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A study of environmental impact of air pollution on human health: PM deposition modelling

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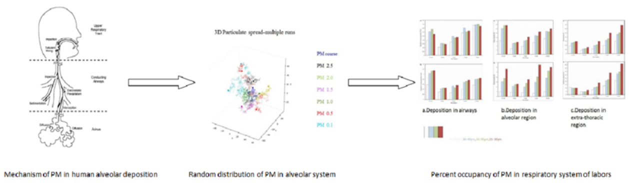
Graphical abstract



Abstract

Earth is comprised of land, air and water. Air contains oxygen, nitrogen, carbon dioxide, water vapor, and other gases are present above the permissible limit, and it creates effects on human health. It is one of the most important public health issues due to the development of urbanization, industrialization, and globalization in large cities. Air pollution levels in developed countries have been increasing in recent years. In developing countries air pollution levels are still high. In recent years, health studies have become visible showing harmful health effects in lungs and respirable system. Air pollution is responsible for 7 million deaths annually. It affects the health of humans and other living beings in our world. The government has developed the guidelines for air quality and rule to restrict emissions in effort to control air pollution. These updated AQGs provide exact guidelines for PM10 and PM2.5. The primary objective of this paper is to study ambient air quality and its impact on lungs. Particulate matter are the particles suspended in air/atmosphere. Mainly PM10 and PM2.5 Ultra fine particles (<1μm) are mainly responsible for causing interruption for human health.PM10 and PM2.5 are characterized by their presence only within the upper respiratory tract. Some PM2.5 and ultra-fine particles are characterized by their presence of deeper regions of alveoli. Ultrafine particles (PM0.1), which are present in the air in large numbers, pose a health risk. They generally enter the body through the lungs but translocation to essential organs. Compared to fine particles (PM2.5), They cause more pulmonary inflammation and are retained longer in the lung. Their toxicity is increased with smaller size, larger surface area, adsorbed surfacematerial, and the physical characteristics of the particles. Exposure to PM0.1 induces cough and worsens asthma. Metal fume fever is a systemic disease of lung inflammation most likely caused by PM0.1. The disease is manifested by systemic symptoms hours after severe exposure to PM0.1 could cause systemic inflammation, endothelial dysfunction, and coagulation changes that predispose individuals to cardiovascular disease and hypertension.

Keywords: Urbanization, industrialization, air pollution, particulate matter, human health, systematic inflammation

1. Introduction

Pure air is one of the basic requirements for human health and comfort. However, during the process of economic development, air pollution plays a significant role in long term and short-term health effects. Air pollution is one of the major and growing risk factors for poor health which in turn contributes to the countries, the health problem. The risk factors regarding air pollution mainly affect economic development, urbanization, energy consumption, transportation and motorization, as well as increased health risk for urban population. As per the WHO Urban Ambient Air Quality Database (2016), and with several studies of air quality shows poor trend over time. Rapid urbanization and industrial development have affected urban air quality due to vehicle and industrial emissions. For developing countries like India, air pollution has huge impact on human health, agricultural practices, climatic variations, and overall changes in ecosystem. The effects of air pollution can sometimes be observed even when the pollution level is below the level indicated by National Ambient Air Quality Standards (NAAQS). The use of cooking fuels varies between urban and rural households, vehicular density is great different in cities and villages, and differing the study of climate and geography across India affects regional and seasonal levels of ambient air pollution.

Air pollution exposure affect the development of children, with respect to cognitive impairment, and high levels of death from respiratory infections. The elderly is more likely to develop chronic respiratory and cardiac illnesses because of long-term exposure and are more susceptible to heart attacks and strokes during episodic high pollution events. In addition to this, Workers in certain industries may be at a higher risk owing to their increased biological sensitivities and different exposure patterns. The most common ambient air pollutants to come upon in our daily life are particulate matter (PM). During the before stage of economic development, air pollution level was generally low. However, when economic development reaches an in-between stage, air pollution concentration levels also tend to increase to a larger extent or even steadily rise suddenly if no effective better measures are taken. It could also reach a positive inflection point later at a higher developments age due to better environmental awareness and relevant control measures taken in protecting the environment. As zero risk is neither practical nor necessary, it is necessary to set an appropriate air pollutant guideline for air pollution management to be met. Air pollution can harm nearly every organ in the body and particulate matter (PM) is the main offender. PM has been classified by particle size, which is an important factor in its health effects.

Many activities are executed outdoors in predominant in the city. People live alongside the busy roads to execute their work or to promote their wares. People working and visiting in the Shops, Establishments and Institutions alongside the road are facing adverse health effects due to the increase of the concentration of gaseous pollutants from the vehicular movement and Industry stack in the Highway roads.

PM_{10} (particles ≤10 µm in diameter), $PM_{2.5}$ (particles ≤2.5 µm in diameter), also called fine particles, and $PM_{0.1}$ (particles ≤0.1 µm in diameter), also called ultrafine particles (this term is used interchangeably with $PM_{0.1}$ in this document), have different health effects that, in part; result from how these particles navigate the small bronchioles and lung defenses. $PM_{0.1}$ are also called nanoparticles because of their size, although many authors restrict the word "nanoparticles" to the 100-nm or smaller particles produced by controlled engineering processes. Ultrafine particles are dispersed atmospherically in many settings. Examples are found in nature, from forest fires, ocean splashes, and viruses; combustion processes, from vehicular and power plant emissions and tobacco smoking; and synthetic sources, from toner pigment and many engineered products used for microtechnology. These particles may be formed by the coalescence of ions and gaseous molecules produced by combustion, often as acidic and basic ions or other charged species that combine to form more stable molecules or salts.

This process, which usually depends on aqueous oxidation, may explain the sulfate levels of London fog and the effects of humidity on the symptoms of patients with respiratory disease. Coalescing PM0.1 is a major source of PM2.5. The harmful effects of the different PM categories overlap because the corresponding sizes overlap; PM10, which include all smaller particles, will have similar effects to those of smaller PMs, although the effects can be distinguished by taking mass into account. PM10 and PM2.5 are measured by their mass, while particle number measures PM0.1.

Mohanty S.K (1999) monitored the ambient air quality at eleven stations in and around Koraput District at monthly Intervals. Air quality index and standard deviation at different sampling points were calculated. The results show a comparative study of the air quality in different areas of Koraput. The study identifies the potential sources for effective pollution control measures to improve the air quality in Koraput district in future. Parida et al., (2003) resulted RSPM and SPM in industrialization and urbanization in very deep deterioration of India's air quality. Thus, knowing the status of air quality and its effects on human health and his environment. "Roorkee", town (a temple of learning), a semi-urban area was selected as the study area for this work. Primary pollutants, such as suspended particulate matter (SPM) and repairable suspended particulate matter (RSPM or PM10) were monitored in study area at four locations for 1hr sampling period. Vijay Ratan et al., (2005) described the quality of air in the urban areas by one single number known as air quality index (AQI). An equation for calculation of AQI in India based on four pollutants (Nitrogen di oxide, Sulphur di oxide, suspended particulate matter and respirable particulate matter) has been developed. Sehra (2007) was checked Air Quality in Punjab. This paper presents the summary results of a case study of hazardous air pollution problems over a densely populated city Ludhiana situated in Punjab in the form of annual average concentrations of suspended particulate matter (SPM). The present situation is as bad as in other metropolitan Indian cities, such as its capital city Delhi itself. This urban pollution must be checked everywhere in the world for the betterment of everyone Gupta et al., (2008) assessed the air quality indices (AQI) are important to decision makers for implementation of various air pollution control strategies. In this study, the general features of AQI are described. A case study of regional areas is illustrated through computation technique of an AQI, Similarly, air quality assessment (AQA) is another important approach to decision makers for implementation of various are pollution control strategies. In this study, the general features of AQA are described. Singh *et al*., (2008) indicated ambient air quality has been a global phenomenon and is a matter of serious concern. In view of this monitoring was conducted in Varanasi city of Uttar Pradesh in silence, residential, industrial and commercial, total four locations. For the assessment of seasonal variability in ambient air quality concentration, the sampling was carried out during different sampling periods of the year using high volume air samplers at each sampling site. Results were compared with ambient air quality standard laid down by Ministry of Environment and Forests, Govt. of India. It was observed that the concentration of the pollutants is more than the prescribed limits except for the gaseous pollutants. The gaseous pollutants are well within their respective standards for all categories. Vehicular traffic and diesel generator set are the root cause of air pollution, in general in all the areas of Varanasi city. Bigazzi *et al*., (2012) showed the result Impacts of freeway traffic conditions on in-vehicle exposure to ultra fine particulate matter. There is evidence of adverse health impacts from human exposure to traffic-related ultra-fine particulate matter pollution. As more commuters are spending a significant portion of their daily routine inside vehicles, it is increasingly relevant to study exposure levels to harmful pollutants inside the vehicle microenvironment. Vehicle cabin barrier effects are the primary determinant of in-vehicle exposure concentrations, providing 15% protection with the windows down, 47% protection with the windows up and the vent open, and 83-90%protection with the windows up to vent closed (more with the air conditioning on). Koblinger L, Hofmann W. *et al.*, developed a stochastic model for the calculation of aerosol deposition in human lungs. In this model the geometry of the airways along the path of an inhaled particle is selected randomly, whereas deposition probabilities are computed by deterministic formulae. The philosophy of the air way geometry selection, the random walk of particles through this geometry and the methods of aerosol deposition calculation in conductive and respiratory airways during a full breathing cycle are presented. The main features of the Monte Carlo code IDEAL-2, written for the simulation of random walks of particles in a stochastic lung model, are briefly outlined. Hofmann W, Sturm R, Winkler-Heil R, *et al.*, made an attempt to model the Deposition and clearance of insoluble ultrafine particles, ranging from 1 to 100 nm, which were simulated by stochastic models using Monte Carlo methods. Brownian motion is the dominant mode of deposition in human airways. The additional effects of convective diffusion in bifurcations and axial diffusion (convective mixing) primarily affect particle transport and deposition of particles in the 1-10 nm range. Regarding total deposition, the effects of both convective mechanisms are practically compensated by the concomitant effect of molecular radial diffusion (Brownian motion). During the first hours following inhalation, 1 nm particles are predicted to be cleared much faster than particles in the size range from 10 to 100 nm, with a retained fraction of about 80% after 24 h. For 1-10nm.

2. Absorption and retention of PM0.1

Most inhaled particles of 10 µm or larger in aerodynamic diameter impact the nasopharyngeal membranes. Inhaled particles of 5–10 µm usually land on the airways and are normally removed by alveolar macrophages and lung lymphatics. Particles in the range of 1–2.5 µm usually make their way to the terminal bronchiole, the site of greatest accumulation and tissue destruction, as commonly seen in centrilobular emphysema. Particles <1 µm stay airborne longer and easily gain access to alveoli. Although most PM sizes canbe engulfed by cells, $PM_{0.1}$ translocate transcellularly across alveolar epithelial cells by diffusion through thelipid bilayer of the cell wall. Not just phagocytic cells pick up material. All cells absorb cellular fragments of senescent, damaged, or normal cells and exchange and recycle molecular material. The cellular fragments (sometimes termed extracellular vesicles) could easily harbor $PM_{0.1}$.

3. Diseases

Some common diseases associated with coarse, fine and ultrafine particulates are discussed in Table 1.

Table 1. Review of diseases associated with PM

	PM_{10}	$PM_{2.5}$	$PM_{0.1}$
a.	Decreased lung function	Bronchitis	CNS disorder
b.	Increased respiratory symptoms	Lung emphysema, allergy	Metal, polymer fumefever
c.	Hospitalization /other health care visit	Bowel blockage	Diabetes
d.	Mortality / increased plasma viscosity	Circulatory diseases	Cancer
e.	Heart rate variability	Corneal irritation	Pulmonary diseases

4. Methodology

4.1. Work description

Highway road construction is one of the very important construction activities. Due to the incorporation of Heavy construction operations like truck movements, transits, and topsoil excavation materials to aggregate crushing, there is a wider chance for the emission of PM. During the work, the construction workers are heavily affected by the particulates which would be prevailing all through the day. In this work construction laborers are mainly concerned with the health impact assessment by simulating the particulates deposition in their respiratory tract. Increased humidity may ease breathing in children and adults who have asthma or allergies, especially during a respiratory infection such as a cold. But mist from a dirty humidifier or increased growth of allergens caused by high humidity can trigger or worsen asthma and allergy symptoms.

According to a new report published in India, it is tracked down that out of the contaminations, PM2.5 concentration is high in metropolitan cities. Venkat Rao Pasupuleti *et al.* stated that “Air pollution monitoring” sensors are utilized to gather contaminant information. Using AI to predict potential pollutant data by adding a computer that can continue taking current contaminants and with the aid of past contaminants. The platforms used is Anaconda python and coding language python. Temperature, wind speed, wind direction, and humidity are important for the informational index used to train the algorithms for identifying PM2.5, CO, SO_2, NO_2.

The work is aimed for modeling the PM in human respiratory system with the 7 PM sizes ranged (PM 0.1, 0.5, 1.0, 1.5, 2.0, 2.5 and 10µm) are considered for deposition in the human respiratory tract as well as alveolar system. The deposition of PM in human lung is simulated with Python programming and optimized with Monte-Carlo iterative system. The simulation work carried by python programming involves the assumption of lung architecture with

- Airway length
- Diameter of alveoli
- Branching angle with the input feed of 10,000 particulates for the worker distribution is given in Table 2.

Table 2 Category of age-group workers in highway projects

Age group	Designation
41-50 years	A
36-40 years	B
31-35 years	C
21-30 years	D

The operation of python programming is done by assuming the PM particles move through random walk with Brownian motion alongside the respiratory tract and alveolar system.

5. Mechanism of deposition of PM in Human Respiratory system

The PM is assumed to be widespread randomly with the Brownian motion with having their impact in each space carried out by impaction and turbulent mixing (nasal pathways), impaction, sedimentation, electrostatic precipitation and interception (conducting airways) and diffusion (alveolar region) respectively (Figure 1).

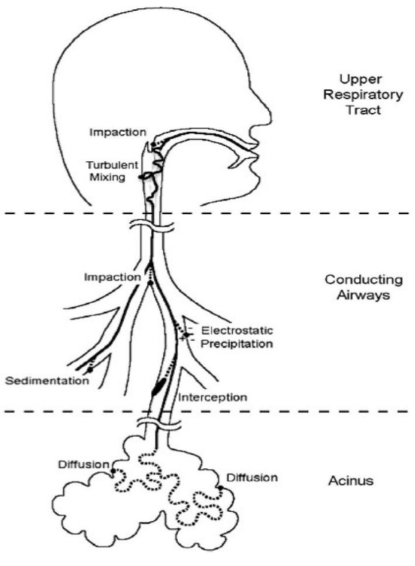


Figure 1. Mechanism of PM in human alveolar deposition

The deposition of PM in human respiratory tract needs to be quantized to assess the long-term health impact on human beings because even 10µg/m3 increase of PM may cause severe health effect. This study is aimed to provide the percent deposition of PM through python programming language and Monte-Carlo formulae method by considering PM movement as random spread inside the respiratory tract.

5.1. Concept of probable modelling

Particles inhaled follow random paths in the lung; this randomness is the result of two different phenomena. The first source of randomness is the selection of the actual paths of individual particles Even in the well-specified airway system of a given lung, due to the many bifurcations from the trachea through the alveolar sacs. There are millions of possible pathways. In stochastic or Monte Carlo modeling the histories of an appropriately large number of particles is simulated, and a new pathway selected for each particle. The expected value of any physical quantity of interest is then given by the average value for that quantity obtained after a given number of simulations. The second source of randomness originates from the physical nature of the walk of a particle even in a well-determined geometry. From the three basic physical mechanisms usually considered in aerosol particle deposition studies, i.e. sedimentation, impaction and Brownian motion, it is the latter which is totally characterized by randomness. The mean free pathlength between two collisions, however, is so small that it is practically impossible to follow the random walk of a particle due to Brownian motion step-by-step. Therefore, the probability of deposition by Brownian diffusion is calculated with analytical formulae derived for the appropriate geometries. Analytical formulae are also used for computing deposition by sedimentation and impaction. In the Monte Carlo process the simulations are not terminated by deposition in the tracheobronchial tree but, the so-called statistical weight of the particles is decreased. In essence, airway geometry is selected randomly, and deposition is calculated deterministically in this model.

5.2. Python modelling

The python simulation work is done for human lung-alveolar system as probabilistic with the feed of 7 Particulates in a random distribution form. The 3D scatterplot of human lung architecture is considered with the alveolar particulates spread interaction, depicted in Figure 2.

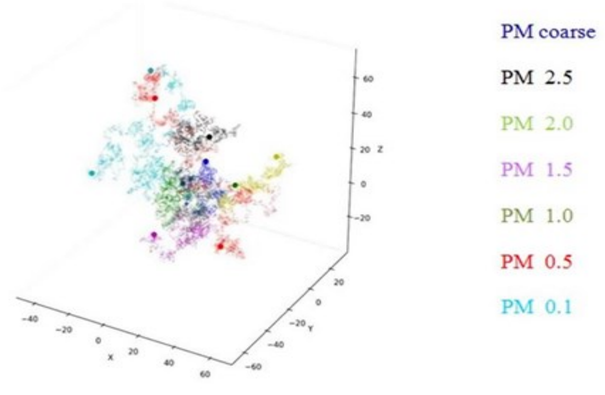


Figure 2. Random distribution of PM in alveolar system

5.3. Monte–Carlo iterative step

The variables obtained by the random walk programming are converted into the PM deposition in the human lungs by Monte Carlo iterative methodology. The Monte Carlo inputs the python output in terms of probable deposition and converts into the resultant PM deposition (%) inside the human alveolar system. The Monte Carlo formulae adopted in this work for determining the percent deposition of PM in human respiratory system is as follows for 8 hr average (per day).

$$\text{Monte Carlo formula} = \frac{30 \times \textit{Number of particles} \times \textit{unit weight of the particulates} (g / cm3)}{\text{tidal volume} \times \text{breathing frequency} (cm3)}$$

6. Result and discussion

The concentration of CO, NOX, SOX, and SPM plays a vital role in the calculation of AQI developed by Environmental Protection Agency (EPA). The various category of the AQI and its range is given in the Table 3 below:

Table 3. Categorization based on AQI

AQI Range (μg/m^3)	Category
0- 50	Good
51 – 100	Satisfactory
101 - 200	Moderate
201 – 300	Poor
301 – 400	Very Poor
> 401	Severe

The Air Quality Index for the study area falls under the category of Poor which indicates that it may cause discomfort to people on prolonged exposures and discomfort to people with heart diseases. The reason for the Poor Air Quality Index in the study area is because of Industry stack emission, improper alignment of roadway, Liberty and Violation of Traffic rules, Lack of vehicular maintenance.

6.1. Result of python simulation works

From this study, a total of 10,000 particles are taken for human airway model for the four-age group and from the python modelling results the PM deposition ranges are found to be PM 0.1› PM 0.5 › PM 1.0 › PM 1.5 ›PM 2.0 › PM 2.5. The PM are found to be coarser inside the human alveolar system. Ultra-fine particulates occupy more random spread other than fine and coarse particulates. The random spread of PM coarse could be found negligibly small due to the particulate's biological mechanisms.

6.2. Results of monte-carlo iterative step

The variables obtained by the random walk programming are converted into the PM deposition in the human lungs by Monte Carlo iterative methodology. A total of 2500 particulates are taken for simulation purposes. The Monte Carlo inputs the python output in terms of probable distribution and converts into the resultant PM deposition (percentage) inside the human alveolar system. PM $_{0.1}$-PM $_{2.0}$ occupies a higher percentage in human alveolar system which will in turn causes immense health effects in the people of age group *21-30* years under study.

6.3. Results of optimization

From the study, the PM occupancy for the age group 21-30yrs (D-Category) is found to be very higher compared with other categorical age group workers. Monte- Carlo iterative formula is applied for D-category workers which results in numerical occupancy of PM, is given in Table 4.

Table 4 Result of Monte-Carlo optimization for D-category labors

Particulate matter(μm)	Extra-thoracic	Tubular	Alveolar
0.1	11.5%	13.6%	11.7%
0.5	6.63%	2.8-5.73%	0.88-2.57%
1.0	13.6-32.8%	3.74-8.18%	0.84-3.52%
1.5	21.4-46.7%	5.57-10.7%	0.66-6.53%
2.0	39-59%	9.24-14.6%	0.70-3.89%
2.5	77-87%	11.4.2-18.7	0.70-3.89%
10	86-95%	11.4-18.7	0.9-1.9%

Table 5 CPCB permissible limit

Pollutant	Annual	24 hours average
PM $_{2.5}$	40 ug/m3	60 ug/m3
PM $_{10}$	60 ug/m3	100 ug/m3

The CPCB standards for the permissible limit for annual and 24- hour average value is mentioned in Table 5.

The results discussed clearly show that the declining age factor shows the increased exposure to PM level because of respiratory level in which people of 21-30 years are deeply affected by Particulates for one day(8hr) work. Group D persons are considered for further simulation operation by Monte-Carlo Iterative step where in which the upper respiratory tract, trachea-bronchial and alveolar considered with 7 particulates. For Monte Carlo simulation, there are a total of 2500 particles (0,250,1000,2500) are considered with the tidal volume of human airway as 2800cm3(for 21-30 years). The particulates are considered with varying shapes having unit density as 1.0g/cm3.

6.4. Validation of monte-carlo iterative method

After prediction of the deposition rate of particulate pollutants using Monte- Carlo Iterative method, validation of the same has been incorporated using cascade impactor equipment at the study locations and the air quality has been monitored. The error percentage is observed to be less than 5% and hence the model suitable to predict the PM deposition rate.

7. Conclusion

The tidal volume of the human respiratory system is subdivided into three regional compartments as extra-thoracic, tubular and alveolar where in which each particulate sized (PM$_{0.1}$-PM$_{10}$) is inputted with a certain number with the corresponding biological occupation using empirical equations for single particle and multi

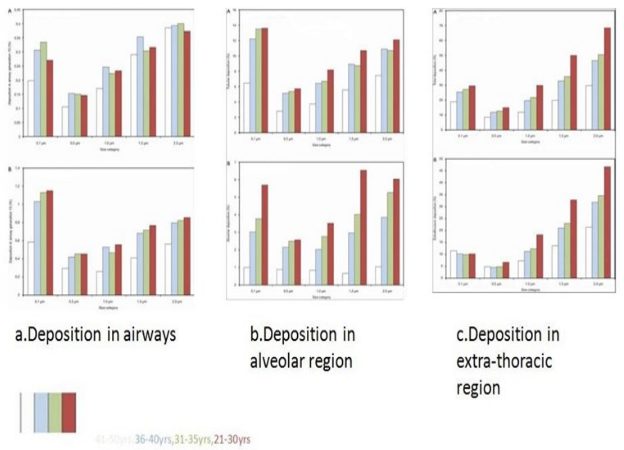


Figure 3 Percent occupancy of PM in respiratory system of labors.

particle deposition. The occupied particles are further integrated with Monte Carlo formula to obtain the percent occupation of particulates in each respiratory region. Figure 3 shows the percentage occupation of PM in each category of human respiratory system. The fine particles can cause oxidative stress, inflammation, which in turn further may be effected in the cardio vascular parts. The laborers that are already with bronchitis, asthma could be at the very risk of pulmonary infections. This study is conducted by neglecting the aerial dispersion of PM particles by considering only the impact of PM in human alveolar system. Mainly PM_{10} and $PM_{2.5}$ Ultrafine particles (<1µm) are mainly responsible for causing interruption for human health. PM_{10} and $PM_{2.5}$ are characterized by their presence only within the upper respiratory tract. Some $PM_{2.5}$ and ultra fine particles are characterized by their presence deeper regions of alveoli. Ultrafine particles ($PM_{0.1}$), which are present in the air in large numbers, pose a health risk. They generally enter the body through the lungs but translocate to essentially all organs. Compared to fine particles ($PM_{2.5}$), they cause more pulmonary inflammation and are retained longer in the lung. Tumor might be induced if alveolar clearance of ultrafine particulates is very minimum.

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