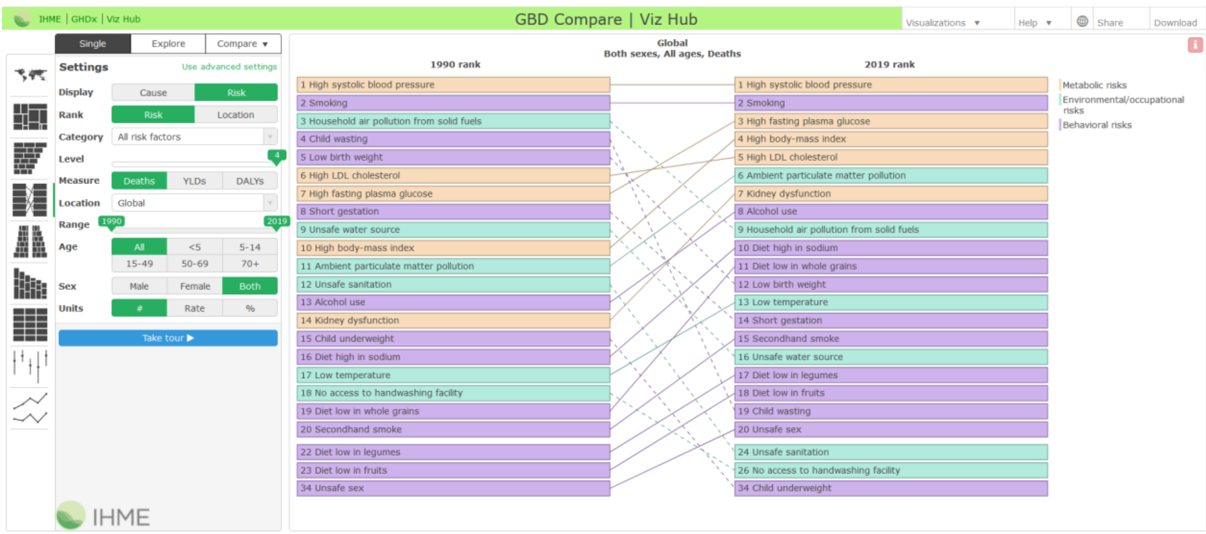
For example, during the 2008 Olympics, the city of Beijing, did not achieve the reductions in the air pollution levels by only cutting the vehicular fleet by half for the games period. They were able to achieve this reduction in conjunction with closing several small and large industrial sites within a radius of 100-km.

The arguments discussed above will not apply for cities where there are no industries (inside and outside the city boundaries) and all the roads are paved with limited construction activities. In this case, transport will be the main culprit.

Question # 08 - Is $PM_{2.5}$ the most harmful of all air pollutants?

Several studies were conducted worldwide to understand the epidemiological nature of air pollution with health impacts. The Global Burden of Diseases study, which is updated every year, provides a library of such studies and a synthesis of results in the form integrated exposure response (IER) curves linking particulate matter and ozone to various health endpoints[1].





[1] Global Burden of Diseases visualization platform @ https://vizhub.healthdata.org/gbd-compare and @ https://www.stateofglobalair.org/resources

Among the environmental risks, air pollution is among the top 10 for exposure from outdoor and indoor air pollution and among the pollutants particulate matter and ozone key. The complexity in singling these two pollutants is primarily due to their chemical composition (FAQ-02) linked to other pollutants, their tendency to stay in the air for longer periods and travel longer distances, and their tendency to go deeper into human body parts and result in chronic diseases. with inter-independencies and the chemical mechanisms involved in the formation of the PM, which combines the properties of most of the criteria pollutants.

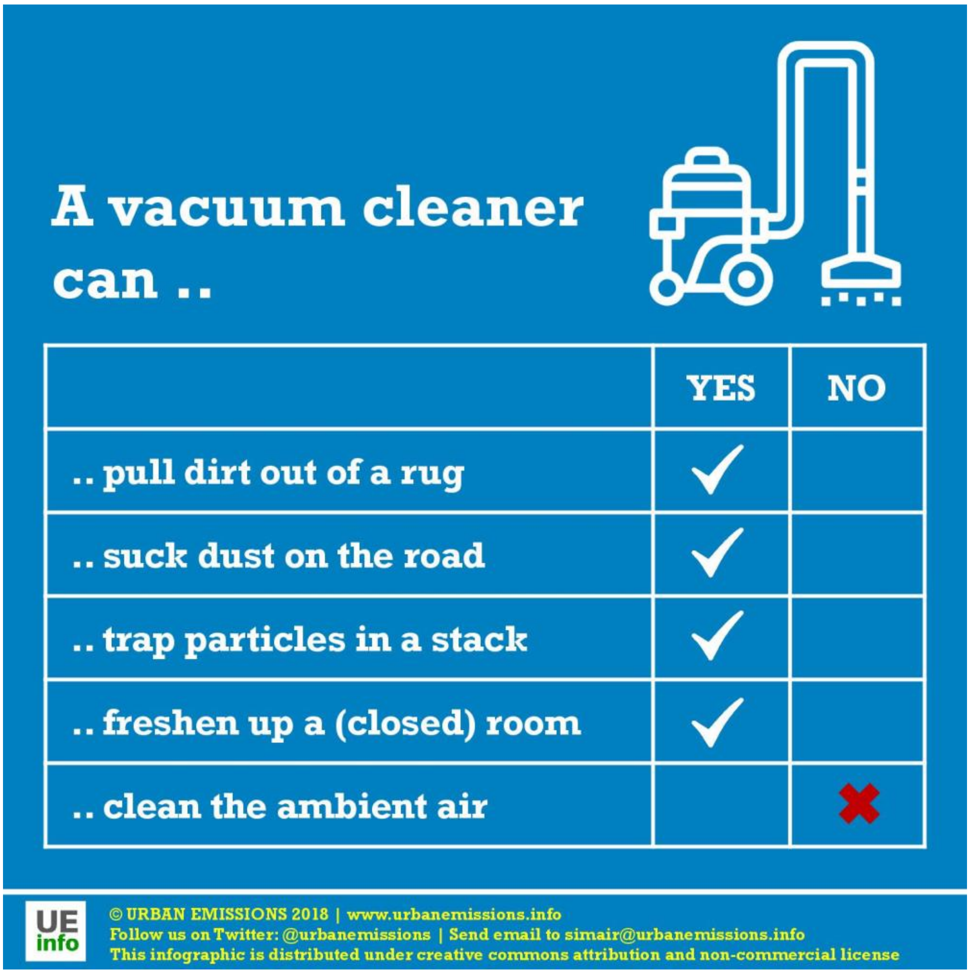
PM2.5 pollution is directly linked to cause or exacerbate asthma, collapsed lung, chronic bronchitis, pneumonia, blocked lung artery, lung cancer, diabetes, blood pressure, complications during pregnancy, early childhood brain function impairment, and even hair loss. While the IER curves give an indication of the possible impacts of air pollution on human health, there are other impacts which need immediate attention, such as smog (visibility impacts), agricultural yield (linked to ozone), and climate change (like changes in monsoon patterns).

Resource material on health impact analysis:

- Visualization portal for 1990-2018 global burden of disease estimates (IHME-GBD)
    - Resource links to methodology and inputs
- Visualization portal for State of the Global Air (SOGA) by Health Effects Institute (HEI)
    - India factsheet and more
- India state-level disease burden initiative by ICMR and PHFI (2019)
    - State-level reports (PHFI)
- Burden of disease attributable to major sources of air pollution in India (GBDMAPS-India) by HEI
- Air Quality Life Index (AQLI) by U.Chicago
- Health impacts analysis tools
    - Household Air Pollution Intervention Tool (HAPIT)
    - Air pollution health effects online tool by TERI
    - CO-Benefits Risk Assessment (COBRA) health impacts screening and mapping tool by USEPA
    - Environmental BENefits MAPping and analysis program (BENMAP) by USEPA
    - AirCounts tool by Abt Associates
    - Tool for health risk assessment of air pollution – AirQ+ by WHO
    - FAst Scenario Screening Tool (FASST) by EU
    - Greenhouse gas – Air pollution INteractions and Synergies (GAINS) by IIASA
    - The Long-range Energy Alternatives Planning – Integrated Benefits Calculator (LEAP-IBC) by SEI

(all links last accessed in February, 2021)

Question # 09 - Can we vacuum our particulate pollution problem using air purifiers and smog towers?



For managing outdoor air pollution, the answer is a big "NO".

Atmospheric science defines the air pollution problem as (a) a dynamic situation where the air is moving at various speeds with no boundaries and (b) a complex mixture of chemical compounds constantly forming and transforming into other compounds. With no boundaries, it is unscientific to assume that one can trap air, clean it, and release into the same atmosphere simultaneously. Expecting filtering units to provide any noticeable results at the community level is unrealistic.

Source: Can We Vacuum Our Air Pollution Problem Using Smog Towers?
@ https://www.mdpi.com/2073-4433/11/9/922

Question # 10 - Can we model particulate matter?

The first step in PM pollution modelling is collation of existing knowledge base. This includes information environmental agencies, NGOs, universities, research institutes, traffic-related departments, energy-consumption statistics, and important point source emitters, followed by building technical capacity to conduct emissions and pollution modelling at various scales – urban and regional, to analyse overall pollution trends, source contributions, and sensitivity analysis of interventions.

The key steps involved in this process are

Refer to SIM-air working paper # 41-2021 on resources and data available to support the above steps and conduct necessary energy, emissions, and air pollution analysis.

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