# PARTICULATE MATTER POLLUTION AND ITS IMPACT ON HUMAN HEALTH

By

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A dissertation submitted to the Department of Mathematic and Natural Sciences in partial fulfillment of the requirements for the degree of
Bachelor of Science in Biotechnology

Department of Mathematic and Natural Sciences
Brac University
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## Declaration

It is hereby declared that

1. The thesis submitted is my/our own original work while completing degree at Brac University.
2. The thesis does not contain material previously published or written by a third party, except where this is appropriately cited through full and accurate referencing.
3. The thesis does not contain material which has been accepted, or submitted, for any other degree or diploma at a university or other institution.
4. I/We have acknowledged all main sources of help.

**Student's Full Name & Signature:**

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# Approval

The thesis/project titled "Particulate matter pollution and its impact on human health" submitted by Anika Tasneem (16336001) of Summer, 2020 has been accepted as satisfactory in partial fulfillment of the requirement for the degree of Bachelor of Science in Biotechnology on 25.07.2020.

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# Ethics Statement

No humans or animals were harmed during the making of this study.

# Abstract

One of the major types of air pollution is particulate matter type air pollution. This type of air pollution is mainly caused by the suspended particles created from burning fuels or other harmful gases leading to the formation of particulate matter following secondary chemical reactions. The result of particulate matter air pollution is the formation of long term chronic or acute diseases effecting the respiratory, epithelial and cardiovascular system forming allergic reactions, bronchial diseases, asthma, cardiovascular disease, etc. and the long term exposure may also lead to cancer formation. The reason for forming this type of pollution are improper uses of chemicals, burning fuels, industrialization, etc. Although some preventative measures are still taken and some of them are under developed but they are not enough. It is needed to be improved along with the cooperation of the whole country and individuals. In this review paper, we enlighten ourselves about the idea of particulate matter air pollution, its sources, and worldwide scenarios, the reasons for forming this type of pollution but most importantly its adverse effects on human health and the possible probabilities of its prevention.

# Dedication

Dedicated to my father and mother for always supporting and believing in me

## Acknowledgement

First and foremost, I am beholden to the Almighty Allah for blessing me with the good health and knowledge for completing by review paper for my undergraduate study. I have received help from many individual during completing this review paper and I wish to thank them with gratitude and

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**Anika Tasneem**

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# List of Acronyms

| | |
|---|---|
| SPM | Suspended Particulate Matter |
| IARC | International Agency for Research on Cancer |
| WHO | World Health Organization |
| $SiO_2$ | Silicon dioxide |
| $NO_x$ | Nitrogen Oxides |
| CO | Carbon Monoxide |
| $SO_2$ | Sulfur dioxide |
| PM | Particulate Matter |
| $\mu g/m^3$ | Microgram per Cubic Meter |
| DALY | Disability-adjusted life-year |
| t-PA | Tissue Plasminogen Activator |
| PAI1 | Plasminogen Activator-1 |
| ANS | Autonomic Nervous System |
| NAQFC | National Air Quality Forecast Capability |
| TSP | Total Suspended Particles |
| SNS | Social Network Service |
| USA | United States of America |
| AQI | Air Quality Index |
| AIF | Adaptive Iterative Forecast |
| DRNN | Deep Recurrent Neural Network |
| RNN<br>VOC | Recurrent Neural Network<br>Volatile Organic Compound |

# Chapter 1

# Introduction

## 1.1 Air Pollution

Air pollution is one of the types of pollution which is equally severe and health risking. Air pollution is basically when air is contaminated by the mixture of various harmful particles mainly, solid particles and gases. This pollution is caused due to car emissions, smog, and emissions from factories, chemicals, dust, pollen, etc. Ozone gas plays a prominent part in air pollution. Besides some other pollutants are increased levels of carbon monoxide, nitrogen dioxide, sulfur dioxide and particulate matter (PM).

According WHO, air pollution kills about 7 millions of people throughout the world in one year. The date of WHO also shows that 9 out of 10 people breathes contaminated air filled with life risking pollutants. The major problem of air pollution is that it is constantly causing immense health risking diseases like stroke, heart diseases, cardiovascular diseases, lung cancers, chronic obstructive pulmonary disease, and acute respiratory infection. It is discovered that more than 3 million premature death are causing due to the effects of air pollution. [1]

It is also observed that in developed countries the concentration of the pollutants mentioned are less compared to low and middle income countries (China and India) where, the condition of air is becoming toxic every day. Whether it be low income country or high income country the main goal is to control this pollution and take precautions from the adverse effect of it on the public health is the main concern as the effects air pollution are causing some of the major health risking diseases.[1]

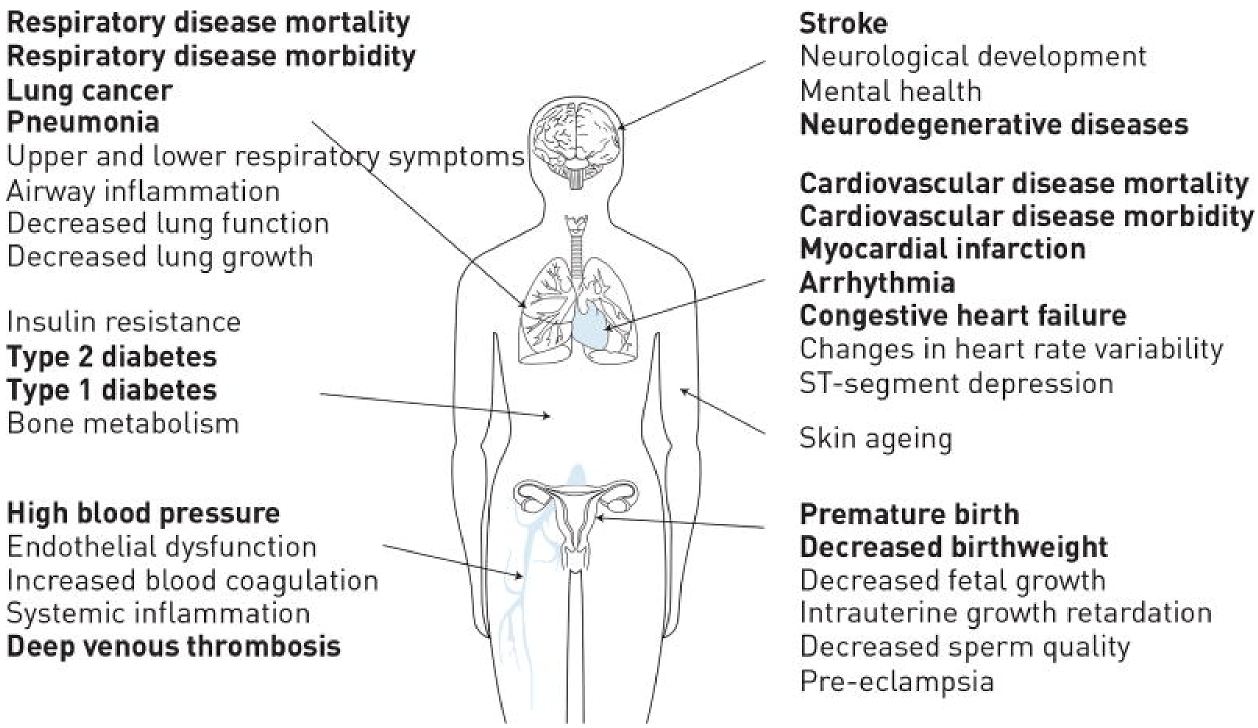



*Figure 1.1: Overview of diseases, conditions and biomarkers affected by outdoor air pollution*(Source: Rückerl R, Schneider A, Breitner S, Cyrys J, Peters A Inhal Toxicol. 2011 Aug; 23(10):555-92)

## 1.2 Types of Air Pollution and major pollutants

Air pollution can be divided into two major types mainly based on the pollutants. They are:

- Particulate type air pollution
- Gaseous type air pollution

### Particulate type air pollution

This type of air pollution is mainly caused by the suspended particles created from burning fuels. The SPM are the suspended particles created from smoke, dust and vapor. These suspended particles or the airborne particles are very dangerously effecting our health by causing mainly lung damages and respiratory diseases. [2]

### Major pollutants of particulate type air pollution

**Silica:** Silica (Silicon dioxide, $SiO_2$) is found almost everywhere as it is the major component of soil, clay and sand. It may remain in its free form most crystalline or in a combined form with other elements. The main disadvantage of this pollutant is it causes respiratory diseases like Silicosis if tiny particles of silica is intake. [3]

**Asbestos:** Asbestos is an incombustible chemical compound mainly used for fire proofing materials or insulator. This matter when suspended in air results high risk in forming cancer. Also, causing the disease called asbestosis due to the long term exposure to asbestos fibers. [4]

**Lead:** The petrol are basically mixed with lead, so, when fuels are burned from these automobiles lead is released in the air. Lead can be found in many substances like hair dye, diesel, paints, etc. and they can accumulate both on animals and plants causing nervous, digestive, etc. diseases also leading to cancer. [5]

**Gaseous**

This type of pollution is caused due to the accumulation of noxious gases such as, sulfur oxide, carbon monoxide, nitrogen oxide and other toxic vapors. These can take part in further chemical reactions in the atmosphere forming smog and also causes acid rain also forms secondary pollutants like ozone. [6]

**Major pollutants of gaseous type air pollution**

**Sulfur dioxide ($SO_2$):** Sulfur dioxide is produced from burning fuels mainly containing phosphates, papers, thermal power plant, coal, metal smelting, etc. When mixed with air it causes acid rain ultimately hampering both plants and animals. [7]

**Carbon monoxide (CO):** Carbon monoxide is formed from burning fuels like coal, wood, paper, petrol, diesel, etc. but when they are burned incompletely then carbon monoxide is formed. CO hampers the transfer of oxygen by blood, slows down our reflexes, visual impairment, loss of consciousness, headaches and many more. [8]

**Nitrogen oxide ($NO_X$):** One of the main form that is found in the environment is nitrogen dioxide which is produced from burning fuel, power plants, industrial boilers, etc. causing incidents of asthma in children. [9]

Besides, some other gaseous pollutants are ozone, hydrocarbons, hydrogen sulfide, radon, hydrogen floride, ammonia, chlorofluorocarbon, etc.

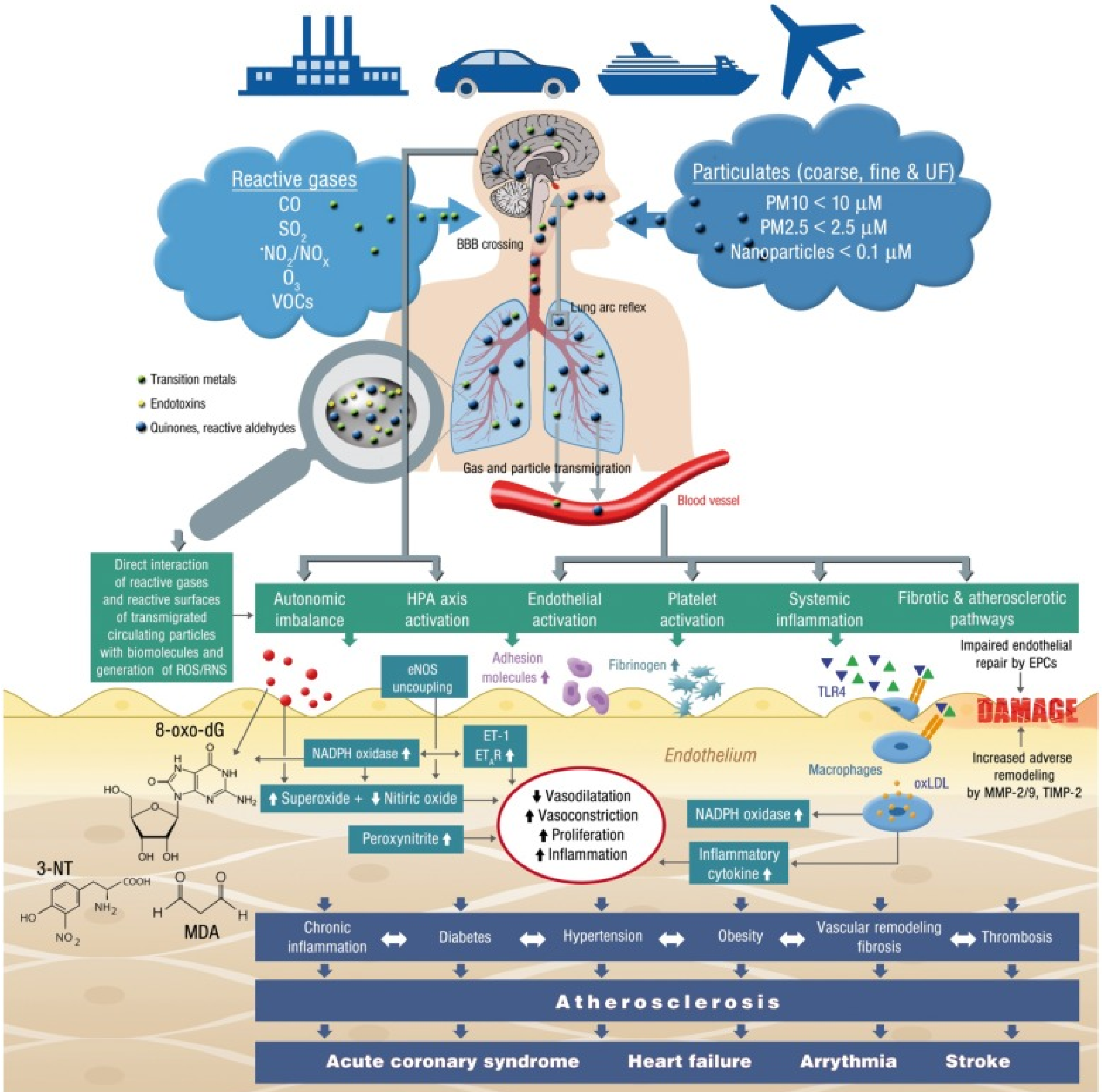



*Figure 1.2: Summary of pathophysiological mechanisms by which air pollution components*(Source: Münzel, T., Gori, T., Al-Kindi, S., Deanfield, J., Lelieveld, J., Daiber, A., & Rajagopalan, S. (2018). Effects of gaseous and solid constituents of air pollution on endothelial function. *European heart journal*, *39*(38), 3543–3550. https://doi.org/10.1093/eurheartj/ehy481)

# Chapter 2

# Particulate matter pollution

## 2.1 What is particulate matter pollution?

The particulate matter air pollution is basically a type of air pollution where the air contains small particles of non-visible amount of size whether they be in solid form or in precipitations though we can see some of the particles like dust or based on the darkness of color like smoke. Long time exposure to this type of pollution causes health risks and cardiovascular, respiratory, bronchial, etc. diseases from the many sources like lead, silica, asbestos, etc. [2]

## 2.2 Types of particulate air pollution

The types of particulate air pollution is classified based on the size of the pollutants present in the air. The sizes of the pollutant may exist from 0.005 microns to 100 microns in diameter. [9]

If the particle size ranges less than or equal to 10 micron in diameter it is called PM10 and if the particle size ranges less than or equal to 2.5 micron in diameter it is called PM2.5 it is also known as fine PM. There are some other types as well based on how small the particles can get like particles less than or equal to 0.1 microns in diameter are called PM (0.1) or ultra-fine. [9]

The less is the size of the particulate matters higher is the chance for causing health problems as in gets easier for our bodies to accumulate those particles. All the PM less than 10 micron in diameter can be easily inhaled by the respiratory system causing various respiratory diseases by affecting the lungs. [9]

There are few methods of measuring the PM particles from them one of the common and old trick is to measure the color intensity of black smoke passed through a filter paper though it may not show the accurate results.

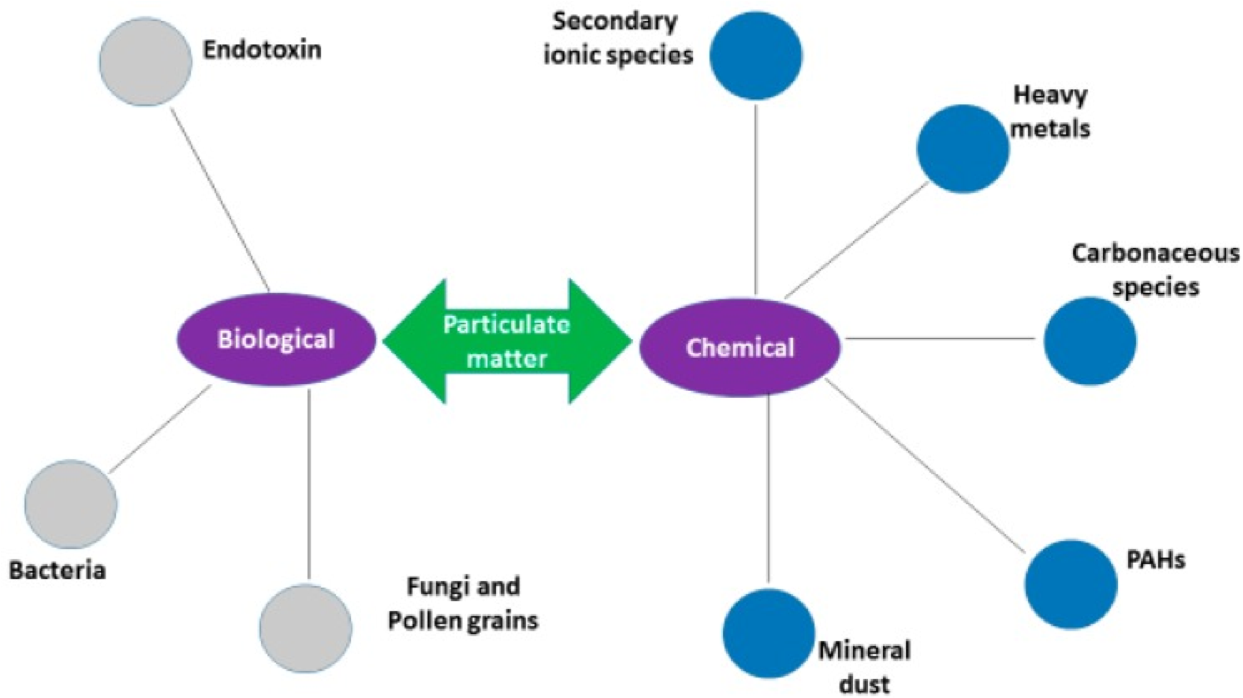



*Figure 2.2: Biological and chemical components of particulate matter* (Source: Morakinyo, O. M., Mokgobu, M. I., Mukhola, M. S., & Hunter, R. P. (2016). Health Outcomes of Exposure to Biological and Chemical Components of Inhalable and Respirable Particulate Matter. *International journal of environmental research and public health*, *13*(6), 592. https://doi.org/10.3390/ijerph13060592)

## 2.3 How is particulate matter air pollution different from air pollution?

Air pollution involves both harmful materials whether it be gaseous or particles present in them. This type of pollution may consist of many types based on the amount of harmful substances present in it in terms of the chemical composition. It can also be classified into indoor and outdoor type of air pollution based on the amount of chemicals, burning of fuels, heating materials, industrial equipment and etc. But of all the types the harmful ones are particulate matter (PM), gaseous like sulfur dioxide ($SO_2$), nitrogen oxides ($NO_x$), ozone ($O_3$), and carbon monoxide (CO) are most likely the harmful ones. [10]

Therefore, from the above given discussion it must be clear that the particulate matter (PM) air pollution is a type of air pollution which is more severe than any other types of air pollution. One of the vital elements for the cause of air pollution are basically the particulate matters which remains suspended in the air. IARC categorized particulate matter as a Group-1 carcinogen. This type of air pollution is highly responsible for premature death, respiratory diseases like asthma, cardiovascular diseases and etc. also long exposure leads to many chronic and fatal diseases. [11]

# Chapter 3

## Global scenarios of particulate matter air pollution and air pollution

PM pollution is one of the main causes of death caused air pollution as PM air pollution is a type of it which almost causes about nearly 7 million of death per year throughout the year. From 2005 to 2014, 37,967 respiratory deaths followed in Tehran in which 21,913 (57.7%) were male. $PM_{10}$ and $PM_{2.5}$ also presented noteworthy affairs with respiratory deaths in the elder age groups. [10]

Daily occurrences of death can be observed due to the cause of PM pollution which is revealed by researches from Europe and America. It is predicted that outdoor air pollution in cities and villages affected 3 million premature death all over the world in 2012 and 88% of these losses take place in low and middle-income countries, typically in south East Asia and the western Pacific. According to the WHO assessments, 14% of initial respiratory deaths and 14% of lung cancers are possibly affected by air pollution. [10]

### 3.1 Study of particulate matter air pollution along with air pollution of Tehran

It is already known to us that countries with low income rates are with high risks of affecting from PM pollution. Now, let us look at the data of the 10-year dated research, 37,967 respiratory deaths followed in Tehran, in which 21,913 (57.73%) cases were male and 16,047(42.27) were female. The male to female sex ratio was 1.36, 9065 (23.87%) deaths occurred in spring, 8528 (22.46%) in summer, 9323 (24.55%) in autumn and 11,051 (29.1%) in winter. [10]

*Table 3.1(1): Incidence of male, female and total respiratory deaths in 2005–2014*(Source: Dehghan, A., Khanjani, N., Bahrampour, A., Goudarzi, G., & Yunesian, M. (2018). The relation between air pollution and respiratory deaths in Tehran, Iran- using generalized additive models. *BMC pulmonary medicine*, *18*(1), 49. https://doi.org/10.1186/s12890-018-0613-9)

Frequency of male, female and total respiratory deaths in 2005–2014

| | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Male | 1772 | 1731 | 1774 | 1873 | 1850 | 2257 | 2323 | 2511 | 2936 | 2886 | 21,913 |
| Female | 1272 | 1290 | 1302 | 1210 | 1415 | 1700 | 1763 | 1803 | 2126 | 2166 | 16,047 |
| Sex Ratio | 1.39 | 1.34 | 1.36 | 1.54 | 1.30 | 1.32 | 1.31 | 1.39 | 1.38 | 1.33 | 1.365 |
| Age- standardized rate[a] | 117.49 | 114.09 | 117.05 | 112.78 | 119.91 | 120.62 | 118.99 | 113.73 | 119.6 | 119.2 | – |

[a]Deaths per 100,000 population

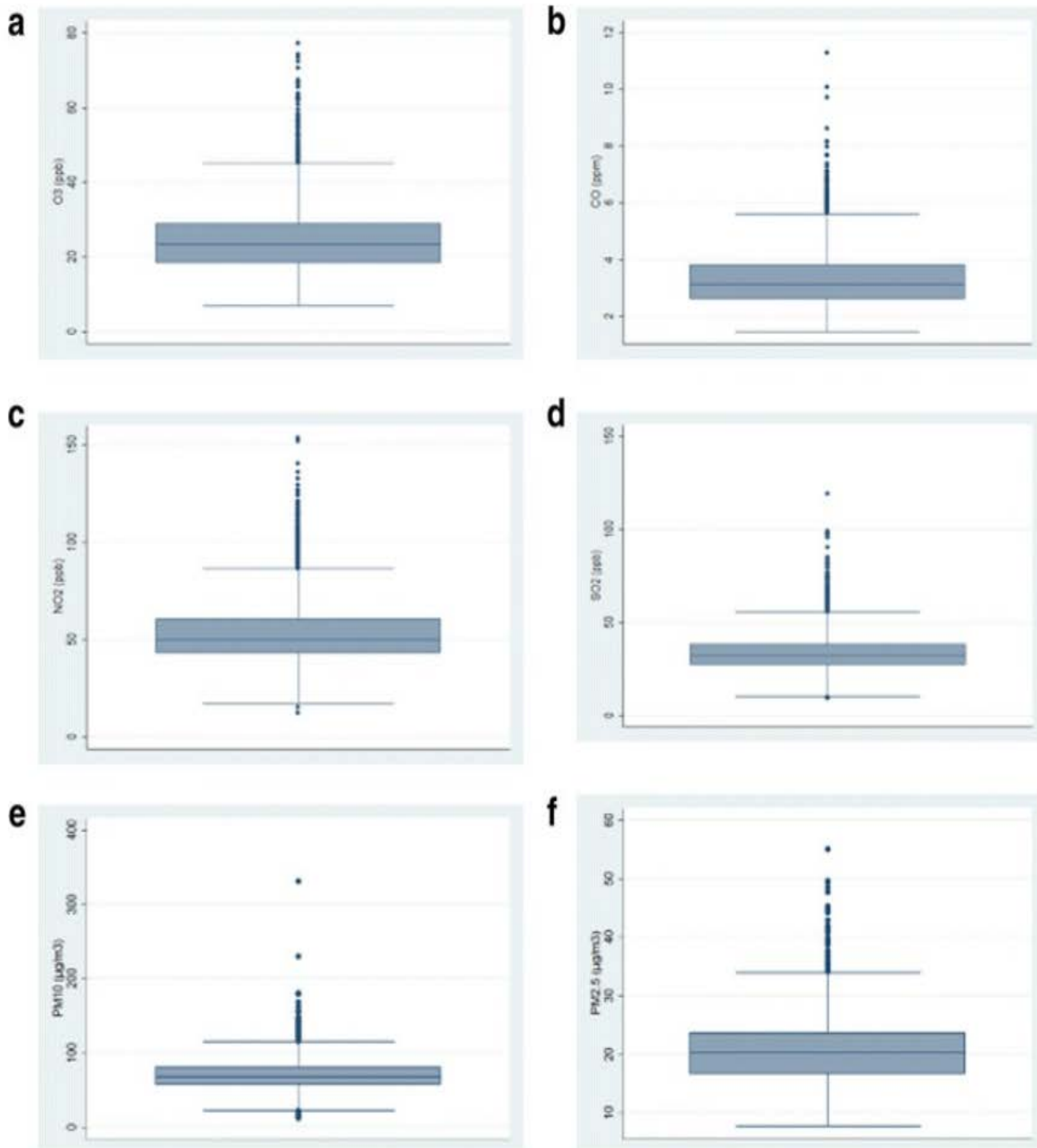
*Table 3.1(2): Results of adjusted Generalized Additive Model and the effect of pollutants on respiratory deaths in peoples 18–60 years old*(for 1 unit increase in CO and 10 units increase in all other pollutants) (Source: Dehghan, A., Khanjani, N., Bahrampour, A., Goudarzi, G., & Yunesian, M. (2018). The relation between air pollution and

respiratory deaths in Tehran, Iran- using generalized additive models. *BMC pulmonary medicine*, *18*(1), 49. https://doi.org/10.1186/s12890-018-0613-9)

Results of adjusted Generalized Additive Model and the effect of pollutants on respiratory deaths in peoples 18–60 years old (for 1 unit increase in CO and 10 units increase in all other pollutants)

| | Lag | df | RR | 95% CI for RR | *P*- Value |
|---|---|---|---|---|---|
| Lag 0 | $O_3$ (ppb) | 7.57 | 1.07 | 0.99–1.09 | 0.128 |
| | CO (ppm) | 6.33 | 0.99 | 0.93–1.04 | 0.549 |
| | $NO_2$ (ppb) | 1 | 1.05 | 1.00–1.09 | 0.034 |
| | $SO_2$ (ppb) | 3.19 | 0.96 | 0.90–1.02 | 0.195 |
| | $PM_{10}$ (μg/m$^3$) | 7.47 | 1.02 | 1.00–1.04 | < 0.001 |
| | $PM_{2.5}$ (μg/m$^3$) | 3.25 | 1.05 | 0.96–1.13 | 0.198 |
| Lag 1 | $O_3$ (ppb) | 5.57 | 1.04 | 0.99–1.08 | 0.117 |
| | CO (ppm) | 5.14 | 0.97 | 0.93–1.03 | 0.345 |
| | $NO_2$ (ppb) | 7.07 | 1.05 | 1.01–1.10 | 0.026 |
| | $SO_2$ (ppb) | 1 | 0.96 | 0.90–1.02 | 0.206 |
| | $PM_{10}$ (μg/m$^3$) | 7.08 | 1.03 | 1.01–1.05 | 0.001 |
| | $PM_{2.5}$ (μg/m$^3$) | 2.87 | 1.06 | 1.02–1.06 | < 0.001 |
| Lag 2 | $O_3$ (ppb) | 5.28 | 1.06 | 1.01–1.11 | 0.014 |
| | CO (ppm) | 4.98 | 0.98 | 0.96–1.04 | 0.597 |
| | $NO_2$ (ppb) | 4.14 | 1.06 | 1.01–1.10 | 0.011 |
| | $SO_2$ (ppb) | 1.61 | 0.95 | 0.88–1.01 | 0.087 |
| | $PM_{10}$ (μg/m$^3$) | 6.84 | 1.03 | 1.01–1.05 | 0.003 |
| | $PM_{2.5}$ (μg/m$^3$) | 3.16 | 1.04 | 1.01–1.07 | < 0.001 |
| Lag 3 | $O_3$ (ppb) | 6.96 | 1.07 | 1.02–1.12 | 0.004 |
| | CO (ppm) | 6.99 | 0.97 | 0.92–1.02 | 0.250 |
| | $NO_2$ (ppb) | 2.2 | 1.04 | 0.99–1.10 | 0.084 |
| | $SO_2$ (ppb) | 8.61 | 0.95 | 0.89–1.01 | 0.120 |
| | $PM_{10}$ (μg/m$^3$) | 7.47 | 1.02 | 0.95–1.09 | 0.156 |
| | $PM_{2.5}$ (μg/m$^3$) | 3.21 | 1.02 | 0.95–1.09 | 0.094 |
| Mean Lag 4–8 | $O_3$ (ppb) | 8.61 | 1.04 | 0.99–1.09 | 0.119 |
| | CO (ppm) | 4.49 | 0.97 | 0.93–1.03 | 0.433 |
| | $NO_2$ (ppb) | 2.7 | 1.03 | 0.98–1.07 | 0.243 |
| | $SO_2$ (ppb) | 1 | 0.95 | 0.89–1.02 | 0.137 |
| | $PM_{10}$ (μg/m$^3$) | 7.73 | 1.02 | 1.00–1.04 | 0.017 |
| | $PM_{2.5}$ (μg/m$^3$) | 4.26 | 1.00 | 0.97–1.04 | 0.341 |

No linear connection is to be seen of respiratory disease for CO and SO2 in male, female and in every age individuals.[13]




The box plots for air pollutants (**a**: $O_3$, **b**: CO, **c**: $NO_2$, **d**: $SO_2$, **e**: $PM_{10}$ and **f**: $PM_{2.5}$)

*Figure 3.1: The box plots for air pollutants (a: $O_3$, b: CO, c: $NO_2$, d: $SO_2$, e: $PM_{10}$ and f: $PM_{2.5}$)*(Source: Dehghan, A., Khanjani, N., Bahrampour, A., Goudarzi, G., & Yunesian, M. (2018). The relation between air pollution and respiratory deaths in Tehran, Iran- using generalized additive models. *BMC pulmonary medicine*, *18*(1), 49. https://doi.org/10.1186/s12890-018-0613-9)

The outcome of this research indicated that the day-to-day regular concentrations for $PM_{2.5}$ was 20.68 µg/m3 and for $PM_{10}$ was 69.75 µg/m3 and these two concentrations were greater than the WHO 2014 standards yearly inceptions (20 and 10 µg/$m^3$, respectively). Though, the 98th percentile of CO, $O_3$ and

The amount of $PM_{10}$ concentration in the environment was higher than the WHO guidelines in about in 3173 from 3652 days along with the $PM_{2.5}$ amounts in 315 days from 1826 days. The yearly average of $NO_2$ in 2004 to 2009 was greater, but in 2010 to 2013 was lesser than WHO standards. [10]

## 3.2 Overall scenario

The exposure to PM pollution matters in various aspects but if we focus on China we will find that lies differences between the socio classes be it among rich to poor people. The more is the higher level class the lesser is the exposure to PM pollution. It is also related to local level health wise. For instance a research six districts in Sao Paulo, Brazil, showed that PM10 had fewer effect on respiratory disease related death within elders in regions with a greater ratios of schooling system and rich families, and it had greater effect in areas where ratio of poor people living were more [20]. Another study in Hamilton city in Canada showed that PM pollution plays a major role in areas where the scale of unemployment and education is lesser [21].

Also a research of Hong Kong, China, observed that air pollution had a high effect on the number of death of people renting houses than those who own private properties and a higher effect on working class than the unemployed [22]. Also the advanced regions like, Rome and Norway showed the same results. [23, 24].

Again, few researches shows that the health inequities related to air pollution individually. For instance, a research of twenty cities inside the America indicated that distinct schooling significantly modified the association between PM10 and death rate; mainly, the developed schooling stages of the distinct person the less is the effect of PM10 on death scenarios [25]. Again, the same is the result for many researches in China [26]. Furthermore, as a consequence of the rigorousness of air pollution amplified, health differences between people dissimilar socio-economic backgrounds would intensify [26]. On a different note, a decent natural atmosphere might decrease health dissimilarities [27].

The yearly contact to particulate matter, in India in 2017 was 89·9 $\mu g/m^3$, ranking maximum in the world. The maximum pollution $PM_{2\cdot5}$ in India in 2017 was in Delhi, followed by Uttar Pradesh, Bihar, and Haryana in north India (range 125·7–174·7 $\mu g/m^3$), and then in Rajasthan, Jharkhand, and West Bengal (range 81·4–93·4 $\mu g/m^3$).

*Table 3.2: Distribution of annual mean $PM_{2·5}$ concentration, proportion of population using solid fuels, and ozone concentration in the states of India grouped by SDI, 2017*(Source: India State-Level Disease Burden Initiative Air Pollution Collaborators (2019). The impact of air pollution on deaths, disease burden, and life expectancy across the states of India: the Global Burden of Disease Study 2017. *The Lancet. Planetary health*, *3*(1), e26–e39. https://doi.org/10.1016/S2542-5196 (18)30261-4)

| | Population-weighted annual mean $PM_{2·5}$µg/m$^3$ (95% UI) | Percentage of population using solid fuels (95% UI) | Population-weighted ozone concentration in parts per billion (95% UI) |
|---|---|---|---|
| Low SDI states (675 million) | 125·3 (87·5–167·3) | 72·1 (71·1–73·0) | 63·6 (63·5–63·8) |
| Middle SDI states (387 million) | 58·7 (44·8–76·6) | 46·7 (45·7–47·8) | 59·0 (58·7–59·4) |
| High SDI states (318 million) | 56·6 (44·0–71·6) | 31·0 (30·0–32·1) | 56·3 (55·8–56·8) |
| India (1380 million) | 89·9 (67·0–112·0) | 55·5 (54·8–56·2) | 60·1 (59·9–60·2) |

Population in 2017 given in parentheses. SDI=Socio-demographic Index. UI=uncertainty interval.

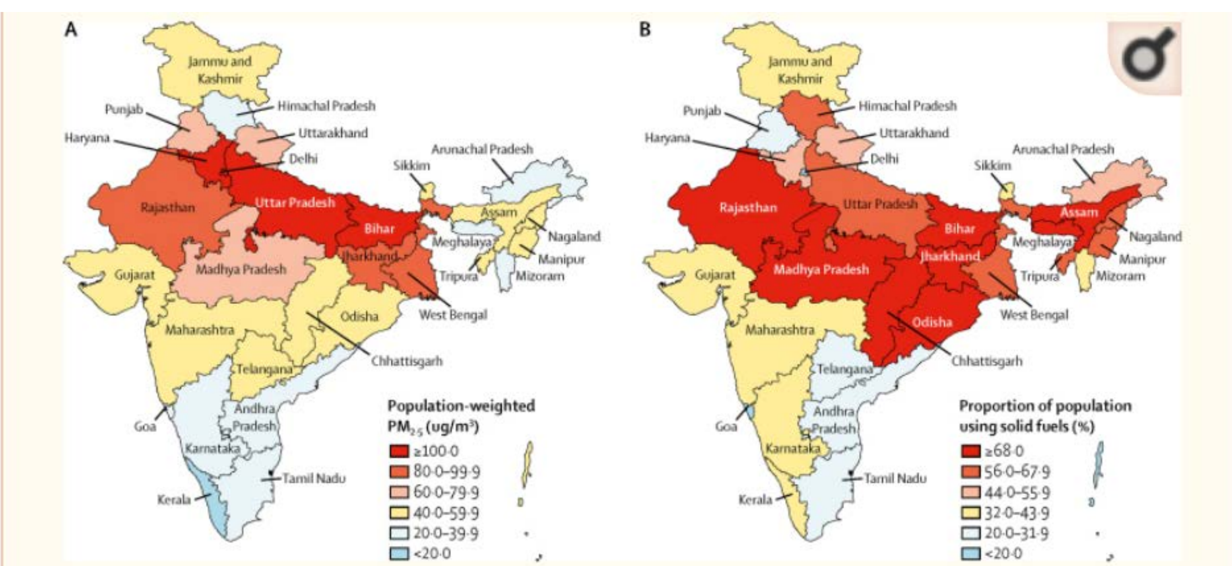


*Figure 3.2(1): $PM_{2.5}$ concentration and use of solid fuels in the states of India, 2017(Source: India State-Level Disease Burden Initiative Air Pollution Collaborators (2019)*. The impact of air pollution on deaths, disease burden, and life expectancy across the states of India: the Global Burden of Disease Study 2017. *The Lancet. Planetary health*, *3*(1), e26–e39. https://doi.org/10.1016/S2542-5196 (18)30261-4)

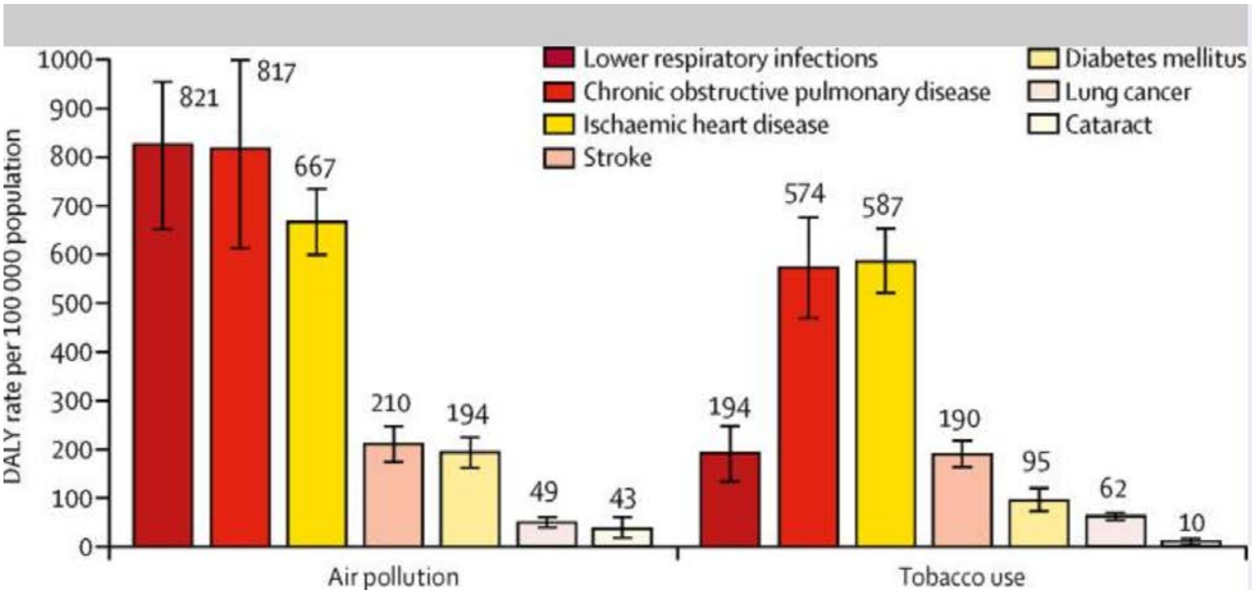



*Figure 3.2(2): DALY rates attributable to air pollution and tobacco use in India, 2017*(Source: India State-Level Disease Burden Initiative Air Pollution Collaborators (2019). The impact of air pollution on deaths, disease burden, and life expectancy across the states of India: the Global Burden of Disease Study 2017. *The Lancet. Planetary health*, *3*(1), e26–e39. https://doi.org/10.1016/S2542-5196 (18)30261-4)

The highest values were from lower respiratory infections (29·3%), chronic obstructive pulmonary disease (29·2%), and ischemic heart disease (23·8%), followed by stroke (7·5%), diabetes (6·9%), lung cancer (1·8%), and cataract (1·5%). The DALY rate attributable to air pollution in India in 2017 was greater for lower respiratory infections than tobacco use. [30]

# Chapter 4

## Reasons for particulate matter air pollution

Air pollution ranks fourth among the worldwide menaces followed by hypertension, dietary habits and smoking. [31] It is estimated by the World Health Organization (WHO) that the number of early premature death raises up to 7 million due to the effects of air pollution which is the result of outdoor air pollution causing about diseases like ischemic heart disease at 40%, stroke at 40%, chronic obstructive pulmonary disease at 11%, lung cancer at 6%, and acute lower respiratory infections in children at 3% [32], all are the effects of air pollution respectively. The major causes of this air pollution are the burning of fuels, dusts, rodents, [33] but most importantly, particulate matter ($PM_{2.5}$, $PM_{10}$), sulfur dioxide ($SO_2$), and nitrogen oxides ($NO_2$), which ultimately leads to the formation of particulate matter.

Now, the main reason for the cause of particulate matter type of air pollution is basically dependent on the amount of particulate matter present in the air and why they are suspended in the air at the first place. Some of the major components of particulate matter and the reason of them to suspend in air are given below:

**Silica:** Silica (Silicon dioxide, $SiO_2$) is found almost everywhere as it is the major component of soil, clay and sand. It may remain in its free form most crystalline or in a combined form with other elements. When it remains in a free form due to various man made uses they can easily float in the air hence causing health issues.

**Asbestos:** Asbestos is an incombustible chemical compound mainly used for fire proofing materials or insulator. This matter when suspended in air results high risk in forming cancer. Also, causing the disease called asbestosis due to the long term exposure to asbestos fibers. [4]

**Lead:** The petrol are basically mixed with lead, so, when fuels are burned from these automobiles lead is released in the air. Lead can be found in many substances like hair dye, diesel, paints, etc.

Also, there are some harmful gases when mixed with air leads to the formation of particulate matter with the help of secondary chemical reactions. These types of gases and the reasons for their formation are:

**Sulfur dioxide ($SO_2$):** Sulfur dioxide is produced from burning fuels mainly containing phosphates, papers, thermal power plant, coal, metal smelting, etc. When mixed with air it causes acid rain ultimately hampering both plants and animals. [7]

**Carbon monoxide (CO):** Carbon monoxide is formed from burning fuels like coal, wood, paper, petrol, diesel, etc. but when they are burned incompletely then carbon monoxide is formed. CO hampers the transfer of oxygen by blood, slows down our reflexes, visual impairment, loss of consciousness, headaches and many more. [8]

**Nitrogen oxide ($NO_X$):** One of the main form that is found in the environment is nitrogen dioxide which is produced from burning fuel, power plants, industrial boilers, etc. causing incidents of asthma in children. [9]

Besides, some other gaseous pollutants are ozone, hydrocarbons, hydrogen sulfide, radon, hydrogen fluoride, ammonia, chlorofluorocarbon, etc.

# Chapter 5

# Impacts on human health

## 5.1 Why is it bad on physiology?

WHO evaluates that early mortality due to air pollution is crossing around 7 million, by which the ratio of mortality due to outdoor air pollution includes heart disease at 40%, stroke at 40%, chronic obstructive pulmonary disease at 11%, lung cancer at 6%, and acute lower respiratory infections in children at 3% [14]. Also, intense weather occurrences and air pollution effect contagious diseases due to water, food, insect vectors, and rodents [15]. The main sources of air pollution are particulate matter ($PM_{2.5}$, $PM_{10}$), sulfur dioxide ($SO_2$), and nitrogen oxides ($NO_2$), which produce particulate matter (PM) by straightly affecting the air or adjusting into secondary pollutants by chemical reactions in the atmosphere [16]. Meanwhile the International Agency for Research on Cancer (IARC) categorized PM as a Group-1 carcinogen, awareness in the special effects of PMs on health is increasing [17]. Particulate matter has been recounted to intensify the hazard of respiratory-related diseases such as asthma and chronic obstructive pulmonary disease, along with cardiovascular diseases like uneven heartbeats, vascular dysfunction, and arrhythmia [18] along with acute and chronic early mortality rates [19].

## 5.2 Epidemiological studies linking Pm exposure to morbidity and mortality in humans

From the very beginning of the 20$^{th}$ century more precisely the first half of it we got to know that high levels of exposure of PM air pollution is  life threatening. Such incidents related to smog in Meuse Valley, Belgium (1930), Donora, Pennsylvania (1948), and London, UK (1952) caused many people to suffer from cardiac and respiratory diseases along with hospitalization and even to death. More than about 4,000 people were death from which 10,000 people were severely affected health wise directly linked from the London smog incident. [64, 65]

For the damages above several strategies were taken of which the application of Clean Air Act in 1970 was noteworthy. [66] It was observed that when the PM level were decreased PM related death and health diseases were also decreased and the current epidemiologic studies shows a direct connection between PM contact and death occurring through cardiopulmonary diseases. [67]

## 5.3 Short term and long term exposure studies to PM air pollution

The indications of both long term and short term exposure to PM air pollution shows a linked between health hazards and even death. Though it might not instantly affect our death but the day-to-day exposure maybe lead us to pre mature death. A worldwide evaluation of the effects of air pollution on heath was carried out in the Global Burden of Diseases, Injuries, and Risk Factors Study 2015 (GBD 2015) [68]. This research showed that $PM_{2.5}$ is the fifth-ranking mortality risk factor, leading to 4.2 million deaths and 103.1 million disability-adjusted life-years in 2015. The highest amount of pre mature death due to the effects of air pollution occurred in China of about 1.11 millions of death which almost corresponds to 40.3% of deaths due to stroke, 26.8% of deaths due to ischemic heart disease, 23.9% of deaths due to lung cancer, and 18.7% of deaths due to chronic obstructive pulmonary disease (COPD) to $PM_{2.5}$ exposure [69]. Given the GBD 2015 research, these symbolizes the 1st, 2nd, 4th, and 5th leading causes of death in China, respectively. [70]

## 5.4 More risk on age groups and other factors

Age plays one of the most common and constant effect on both long term and short term exposure to particulate matters. But the highly risky age groups are mainly the elders ranging from the ages above 60 years, which may lead to hospitalization or worse to death as their immune system is weak compared to the younger population. But also we need to consider the exposure to particulate matters of these older persons whether they are more outdoor or indoor person, also based on their social interactions. It is also seen that not only the older age groups, children are also vulnerable to the adverse effects of particulate matter air pollution as their immune system are under development, not fully formed also they inhale more air per body weight, also they have more exposure to outdoor activities. Premature death may occur to infants exposing to $PM_{2.5}$ and $PM_{10}$ [59, 60]

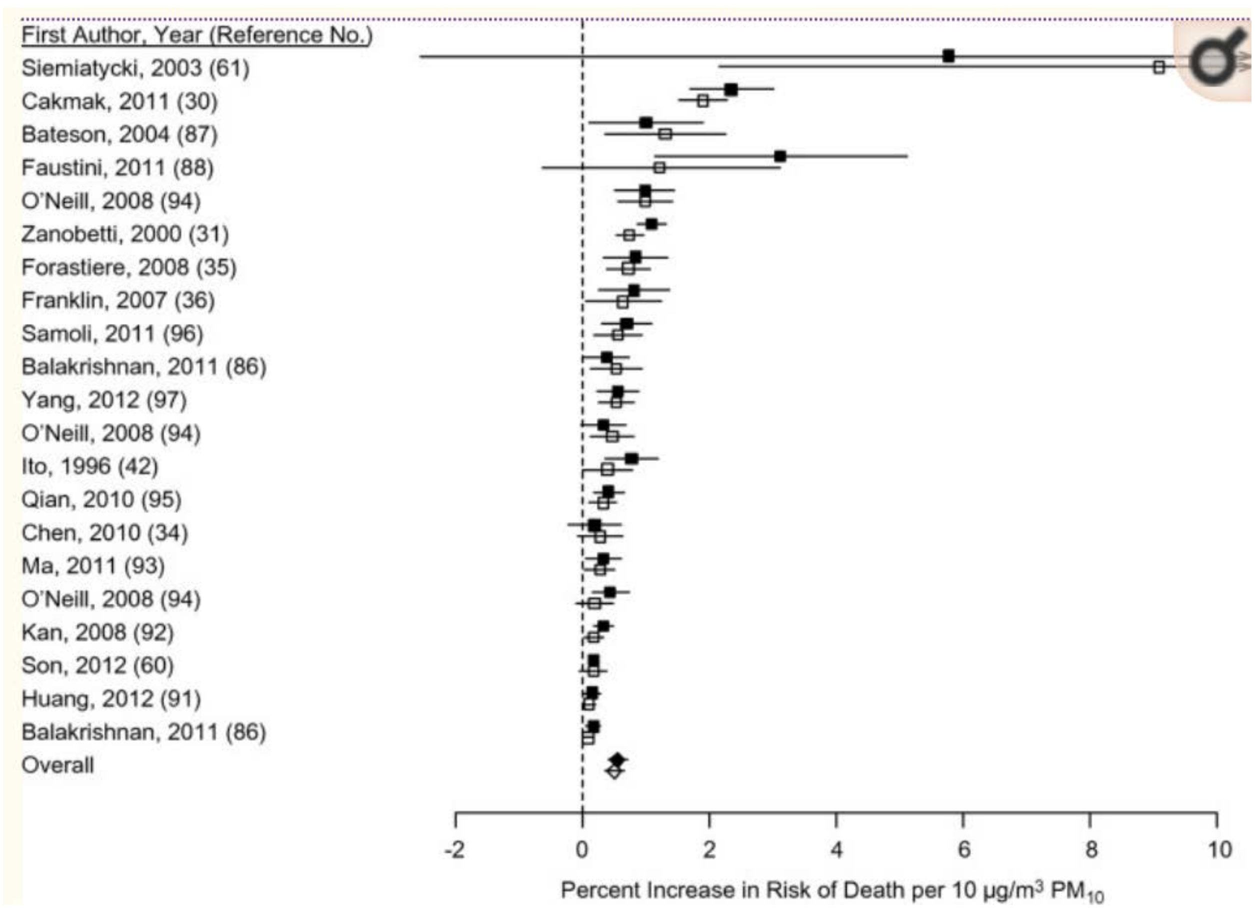



*Figure 5.4:Meta-analysis of the association of age with increased risk of death by exposure to particulate matter*(Source: Bell, M. L., Zanobetti, A., & Dominici, F. (2013). Evidence on vulnerability and susceptibility to health risks associated with short-term exposure to particulate matter: a systematic review and meta-analysis. *American journal of epidemiology*, *178*(6), 865–876. https://doi.org/10.1093/aje/kwt090)

Risks for older populations were higher than for younger persons [61]. There were no solid evidences regarding whether male or female are more susceptible to the exposure to particulate matter. It widely depends on the nature of living. Whether the person is more outdoor or indoor oriented, whether they smokes or drinks, cooks and other activities. It does not necessarily varies if a person is a male or female. Although few studies may suggest that women are at higher risk and susceptible to this type of pollution than men but it is recommended to further emphasis on this type of information. [62]

It is also estimated that the influence of particulate matter air pollution depends on race and ethnicity as well. Because, in any country the minority are less privileged. They are not treated as the part of that particular country as a result their living standards are not high which leads them on more exposure to particulate matter. Like the areas where the minorities resides are very unhygienic also they tend to work to the places where there is more exposure to this type of pollution. [63]

## 5.5 Susceptibility to PM- induced morbidity and mortality

High levels of exposure to PM has been connected with various diseases but old age, people with low socioeconomic status, preexisting heart and lung disease, and smoking are the most vulnerable. The elder people and unemployed are at the most vulnerable state to the negative effects of the short-term exposure to PM [71]. Death occurring through ischemic heart disease with prolonged contact with $PM_{2.5}$ between non-smokers, smokers, ex-smokers, and existing smokers. [72] Although it was found out that the possibility of mortality due to arrhythmia, hearth failure, and cardiac arrest was not preeminent by $PM_{2.5}$ for nonsmokers, nonetheless it considerably raised for ex and existing smokers.

## 5.6 Effects on the cardio vascular system

The exposure to particulate matter leads to severely affect the cardiovascular system. It may lead to cardiovascular diseases like ischemic heart diseases, heart failure and cerebrovascular diseases. All of these diseases can result from the exposure to $PM_{2.5}$ levels.

The prolonged and temporary contact with $PM_{2.5}$ leads to high amounts of threat related to ischemic heart disease whether they be deadly or non-serious [73, 74, 75, 76]. The threat to myocardial infarction is also related to the contact with $PM_{2.5}$ [77, 78] but a little less than the probability of developing ischemic heart disease by the ACS research. Some further studies and meta-analysis also shows that the exposure to $PM_{2.5}$ leads to a direct link to heart failure [79, 74, 80, and 81]. A very direct connection also exists in between $PM_{2.5}$ exposure and cerebrovascular disease [82, 83]. Some short-term researchers also shows that though air pollution is linked to the risk of ischemic, but not hemorrhagic stroke [84, 85].

### 5.6.1 Subclinical effects

The result of the contact with PM air pollution is linked with subclinical effects mainly with cardiovascular disease. These contains systemic inflammation and oxidative stress, atherosclerosis, thrombosis, endothelial dysfunction, hypertension, cardiac remodeling, and arrhythmia [67].

## 5.6.2 Inflammation, oxidative stress, and atherosclerosis

PM inhalation results in inflammatory signs equally between lungs and also systemically. Increased pulmonary neutrophil numbers were seen to volunteers who were contacted with PM by inhaling the air for 2 hours [86]. Circulating levels of C-reactive protein, fibrinogen, IL-1β (interleukin-1β), IL-6 (interleukin-6), GM-CSF (Granulocyte-Macrophage Colony Stimulating Factor), and TNF-α (Tumor Necrosis Factor-α) are also the results of the direct contact of PM filled air [86-89]. Systemic markers of oxidative stress, including atherogenic precursors such as oxidized lipids is also related with the contact of PM [90- 93]. By the help of carotid artery intima-media thickness as a substitute for atherosclerotic progression, multiple researches, together with the Multi-Ethnic Study of Atherosclerosis (MESA) gave us the results that intima-media thickness relates positively with long-term exposure to PM [95–97]. Further researches showed the results that coronary artery calcification relates with dwelling in a city center or nearby a main roadway [98].

Researches in the atherosclerosis model apolipoprotein E (ApoE) knockout mice shows that contact PM leads in high range of oxidized low-density lipoproteins, lipid peroxidation, and systemic oxidative stress. This increases atheroma burden, and plaque cellularity and lipid content [96- 99].

## 5.6.3 Hypercoagulability and thrombosis

A prothrombotic phase is inhibited which can result in arterial thrombotic and venous thrombotic conditions [100, 101]. It also causes along with Von Willebrand factor [102–104]. Also several pathways are hampered by PM exposure such as prothrombotic pathways, and antifibrinolytic pathways

Also prothrombotic pathways, antifibrinolytic pathways are correspondingly triggered by PM contact. The increase of PAI1 is observed due to the exposure of PM which also hampers the t-PA movement [104–108]. Studies have also found out that the exposure to PM increases the plasma viscosity, platelet activation, and *ex vivo* coagulation [109–112].

The effects of PM contact on cardiovascular biomarkers were seen when China 2008 Summer Olympics in Beijing. The PM pollution were decreased as strict majors were taken by the government there back then as remarkable decrease of Von Willebrand factor were seen in the test subjects. These factors again increased when the strictness was removed [103].

## 5.6.4 Endothelial dysfunction, higher levels of blood pressure and cardiac remodeling

Equally small or long term contact to PM has been related between the variations in heart related activity. Exposure to diesel exhaust or PM leads to vascular dysfunction [105, 112–115]. The long-lasting contact to $PM_{2.5}$ is linked with less flow-mediated dilation of the brachial artery and retinal narrowing [116, 117].

Multiple researches in accordance to long-lasting PM contact leads to the formation hypertension [118, 119]. Controlled-exposure studies using severe contact of humans to PM or diesel exhaust showed quick rises in systolic blood pressure due to the contact [120, 121]. Contact to PM also leads to the rise of the hazards of gestational hypertension [122, 123].

Lastly, traffic exposure has been related to left and right ventricular hypertrophy, shows that pollution-associated vasoconstriction and hypertension may worsen congestive heart failure [124, 125]. Same consequences may be found in mice. The mice has been contacted with PM shows cardiac arrests and fibrosis in the reaction to angiotensin II infusion [126]. A long-term contact to mice to concentrated ambient particles leads to increased ventricular size systolic and diastolic dysfunction, and myocardial fibrosis [127].

### 5.6.5 Cardiac electrical changes and irregular heart rhythm

In patients with implantable cardioverter defibrillators, positive relations have been made between temporary rises in air pollution and occurrence of cardiac arrhythmias together with atrial fibrillation, ventricular fibrillation, and ventricular tachycardia [128]. Contact to air pollution is also associated with, increased heart rate and changes in heart-rate variability [129].

The highest number of links between arrhythmia and pollution contact was found when the examination was limited to a small number of patients with repeated arrhythmias, proposing that the dangers of arrhythmia is limited to the most vulnerable persons [128]. It was also seen that the wild-type mice did not show any signs of arrhythmias after the contact with PM but very strong results of arrhythmias were observed in genetically engineered mice to display the cardiomyopathy alterations which linked to congestive heart failure [130].

### 5.6.6 Metabolic syndrome and insulin resistance

Multiple researches showed the linked to PM occurring insulin resistance and type II diabetes which leads us to the information that PM are highly hazardous for type 2 diabetes patients, also an essential hazardous cause for cardiovascular disease. These results have both been found in mature adults and also in children [112]. An alternative research on collecting data from 3,500 persons from Germany showed that each 1 μg/m$^3$ of traffic-related $PM_{2.5}$ leaded to type II DM of 1.36 (95% CI.97-1.89) after considering age, gender, BMI, and socioeconomic status [133]. This experiment was differentiated with people living near to a close main road to people living far 200 meters from the man road [132]. It also signifies that the chances of PM with related with type 2 diabetes is higher in women [137].

The contact of PM is related to insulin sensitivity is confirmed by animal testing. Mice genetically predisposed to type II Diabetes, or mice nurtured to high-fat diet and contact PM shows high amount of insulin resistance and glucose intolerance [135]. Fascinatingly, undeveloped mice when they are in contact with PM at the starting of 3 weeks of age establishes insulin resistance after 10 weeks of contact deprived of extra stress demonstrating a scope of to the special effects of PM [136].

### 5.6.7 Biological mechanisms

Researches have linked the direct connection of PM leading to cardiovascular diseases found in human as well as in animals (Figure 5.6). Currently, there are 3 theories [138] from which the 1st one that suggests the intake of PM triggers the inflammatory reactions in the lung leading to systemic inflammation, which induces thrombosis, endothelial dysfunction, and atherosclerosis. The 2nd one proposes that breathing PM induces the sensory receptors in the lung which leads to disproportioning ANS, leading to alternate the heart rate, vasoconstriction, endothelial dysfunction, and hypertension. The 3rd theory suggests that mainly the ultrafine particles ($PM_{0.1}$) along with other PM can openly cooperate with the target tissues by arriving into the circulation from the lung, although, this theory has not been proved yet and it's debatable [67].

Current researches shows that almost all of the ultrafine particles are removed from the lung considering them as bigger particles [139]. However, some of the soluble PM may be passed into the circulation when they are inhaled.

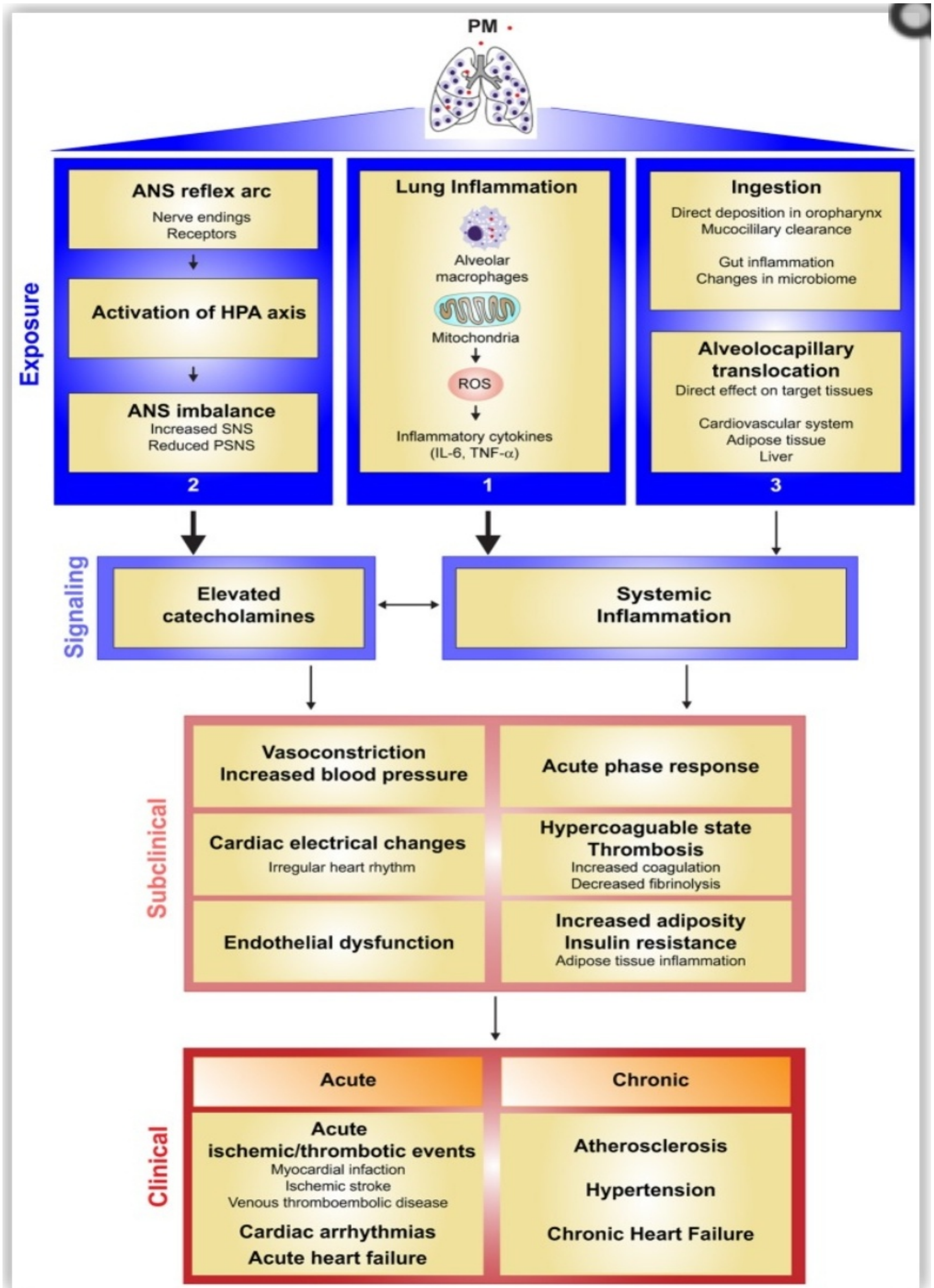



*Figure 5.6.7: Current evidence for the mechanisms by which particulate matter air pollution causes cardiovascular health effects.*(Source: Hamanaka, R. B., & Mutlu, G. M. (2018). Particulate Matter Air Pollution: Effects on the Cardiovascular System. *Frontiers in endocrinology*, *9*, 680. https://doi.org/10.3389/fendo.2018.00680)

## 5.6.8 Reactive oxygen species and mitochondria

As we got to know before that PM induces many physiological damages to our body from which two of them are the production of reactive oxygen species (ROS) and oxidative stress responses [142]. The contact to air pollution is linked with systemic markers of oxidative stress [141]. Researches showed that ROS levels and oxidative stress rises when the cells are in contact with PM through *in vitro* process at cellular level including nasal, airway, and lung epithelial cells [140], macrophages [142], endothelial cells [143], cardiomyocytes [144],gastrointestinal epithelial cells [145], epidermal keratinocytes [146], and corneal epithelial cells [147].

Furthermore, high level of ROS stages leads to PM-induced biologic cytokine formation and introduction of apoptosis [140]

Even though PM-adsorbed chemicals and metals produces free radicals inside cells, cells can react to this stimuli with the formation of ROS as signaling molecules [148]. Mitochondrial generation of ROS is an important factor but the contact of PM with it has caused to alter mitochondrial morphology and function [149].

## 5.6.9 Alveolar macrophages

Alveolar Macrophages exist in on the luminal epithelial exterior of alveoli and are vital for lung expansion, and our immunity [150]. Treating them *in vitro* with PM provokes a transcriptional up regulation of inflammatory cytokines including TNFα, IL-1β, IL-6, IL-8 and GM-CSF [151].

The epithelial cells of lungs also react to PM treatment *in vitro* [152]; though, researches in animals proposes that the response of them to PM contact is needed for downstream cardiovascular effects.

## 5.6.10 Sympathetic activation and endogenous catecholamine

Since PM pollution plays a major role in inconsistency on heart rates along with blood pressure it might also increase or provoke the balance amongst the sympathetic and parasympathetic arms of the autonomic nervous system. Certainly, a research of Brazilian sugarcane farmers established that throughout yielding time, as soon as PM is in elevation due to sugarcane burning, workers' blood pressure and heart rate inconsistency capacities linked expressively with sympathetic nerve action calculated by micron urography [153]. Current research indicated that higher contact to PM was linked with high serum levels of norepinephrine and epinephrine, among other stress hormones [154].

## 5.6.11 Higher levels of adiposity and adipose inflammation

Research conducted on animals indicates that long-term contact to PM leads to increased adipocyte size and increased visceral fat mass. PM contact encourage genes connected with lipogenesis in adipose tissue, impaired adipose mitochondrial function, and alters in circulating stages of leptin and adiponectin. This amplified adiposity was also linked with amplified macrophage infiltration into adipose tissue [155].

### 5.6.12 Epigenetic changes

It is still not known how PM pollution and epigenetic changes are correlated with one another but studies shows that if someone is contacted with PM as early as possible the longer are its effects. Contact of pregnant mice to diesel exhaust leaded to increased vulnerability to pressure load and leaded to heart failure in pups raised to adulthood [156].

## Chapter 6

## Preventions

South Korea made the strategies for TSP in the "Framework Act on Environmental Policy" in 1991. The death rates have been gone up in South Korea assumed to be 11,944 (24 deaths per 100,000 population) in 2008. As South Korea contains higher number of PM concentrations compared to most of the therefore, their contact rates are also high [38]. The $PM_{10}$ pollution concentration in South Korea was 51–61 μg/$m^3$ throughout 2001–2006, but after strategic planning in the Seoul metropolitan area (2005–2014), since 2007 it has been declining. Though air pollution is decreasing recently [39] mainly because of the pollution created in the cities also the rise of smog along with PM present in it in China. [40, 41]

It is difficult to control particulate matters to suspend in the air but improved measures are taken by the governments of low income countries along with the countries with high level of population. But also taking these measures effectively is quite tough due to over usage of these pollutants and being very small in size. The daily data are mainly collected by the developed and developing countries in this way a statistical review can be provided about the daily situations of PM concentrations to raise awareness if the condition worsen ups to its citizen like- children, asthma patients, and elderly, can easily have the access and awareness. [42]

A model developed to show the relationship between PM exposure and renal function were shown [43]. A model established named Poisson generalized linear model, show the correlations of the death rates caused by $PM_{2.5}$[44]. Cobourn established a nonlinear recession model using the data of 3 large cities of China namely, Beijing, Nanjing, and Guangzhou [45]. Brian et al. developed a model named NAQFC which will show the ozone concentration predictions for the surrounding areas of the United States [46]. Giri et al. explored the connection between $PM_{10}$ concentration and weather conditions in the Kathmandu area, Nepal, and established that seasons highly affect $PM_{10}$ concentration and air quality [47]. Additionally, Seinfeld and Pandis showed that the diffusion of pollutants is determined by atmospheric conditions such as wind speed, temperature, and insolation [48].

Additionally, the increase of the expansion of artificial intelligence gradually can be a fruitful way to resolve and identify air pollution. Papanastasiou et al. gathered air pollution and climatological statistics to determine $PM_{10}$ concentration in the Volos area, Greece, along with a neural network and verified that air pollution is interconnected to atmospheric elements [49]. Chaloulakou et al. proved that the error to predict by a neural network model is the same as of a linear regression model using various parameters to measure the daily concentration of particulate matter lesser than 10 microns [50]. Barai et al. gathered 15-year (1985–1999) yearly data of VOC, $NO_x$, CO, $SO_2$, $PM_{10}$, and $PM_{2.5}$ shows that a neural model works fine if it has a large-scale training data set [51]. Ghazi and Khadir gathered $PM_{10}$ data along with temperature data such as wind speed, humidity, and temperature from 1 January 2003, to 12 December 2004, and showed that an RNN model [52]. Ong et al. used wind direction, wind speed, temperature, amount of sunshine, humidity, and precipitation data of 52 cities in Japan to assume $PM_{2.5}$, and established a DRNN model which contains an auto encoder to record the conditions [53]. Hooyberghs et al. established a neural network model that forecasts the day-to-day average $PM_{10}$ concentration in Belgium and determined the variations in day-to-day average $PM_{10}$ concentration in Belgian city regions are dependent on the values for $PM_{10}$, wind speed, temperature, the amount of clouds, and wind direction [54]. Koo et al. developed a data analyzer which can easily detect the pollution taking place today and the following day based on the amount of ground pollutants present in the air. [54] Lee et al. suggested a model which can assume the daily average and maximum PM pollution by regression analysis, neural network analysis, and support vector regression analysis [55].

Luo, Yang, Huang, Mahajan, and Chen invented a forecasting method showing highest level of accuracy in Taiwan. The system is called AIF with the help of which we can gather information from previous incidents [56].Mei, Li, Fan, Zhu, and Dyer proposed an idea to identify AQI with the help of social media posts in China [57]. When the concentration of yellow sand raised in USA, the people posted the conditions in social media and made other people aware of it. Nowadays SNS has been playing a huge role in awaking the public about the climatic conditions. The Ministry of Security and Public Administration showed that people responded to their social media when there was any increase in PM pollution to a certain area and made everyone aware of it.

The above mentioned cases where some of the preventive measures taken to identify particulate matter air pollution. Still now new ideas along with new technologies are improving in order to control this type of pollution. The government of both developed and under developed countries are taking initiatives as well along with the help of its citizens for the collection of data for analysis.

# Chapter 7

## Conclusion

To conclude, particulate matter air pollution is one of the dangerous type of air pollution which is needed to be prevented. As we already are aware of the facts that it is the reasons for causing many diseases like respiratory diseases, bronchial diseases, asthma, cardiovascular diseases and etc. Though it includes in one of the type of air pollution its effects are very high health wise and also degrading the environment as well.

The presence of particulate matters are high in low income countries mainly due to the low standards of life and no health code regulations which ultimately leads to the uncontrollable uses of fuel burning as a result leading the particulate matters suspending into the air, but their presence can also be detected in developed countries as well. However, measures are taken to prevent or at least bring this pollution in a controlled manner but it's still not yet under control.

As a result, each and individuals need to be aware of handling any substances that may lead to the formation of particulate matter in this way this type of pollution can be prevented. Every individuals need to be guided properly by giving the proper knowledge about the consequences.

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