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EFFICACY ANALYSIS & DEVELOPMENT OF HYBRID FILTER MATERIAL FOR MASK- A CASE STUDY

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Submitted by

MANSI PATHAK

2K18/ENE/17

Under the supervision of

Dr. ANUBHA MANDAL

Dr. GEETA SINGH

DEPARTMENT OF ENVIRONMENTAL ENGINEERING

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering)

Bawana Road, Delhi-110042

JULY, 2020

DELHI TECHNOLOGICAL UNIVERSITY

(FORMERLY DELHI COLLEGE OF ENGINEERING)

BAWANA ROAD, DELHI-110042

CANDIDATE DECLARATION

I, Mansi Pathak, Roll No. 2K18/ENE/17 student of M.tech (Environmental Engineering), hereby declare that the project dissertation titled "Efficacy Analysis & Development of hybrid filter material for mask- A Case Study" which is submitted by me to the Department of Environmental Engineering, Delhi Technological University, Delhi in fulfillment of the requirement for the award of degree of Master of Technology, is fully original and is not copied from any source without proper citation. This work has not previously been the basis for the award of any Degree, Diploma, Fellowship or other similar title or recognition.

Place: Delhi MANSI PATHAK

Date:

DELHI TECHNOLOGICAL UNIVERSITY

(FORMERLY DELHI COLLEGE OF ENGINEERING)

BAWANA ROAD, DELHI-110042

CERTIFICATE

I hereby certify that the Project dissertation titled "Efficacy Analysis & Development of hybrid filter material for mask - A Case study" which is submitted by MANSI PATHAK, 2K18/ENE/17, Department of Environmental Engineering, Delhi Technological University, Delhi in fulfillment of the requirement for the award of the degree of Master of Technology is a record of the project work carried out by her under my supervision. To the best of my knowledge this work is fully original and has not been submitted in any Degree or Diploma to this University or elsewhere.

(Dr. ANUBHA MANDAL)

SUPERVISOR

(DR. GEETA SINGH)

CO-SUPERVISOR

Place: Delhi

Date:

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Place: Delhi **MANSI PATHAK**

Date:

ABSTRACT

Air pollution is one of the major challenging problems of our environment at present. Polluted and populated urban areas need more concern due to the presence of several sources such as factories, industries, vehicular emissions, garbage burning, construction and demolition projects etc. which contribute towards increasing air pollution in cities and towns. Meteorological conditions also play a key role in the dispersion and movement of such pollutants. Human exposure to air pollution is a major risk for health, inhaling this polluted air causes several detrimental impacts on health of living beings which include asthma, fatigue, chest pain, shortness of breath, sore throat, cardiovascular and heart diseases etc. A common preventive measure known and used by public in such conditions is different varieties of face masks which restrict the particulates (majorly PM_{10}, $PM_{2.5}$ AND PM_1) and other criteria pollutants to an extent. Different masks perform differently according to their efficiencies and the material they are made of, which is directly related to the cost of the masks. Major portion of the population is unaware of the requirement and type of masks to be used for various environments and purposes. Masks are classified into several categories on the basis of usage, material, design, efficiencies and many other key factors. Scientists keep on improving the researches done to make relatively cost effective and efficient masks which provide more protection against the harmful particulates that deposit into the human respiratory system and cause several health issues.

Along with industrial development of a nation its emission also increases and the need to cope with that urges so development of several methods is necessary to reduce the exposure of those emissions on living beings.

The main objective of this study is to contribute towards improving and developing efficient face masks which can reduce exposure from these harmful emissions by analyzing the efficiencies of several masks available and developing a relatively improved version of them.

Keywords: Air pollution, particulates, masks, criteria pollutants.

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CAP	Criteria Air Pollutants
AQI	Air Quality Index
PM	Particulate Matter
NAAQS	National Ambient Air Quality Standards

CHAPTER 1

INTRODUCTION

1.1 Definition

When one thinks of air pollution, it is probably things like smog, dust, soot, particles and emissions from various sources like vehicles, industries, power plants and so on. Pollutants occur when excessive quantities of any harmful substance such as gases, particulates particles and biological molecules enter and stay into the earth's atmosphere.

According to The Air (Prevention and Control of Pollution) Act, 1982, "Air Pollution is the presence of any solid, liquid, or gaseous substance in the atmosphere in such concentration which may or tend to be harmful to human beings or other living creatures or plants or property or environment". Estimates show that 4.2 million deaths happen every year due to ambient air pollution and about 3.8 million deaths due to indoor air pollution from emissions of cook stoves and fuels [1]. There are many sources of air pollution which will be taken into account along with the required precautions to deal with the impacts of air pollution on human health.

1.2 Reasons of Air Pollution

Major reasons of air pollution include:

1. Industries.
2. Transport.
3. Domestic cooking.
4. Waste burning.
5. Construction & demolition projects.
6. Crop residue burning.
7. Farming practices.
8. Wildfires.
9. Mining.
10. Fossil fuel burning.
11. Meteorological conditions.
12. Aviation.
13. Crematorial activities.

1.3 Health Impacts of Air Pollution

It is common for people who tend to spend their time in polluted air to complain about one or more of the following symptoms:

1. Irritation of eyes, nose and throat.
2. Shortness of breath.
3. Fatigue.
4. Headache.
5. Hypersensitivity.
6. Sinus.
7. Cough and sneezing.
8. Chest pain.
9. Asthma.
10. Lung cancer.
11. Skin irritation.
12. Cardiovascular and heart diseases.

People notice these symptoms after being outside for several years and feel better when they come indoors.

Many of these symptoms may also be caused due to other health conditions including common colds or flu and are not necessarily due to poor air quality but in majority of the cases these symptoms are related to air pollution symptoms. This makes identifying and resolving air quality problems more difficult because the condition may not necessarily be due to poor air quality.

1.4 Government initiatives towards reducing air pollution

Government is putting all possible efforts for controlling air pollution in the country. Central government has initiated several regulatory measures to prevent, control and reduce air pollution in the country [2].

- The Central Government has launched National Clean Air Programme (NCAP) as a long-term, time-bound, national level strategy which is meant to tackle the air pollution problem across the country with targets of reduction 20% to 30% of PM_{10} and $PM_{2.5}$ concentrations by 2024 keeping 2017 as the base year for the comparison of concentration. 102 non-attainment cities lying mostly in the Indo-Gangetic plains have been identified on the basis of ambient air quality data for the period 2011-2015 and WHO report 2014/2018. The city specific action plans have been approved for all 102 non-attainment cities for implementation on ground.
- The Central Government has made a Comprehensive Action Plan (CAP) in 2018 that sets timelines and implementing agencies for prevention, control and mitigation of air pollution in Delhi and NCR region.
- Graded Response Action Plan (GRAP) was formulated on January 12, 2017, for prevention, control and abatement of air pollution in Delhi and NCR that identified graded measures and implementing agencies for response to four AQI categories, namely Moderate to Poor, Very Poor, Severe and Severe+ or Emergency.
- Odd-Even Scheme: This scheme is an initiative taken by government of Delhi to reduce the air pollution by applying odd even scheme on four wheelers plying on the roads such that even

numbered four wheelers allowed on even dates of month and odd numbered cars are allowed on odd dates of the month. [3]

- Imposing GREEN TAX on large vehicles.
- Government of Delhi has launched a car-free day campaign "AB BUS KAREIN" since October 22, 2015 to be held on 22nd of every month which was not a big success.[4]
- Revision of rules related to wastes generated in construction and demolition activities.
- Ban on burning of trees, leaves and biomass in Delhi.
- Introduction of compressed natural gas (CNG) for commercial vehicles.
- Metro rail transit system for rapid mass transport is introduced which is a great success.
- Restrictions were imposed in operation of goods vehicles during day time.

1.5 Important Terminologies

1.5.1. Criteria Pollutants

Criteria Pollutants are a set of air pollutants that cause smog, acid rain, and other health hazards.[5] CAPs are typically emitted from many sources in industry, mining, transportation, electricity generation and agriculture. In many cases they are the products of the combustion of fossil fuels or industrial processes.

The major pollutants considered in India are-

1. SO_X - Oxides of Sulphur are emitted from volcanic emissions, metal smelting, burning of fossil fuels, petroleum refining etc.
2. NO_X – Oxides of Nitrogen are emitted from biomass and high temperature combustion processes, burning of fossil fuels, lightening, forest fires etc.
3. CO – Carbon Monoxide is emitted from forest fires, volcanic activity, burning of carbonaceous fuels, emissions from engines, animal metabolisms etc.
4. Particulate Matter – Windblown dust, pollen spores, photo-chemically produced particles, vehicular emissions, commercial and residential combustion, industrial combustion processes, construction industries etc. are sources of particulates in air.
5. Lead – Metal processing plants, lead acid batteries, industrial effluents, waste incineration, automobile exhausts etc. are sources of lead emissions.
6. Ozone - Present in stratosphere at 10-15 km height, Hydrocarbons and NO_X upon reacting with sunlight results in O_3 formation.
7. NH_3 – Agriculture, Industrial processes, vehicular emissions, animal husbandry, fertilizers etc. are sources of NH_3 emissions.

1.5.2. $P.M_{10}$ and $P.M_{2.5}$

$P.M_{10}$ refers to the particle with a diameter of 10µm and they are also called fine particles.

$P.M_{2.5}$ refers to the atmospheric particulate matter that has a diameter of less than 2.5µm which is about 3% of the diameter of human hair.

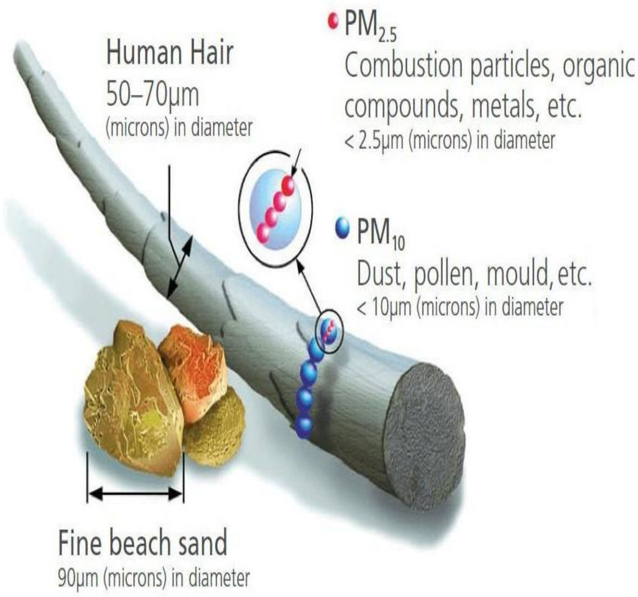

Fig 1.1 $P.M_{10}$ and $P.M_{2.5}$[6]

1.5.3. National Ambient Air Quality Standards (NAAQS)

Table 1.1.National Ambient Air Quality Standards[7]

Pollutant	Time weighted average	Concentration of Ambient Air		
		Industrial area	Residential rural & other area	Sensitive area
Sulphur dioxide (SO_2)	Annual[a]	80 µg/m³	60 µg/m³	15 µg/m³
	24 h[b]	120 µg/m³	80 µg/m³	30 µg/m³
Oxides of nitrogen (NO_2)	Annual[a]	80 µg/m³	60 µg/m³	15 µg/m³
	24 h[b]	120 µg/m³	80 µg/m³	30 µg/m³
Suspended Particulate Matter (SPM)	Annual[a]	360 µg/m³	140 µg/m³	70 µg/m³
	24 h[b]	500 µg/m³	200 µg/m³	100 µg/m³
Respirable Particulate Matter (size Less than 10 µm) RPM	Annual[a]	120 µg/m³	60 µg/m³	50 µg/m³
	24 h[b]	150 µg/m³	100 µg/m³	75 µg/m³
Lead as Pb	Annual[a]	1.0 µg/m³	0.75 µg/m³	0.50 µg/m³
	24 h[b]	1.5 µg/m³	1.0 µg/m³	0.75 µg/m³
Carbon monoxide	8 h[b]	5.0 mg/m³	2.0 mg/m³	1.0 mg/m³
	1 h	10.0 mg/m³	4.0 mg/m³	2.0 mg/m³

1.5.4 Air Quality Index

Air Quality Index (AQI) is a scale based measure used by government agencies to communicate to the public how polluted the air currently is or how polluted it is forecasted to become. Risk to health increases as AQI rises.

AQI	Remark	Color Code	Possible Health Impacts
0-50	Good		Minimal impact
51-100	Satisfactory		Minor breathing discomfort to sensitive people
101-200	Moderate		Breathing discomfort to the people with lungs, asthma and heart diseases
201-300	Poor		Breathing discomfort to most people on prolonged exposure
301-400	Very Poor		Respiratory illness on prolonged exposure
401-500	Severe		Affects healthy people and seriously impacts those with existing diseases

Fig 1.2.Air Quality Index [8]

1.6. Objective of study

- To analyze several masks available in the market by calculating their efficiencies.
- To study about the filtration mechanism.
- To develop several combinations of filter materials for masks.

1.7. Masks Studied

A mask is a preventive material designed to protect the wearer from inhaling hazardous matter, including particulate matter such as dust and air borne microorganisms as well as hazardous fumes, vapours and gases.

1.7.1. Mask A

- Two wheeler riders are prone to be effected by outdoor air pollution as they are 90% more exposed to dangerous pollutants like $PM_{2.5}$, harmful gases and dust particles .This becomes the reason for several chronic allergies, skin problems, and respiratory issues.
- These masks are equipped each with a cotton mask and four PM2.5 filters which are important as the cotton material filters out only bigger dust particles and is not able to filter out dangerous $PM_{2.5}$ which is very small particle size.

- PM2.5 are very small particles about 1/70th of the size of human hair due to which they can penetrate deep inside the lungs and that become the major reason for all respiratory diseases. To filter out PM2.5, PM2.5 filter is provided that needs to be inserted in the cotton mask.
- Price- Rs 274/- and made in India.

Fig 1.3.Mask A

1.7.2. Mask B

- Fashion mask attached filter basically for school or college going students.
- It is provided with PM2.5 filter in single layer.
- Price- Rs 100/- and made in Korea.

Fig 1.4.Mask B

1.7.3. Mask C

- These masks are not able to protect the user from inhaling airborne particles, bacteria or virus and are less effective than respirators like N95 masks, which provide better protection due to their filter material, shape and tight seal.
- Price- Rs 10/- and made in India.

Fig 1.5.Mask C

1.7.4. Mask D

- The alphabet N in N95 and N99 masks stands for 'not resistant to oil'. This means even though they can provide protection against smog, dust, vehicular pollution and other air-borne particulars, they do not protect you against gaseous and oil-based pollutants.
- N95 mask filters up to 95 per cent of particulate matter. The N99 and N100 air masks are capable of filtering PM 2.5 airborne particulate matter with up to 99 to 99.97 percent efficiency.
- Price- Rs 100/- and made India.

Fig 1.6.Mask D

1.7.5. Mask E

- This mask is a 5-layer mask that filters out dangerous PM2.5, PM10 and dust present in air. It comes with exhalation valve to make breathing comfortable. The mask should be used in outdoor conditions only be avoided indoors. The life of each mask is up to 100 hours under normal conditions. The mask is non washable and should be disposed off after use.
- Price- Rs 120/ and made in India.

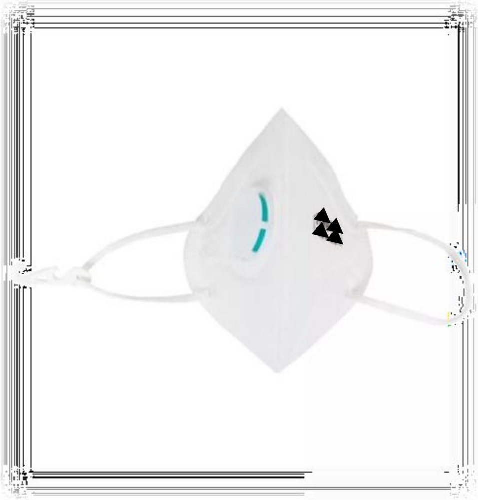

Fig 1.7.Mask E

1.7.6. Mask F

- This mask provides safety against PM2.5 as well as against other large size particles of dust, smoke and other pollutants.
- Price –Rs70/- and made in South India.

Fig 1.8.Mask F

1.7.7. Mask G

- Prevents from large dust and smoke particles but do not prevent any smaller particles like PM10 and PM2.5 so these can't be used during severe pollution episodes.
- Price- Rs 30/- and made in India.

Fig 1.9.Mask G

CHAPTER-2

LITERATURE REVIEW

(John W Cherrie et. al. 2018) Many Beijing residents use disposal face masks to protect themselves and their health from the impact of particulate matter. Several masks which are locally or internationally certified but their real environment performance may not be able to provide foresaid exposure reduction. This study evaluated several face masks which were commercially available to public in China for their real life performance test. [9]

(S. Steve Zhou et. al. 2018) As a preventive measure from exposure to air borne pathogens, particulates and aerosols disposable facemasks are a feasible option. The intrinsic ability of facemasks to restrict such pollutants, pathogens and airborne contaminants is a major factor that governs the effectiveness of mask. The study evaluated performance of a mask, valve, and micro Ventilator based on aerosol filtration efficiency when compared with a new N95 respiratory face mask so as to know their efficacies at individual levels. [10]

(JunjieZhang et. al. 2006) Avoidance of transitory air pollution shows dynamics and nonlinearities, purchase of facemasks increases significantly during major air pollution episodes. The model in this paper tells that with a 100-point increase in Air Quality Index the consumption of masks increase by 54.5% while that of anti-$PM_{2.5}$ masks increase by 70.6 %. The aggregated model estimate shows that changeable pollution levels are used to simulate the pros of improvement in air quality. So by reducing only 10% of heavy pollution days (AQI $\geq$20) the total savings on facemasks would be approximately 187 million USD in China. [11]

(Marzieh Abbasinia et. al. 2018) Nine papers were studied which indicated that the use of nanomaterials in filters of masks can improve the performance and efficiency of breathing, air filtration and also improves improves permeability, increases antimicrobial properties. Along with this they provide reasonable comfort to theusers when compared with conventional masks. [12]

(Anupama Balotra et. al. 2019) Air pollution levels are continuing to increase at an alarming rate in the whole country for past few years. In Delhi’s air the concentration of particulate matter has increased by 66% in the last ten years due to which several health issues have developed. People are not much aware about their surroundings and about the air they breathe so it’s the time to make people aware about several advancements and methods that have been introduced so far to protect them from pollution. The use of masks is one such advancement that can provide optimum level of protection against the pollutants. Although this is also not a permanent solution to the increasing air pollution episodes. Awareness about which masks is needed for which purpose along with proper technique to use that mask should be there among the public. This paper analyzed three Commercial-Off-The-Shelf (COTS)

N-series mask along with the respiratory masks. Handkerchief and Honeywell Anti PM 2.5 are cost effective substitutes for examining the filtration capacity of masks in ideal condition and when they are used around an artificial human face. For the stress-test experiments were performed on respiratory masks at the time pollution is at its peak for the day. Results revealed that all of the masks tested provide good protection against pollution when used in ideal conditions but they were not able to provide the same level of protection when used around an artificial human face. Perfect facial fit of masks was found to be an major factor for getting the best filtration efficiencies. Along with this test the durability test for checking durability was also performed on the masks which gave insights on how frequently one should replace the old used mask with a new one. [13]

(Kabindra M. Shakya et. al. 2016) Less expensive cloth facemasks are majorly used in developing countries as a protective measure from pollution but a very limited amount of data is available about the efficacies. This study checked efficacies of four types of facemasks (one type of surgical mask along with three types of cloth mask) which were commonly used in developing countries. Five mono dispersed aerosol sphere size (30, 100, 500 nm, and 1, 2.5 μm)and diluted whole diesel exhaust was used to analyze the facemasks. Among the three cloth facemasks one with an exhaust valve performed really well with filtration efficiency of 80-90% for measured polystyrene latex particle sizes. Two commercially available fabric masks were found to have least efficacy with filtration efficiency between 39%-65% for PSL particles, and their performance improved with increase in particle size. When the same cloth facemasks were tested using lab generated whole diesel particles the filtration efficiency for three particle sizes (30, 100 and 500 nm)ranged from about 15% to 57%. Performance of Standard N95 mask was used as a comparative standard for comparing the results with cloth masks which suggested that cloth masks are beneficial to a certain extent in protecting users from particles< 2.5μm. Disposable type surgical masks were found to be more effective than cloth facemasks in reducing particulate exposure. [14]

(K Khayan et. al. 2019) The poor air quality due to the increasing contamination of pollutants into the atmosphere has become a global concern for developed as well as developing countries. Impacts that air pollution has made are unavoidable, especially on health. Efforts are continuously being made to reduce the occurrence of air pollution episodes that often by control of sources,media, and protective efforts in human beings. This study focused on efforts to protect from air pollution by carrying out work on designed respiratory masks which have the capacity to adsorb toxic gases in outdoor air by utilizing mask materials available in the market along activated carbon. This study followed an experimental approach by differentiating among the abilities of cotton, spunbound and meltblown polymers in absorbing toxic gases. [15]

(Abhiteja Konda et. al. 2020) The sudden rise of pandemic that affects respiratory system has resulted in increased demand for face masks. During the whole COVID-19 pandemic scenario a large section of population used cloth masks but a very less knowledge is there on the efficacies of several commonly available fabrics that are used in filters and exterior layers of cloth masks. The need arouse from this situation to evaluate filtration efficacies as a function of aerosol particulate sizes for the range 10nm to

10µm which is the range of viruses mostly for respiratory disease transmission. The study was carried out for several common materials like silk,chiffon, cotton, flannel,various synthetic fabrics and their combinations .The filtration efficiencies for several single layer fabrics were found to be in the range between 5 to 80 percent and 5 to 95 percent for particle sizes of <300 nm and >300 nm respectively, the efficacies have improved when multiple layers of materials were used along with specific combinations of different fabrics. Filtration efficiencies of the hybrids like cotton-chiffon, cotton-silk, cotton- flannel was >80 percent (for particles<300nm) and >90 percent (for particles >300nm). The improvement in performance of the hybrid masks is likely because of the combination of mechanical and electrostatic-based filtration. Cotton used in cloth facemasks performed better at greater weave densities or thread count and make significant difference in filtration efficacies. This study puts light on the fact that gaps or spaces caused due to an improper fit of the mask can result up to 60 percent decrease in the filtration efficacy, which makes it a necessary factor to take into account the issue of proper fit along with leakage while allowing the exhaled air to leave efficiently. Several such combinations of available fabrics can be used in cloth masks that provide a significant amount of protection against the transmission of particulate matter. [16]

CHAPTER-3

METHODOLOGY

3.1. Study Area

Seven masks were taken from the local market near DTU Campus & Rohini sector-17 and were given to people residing inside the Campus to wear for pre-decided six days and the data was collected from these masks. The masks used were:

1. **Mask A**: This is N95 air pollution face masks with 4 PM2.5 activated carbon filters.

Fig 3.1.N95 mask with 4 activated carbon filters

2. **Mask B**: This is single layer PM2.5 filter mask.

Fig 3.2.$PM_{2.5}$ Mask

3. Mask C: This is surgical mask and it provides protection from inhaling airborne particles.

Fig 3.3.Surgical Mask

4. Mask D: This is N95 mask with one layer of PM2.5 filter.

Fig 3.4.Single layer $PM_{2.5}$mask

5. Mask E: This mask has five layers of PM2.5 filters.

Fig 3.5.Five layer $PM_{2.5}$ mask

6. Mask F: This mask has only one PM2.5 filter layer.

Fig 3.6.One layer $PM_{2.5}$ mask

7. Mask G: This is a dust mask and is not able to prevent from PM 10 and PM2.5 sized particles.

Fig 3.7.Dust mask

3.2. Equipment Used

The method preferred in this study is the gravimetric analysis of the used masks to calculate the effectiveness of facemasks in the real environment. The used masks were weighed after each use by an electronic weighing machine to record the increase in weight due to the particles entrapped in the filter and mask material.

Fig 3.8.Weighing machine

3.3 Sampling Procedure

The pollutant concentration was calculated from the AQI of selected six days which was combined with the data recorded for the masks gravimetrically as follows:

Pollutant Concentration

AQI was considered for the location DTU, New Delhi. The concentration of pollutants was calculated through the AQI convertor. Six days were selected accordingly to perform the experiments which include heavily polluted days and less polluted so that an average of the readings can be taken to calculate the effectiveness. AQI of these days was taken from the records of CPCB and that was converted into concentration of pollutant (this concentration includes three pollutants $PM_{2.5}$, PM_{10}, SO_2) for that particular day.

AQI and concentration for these days is depicted in the table:

Table 3.1.AQI and Concentrations

DAY	AQI		CONCENTRATION(μg/m^3)
28 Oct, 2019	397	(VERY POOR)	797848.3
29 Oct, 2019	427	(SEVERE)	857920.8
4 Nov, 2019	386	(VERY POOR)	775828.2
5 Nov, 2019	330	(VERY POOR)	663727.7
29 Nov, 2019	93	(SATISFACTORY)	171.0000
30 Nov, 2019	248	(POOR)	446584.9

Table 3.2.Time and Date of Data Taken

DATE	TIME	DURATION
28/10/2019	9AM -7PM	10 HOURS
29/10/2019	9AM-7PM	10 HOURS
4/11/2019	9AM-7PM	10 HOURS
5/11/2019	9AM-7PM	10 HOURS
29/11/2019	9AM-7PM	10 HOURS
30/11/2019	9AM-7PM	10 HOURS

Table 3.3.Data Taken

MASKS	Initial Wt. (gm)	Day1	Day 2	Day 3	Day 4	Day 5	Day 6
MASK A	16.703	16.830	16.843	16.870	16.889	17.010	17.310
MASK B	8.024	8.045	8.091	8.102	8.170	8.235	8.297
MASK C	2.751	2.755	2.764	2.773	2.789	2.797	2.810
MASK D	10.643	10.682	10.695	10.715	10.843	10.891	10.939
MASK E	11.336	11.554	11.719	11.976	12.017	12.113	12.320
MASK F	10.306	10.335	10.342	10.354	10.397	10.407	10.420
MASK G	4.989	4.993	5.009	5.021	5.046	5.060	5.083

3.4 Efficacy Calculation

Example: For MASK A

Volume of air inhaled by an average person in one day= 10.9869184 m^3
Volume of air inhaled by an average person in 10 hours for 6 days= 4.57788267*6= 27.467296 m^3
Total pollutant concentration in air calculated from AQI of six days = 3542080.9 $\mu g/m^3$
Weight of pollutant present of inhaled air = X = 3542080.9* 27.467296= 97291384.5 µg (includes PM_{10}, $PM_{2.5}$, SO_2)

Weight of pollutant restricted by mask = (17.310-16.703) = 0.607 gm

Hence pollutant restricted by mask = Y = $607*10^3$ µg

Effectiveness of mask = $\frac{Y}{X} * 100$ = 0.623= 0.6 (rounded off)

Similarly we have calculated the effectiveness of other masks also by using the gravimetric data which is recorded.

CHAPTER 4

DEVELOPMENT & STRUCTURE OF HYBRID FACE MASKS

Several hybrid masks are being developed which are an improvement over the other. Some masks having hybrid structure are discussed in order of their increasing complex structures:

4.1. Cloth Mask

A basic cloth mask which is made up of two layers is depicted in the figure showing the mechanisms of filtration which as follows:

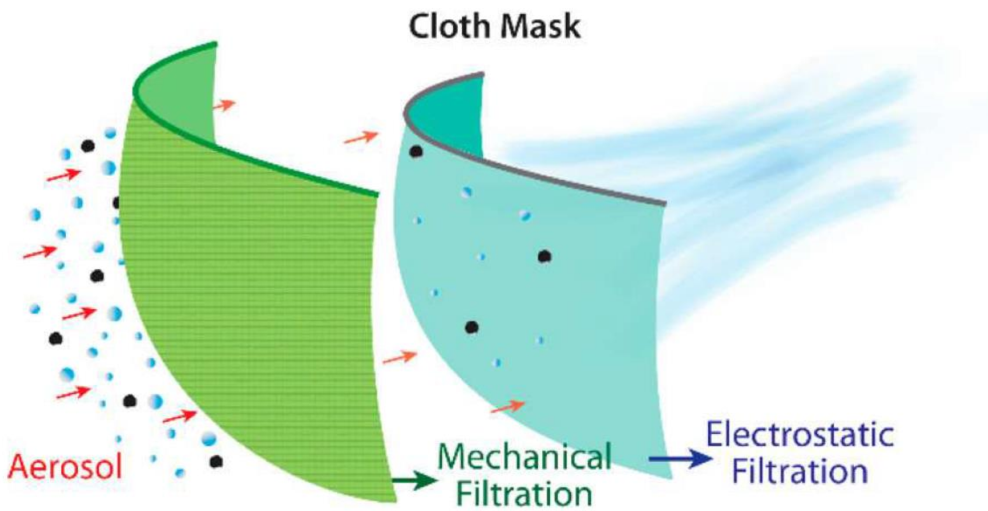

Fig 4.1. Schematic diagram depicting aerosol filtration process of a cloth mask.

MECHANICAL FILTRATION: Mechanical Filtration is basically due to the threads of the first layer of cloth which catches the particles physically. This is not much effective for capturing smaller particle range due to which some particles reach to the second layer and are then captured by the electrostatic filtration mechanism of second layer.

ELECTROSTATIC FILTRATION: When two or more fabrics are rubbed against each other they gain static electricity. Fabrics made from natural fibres like cotton which have high roughness are able to gain the static electricity and filter particles from the air .Earlier facemasks designed used to include wool but with time it was replaced with electrospun polymer fabrics. [17]

Cotton, chiffon and natural silk are able to provide more than 50% efficacy if they have higher thread count per inch along with tight weavings. Cotton quilt having highly tangled fibrous nature provides the best filtration efficiency even for the particles of smaller size range. Proper fit of mask is also an important factor which can lead to reduction in efficiencies of masks due to leakages around the corner areas. [18]

4.2. N95 Respirator

This respirator is designed in such a way that it reduces the inhalation of particles smaller than 100µm nut the filter is non replaceable and it has a certain life for which the filter work efficiently. This respirator provides a protection against 95% of the particulates and it also fits the face well so there are negligible chances of leakage. These types of masks are able to restrict fluids to some extent due to multiple layers having a meshed structure leading to electrostatic attraction of particulates coming in contact with the filter material. [19]

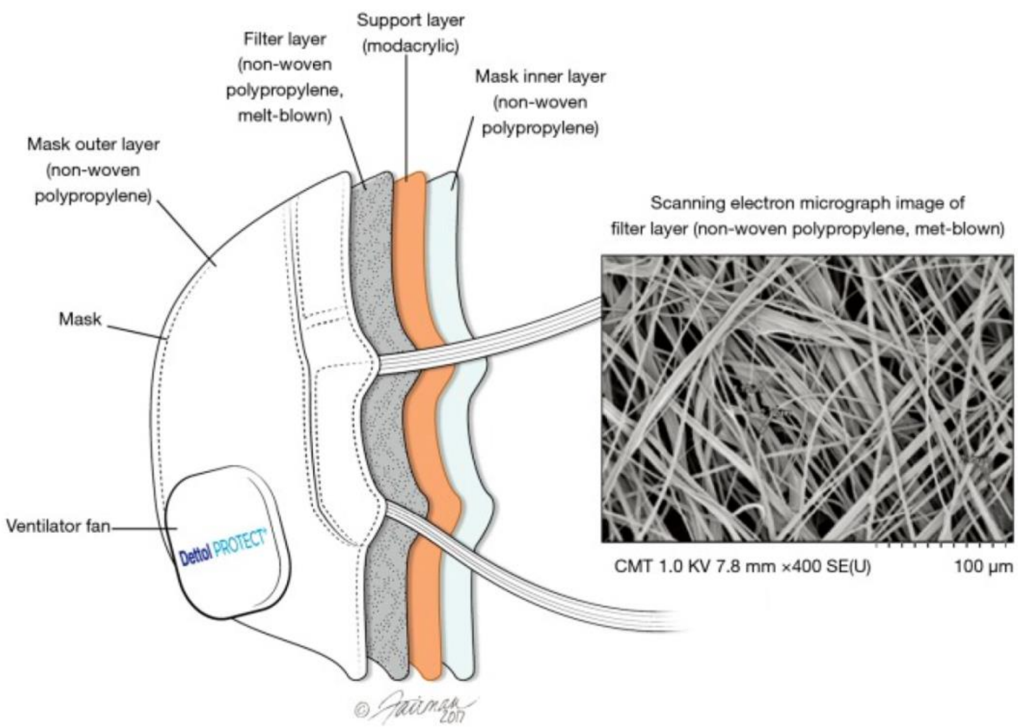

Fig 4.2.Schematic diagram depicting different layers of N95 respirator

4.3. British Made Military Grade Mask

This kind of mask is N99 i.e. it filters more than 99% of particulate particles including PM_{10}, $PM_{2.5}$, and even $PM_{0.3}$. They also provide protection against pathogens to a great extent by use of triple layer system consisting of activated carbon. The three layers in this mask are:

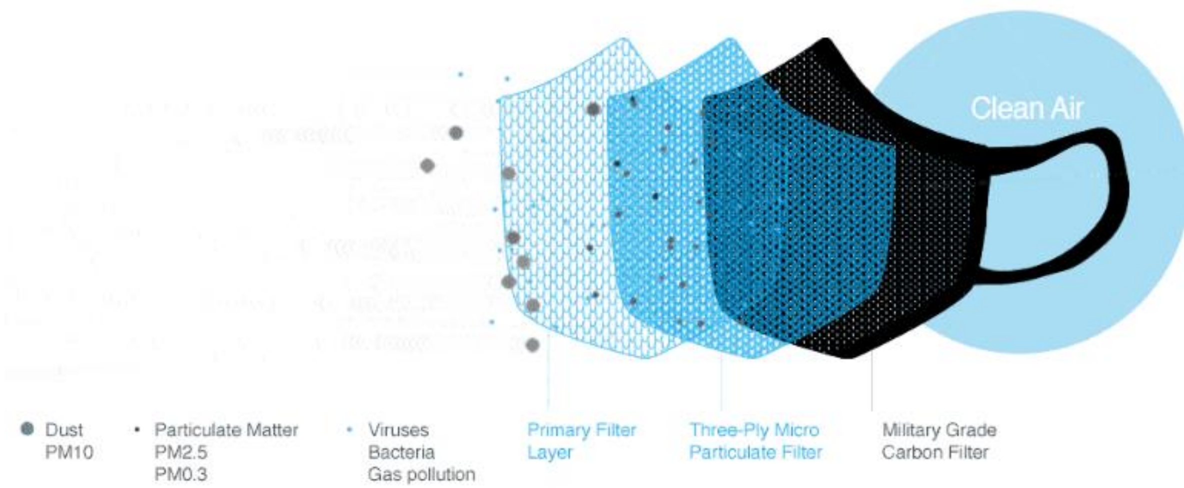

Fig 4.3.British made military grade mask

PRIMARY FILTER LAYER: This is the first layer of mask which filters dust and PM_{10} particles.

THREE-PLY MICRO PARTICULATE FILTER: This is the second layer of mask designed to block $PM_{2.5}$ sized particles. It also restricts $PM_{0.3}$ sized particles to some extent. The material used is non-woven melt-blown polypropylene which is a thermoplastic polymer having random fiber orientation that traps pollution well. Surface area of this material is high so that it captures more particulates.

MILITARY GRADE CARBON FILTER: This layer is made up of pure activated carbon cloth. The principle behind using this material is that all activated carbons whether powder or granule generate Van Der Waal forces due to their porous structure which makes it capable to absorb molecules in their pores.[20]

CHAPTER 5

RESULT AND DISCUSSION

5.1 Ranking of facemasks

Face masks that were observed are being arranged in increasing order of their effectiveness:

Table 5.1.Efficacy of facemasks

S.N.	MASK	EFFECTIVENESS
1	C	0.1
2	F	0.1
3	G	0.1
4	B	0.3
5	D	0.3
6	A	0.6
7	E	1.0

5.2 Feasible Hybrid Facemasks

Several structures of facemasks have been developed till now and many more can be developed by using different combinations of materials available. The suitability of materials of masks is defined by various factors such as thread count, proper inhalation and exhalation, leakage proof etc. Developing several masks using combination of materials requires a lot of practical work to make one of each kind, test it under laboratory conditions as well as in real environment and then compare the overall effectiveness and cost implications so as to get the comparatively best mask possible from these combinations.

Various combinations which are studied till now may it be hybrid or simple cloth masks with different layers of filter material are effective according to the material used and several combinations can be derived from these already designed masks. Some combinations possible which can provide better results if tested are as follows:

1. Cotton- Electrospun Polymer- Cotton.
2. Silk- Electrospun Polymer- Silk.
3. Silk- Electrospun Polymer-Cotton.
4. Polypropylene- Carbon- Polypropylene.
5. Silk-Carbon-Silk.
6. Cotton-Carbon-Cotton.
7. Cotton-Electrospun Polymer-Silk.
8. Polypropylene-Carbon-Silk.
9. Polypropylene-Carbon-Cotton.
10. Silk-Carbon-Polypropylene.
11. Silk- Carbon-Cotton.
12. Cotton-Carbon-Silk.

Many more such combinations are possible with different materials that can be made and tested for getting the best possible combination among them.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

The masks that were observed in this work performed differently under conditions mentioned and the results obtained for their effectiveness can be used at different stages by different people to select the best one. Such ranking should be made available to public so that they can pick the best one as per their requirement and cost implications.

The mask best performed in this work under the given conditions is Mask E having 5 layers of $PM_{2.5}$ filters followed by others. This mask was easy to carry, provides protection to a great extent from air pollution and is also cost effective.

A scale which can compare the effectiveness of facemasks on parameters such as degree of protection against air pollution, ease of use, cost effectiveness etc. would be very helpful for public in order to differentiate among the varieties of masks available in market.

CHAPTER 7

FUTURE SCOPE

7.1 Development of Indoor Facemasks

Face masks are required not only for protection against pollutants outside but they can also be used indoors inside factories, kitchens etc. where the concentration of pollutants and particulates is quite high. But wearing those face masks which are designed for outdoor purposes is not a solution. Special masks need to be designed for indoor purposes which are easy to use and also provides the required degree of protection against pollutants.

7.1.1. Kitchen Facemasks

Most of the times women working inside kitchens perform activities which lead to creation of particulates during food preparation that directly harms their respiratory system. Women spend 3-7 hours per day near stoves while cooking. [21]

Diseases like pneumonia causing more than 50% premature deaths in children under five are caused by particulate matter from household air pollution. [22]

Hence kitchen masks may be designed especially for women who are in direct exposure to such pollutants that impact their health.

7.1.2. Office Facemasks

Offices are places where people work in a closed indoor environment that may or may not be having air conditioning due to which the harmful exhaled air and also an amount of outdoor pollutants which get entrapped impact the health of workers. So in cases where air conditioning facilities are not feasible facemasks designed especially for indoor purpose can be used. Masks need to be much lightweight and also easy to carry so that even they are worn for long hours it doesn’t bother the users.

7.1.3. Industrial Facemasks

Industries that require a lot of manpower with long working hours but due to the nature of work they are not able to incorporate proper ventilation and air conditioning require masks that are especially designed to serve their purpose. Industries are a major source of air pollution outdoors as well as indoors but not much concern is given to poor air quality within the premises of industry itself. So a mask that can be worn inside such industries need to be designed which is light weight, can be used for long hours without much difficulty and also provides proper protection against the indoor air pollutants like CO_X , $NO_{X,}$ SO_X particulates.

CHAPTER 8

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ANNEXURE1. QUESTIONNAIRE

Several questions were asked from a group of 50 people residing near Rohini sector-17 and DTU campus regarding their views and preferences of facemasks they use in daily life which were available in local market and study was done on selected 7 masks. Questions that were asked are listed below:

1. Name………………………
2. Age…………………………
3. Outdoor activity and time…………………………….
4. Masks or any other preventive methods adopted……….……………………
5. Kind of masks preferred……………………..
6. Mask change frequency or days of usage of one mask………………………….
7. Health issues (if any)…………………………
8. Difficulties while wearing masks (mention if Yes): Yes/No…………………….
9. Expectations or Recommendations from masks…………………………

ANNEXURE2. AIR QUALITY DATA

The air quality for the days preferred is as follows:

Table A 2.1.AQI

DAY	AQI		CONCENTRATION(μg/m³)
28 Oct, 2019	397	(VERY POOR)	797848.3
29 Oct, 2019	427	(SEVERE)	857920.8
4 Nov, 2019	386	(VERY POOR)	775828.2
5 Nov, 2019	330	(VERY POOR)	663727.7
29 Nov, 2019	93	(SATISFACTORY)	171.0000
30 Nov, 2019	248	(POOR)	446584.9

The AQI was taken from the CPCB website for the station location DTU. [23]

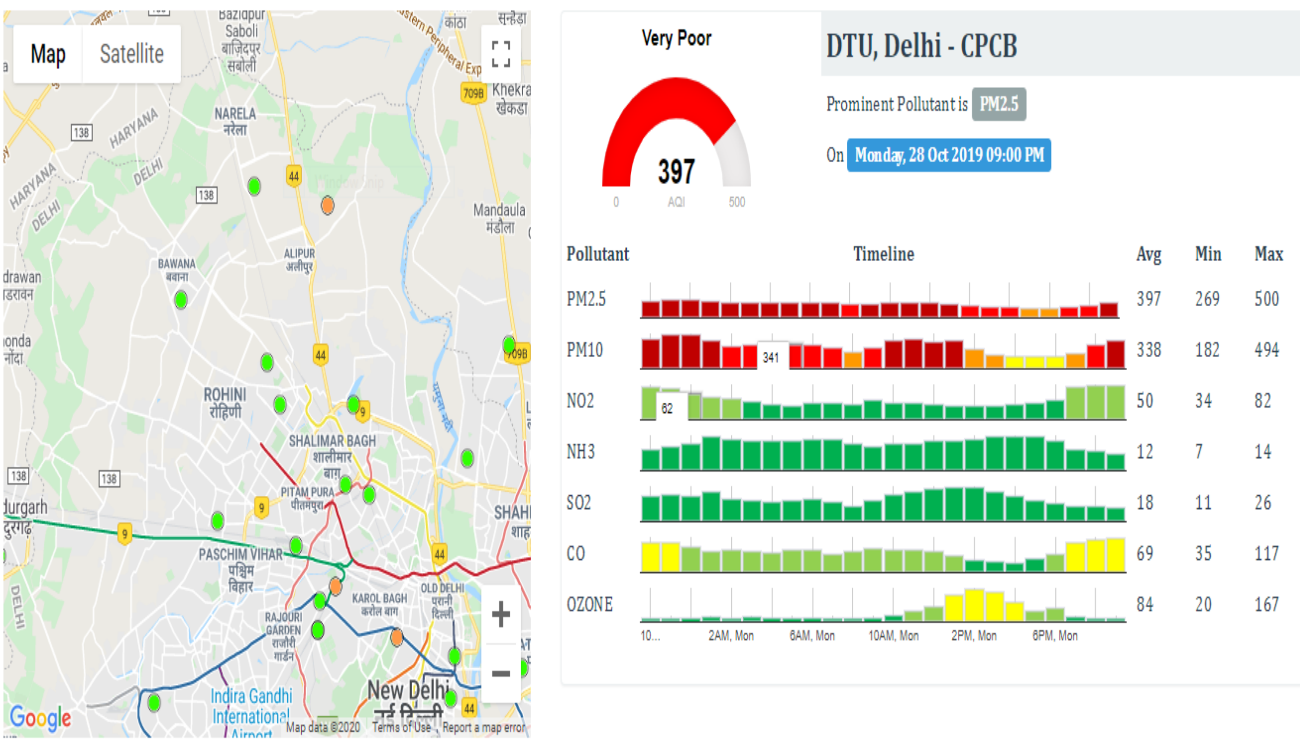

Fig A 2.1.AQI ON 28 Oct, 2019

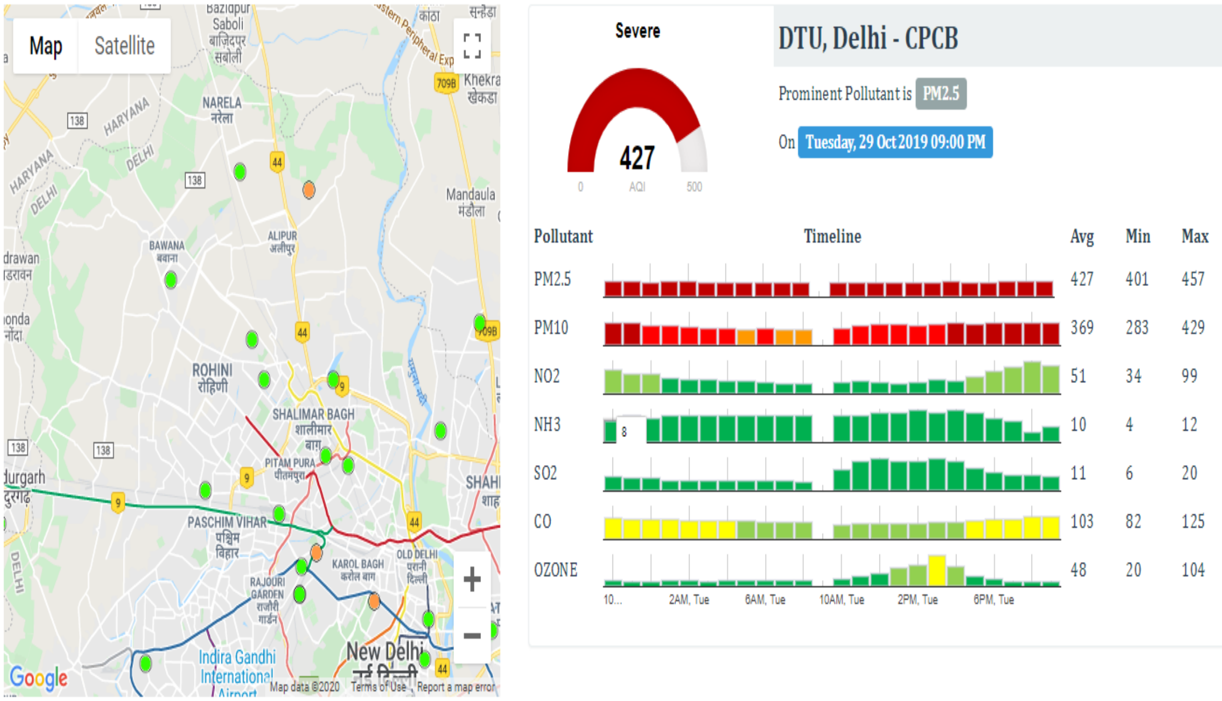

Fig A 2.2.AQI on 29 Oct,2019

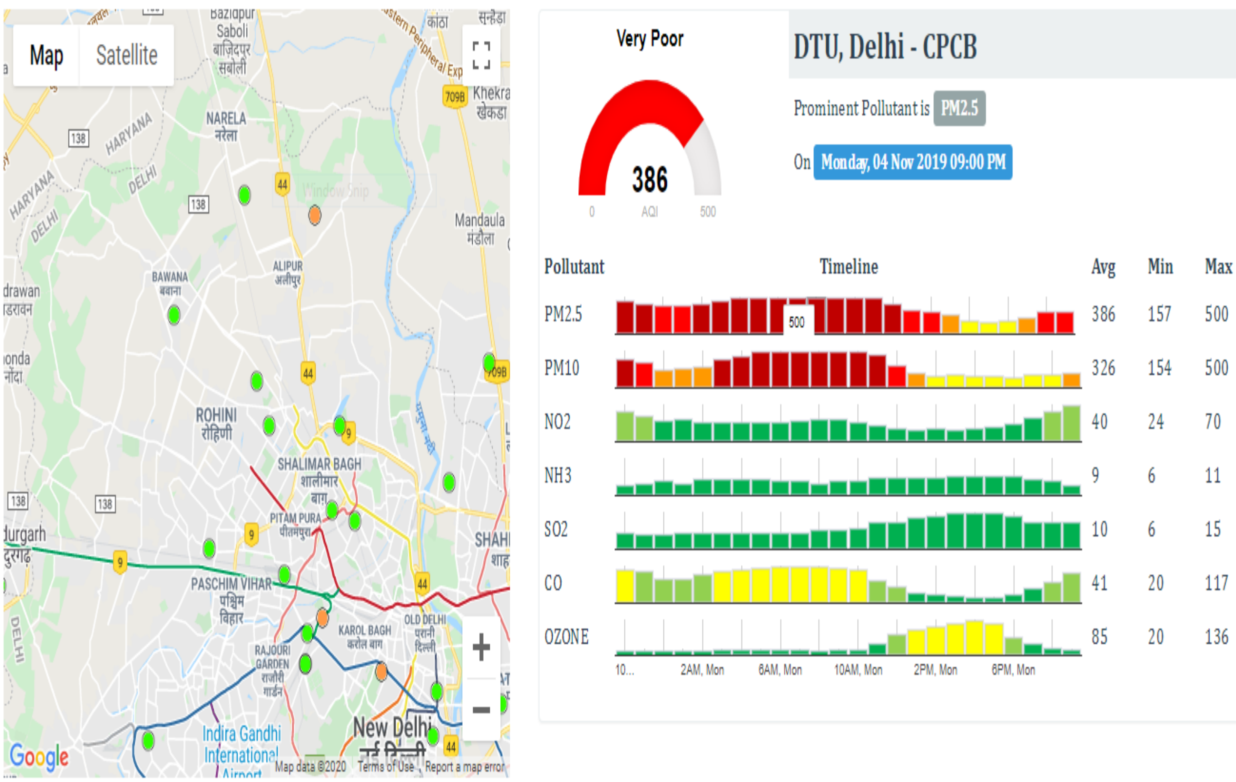

Fig A 2.3.AQI on 4 Nov,2019

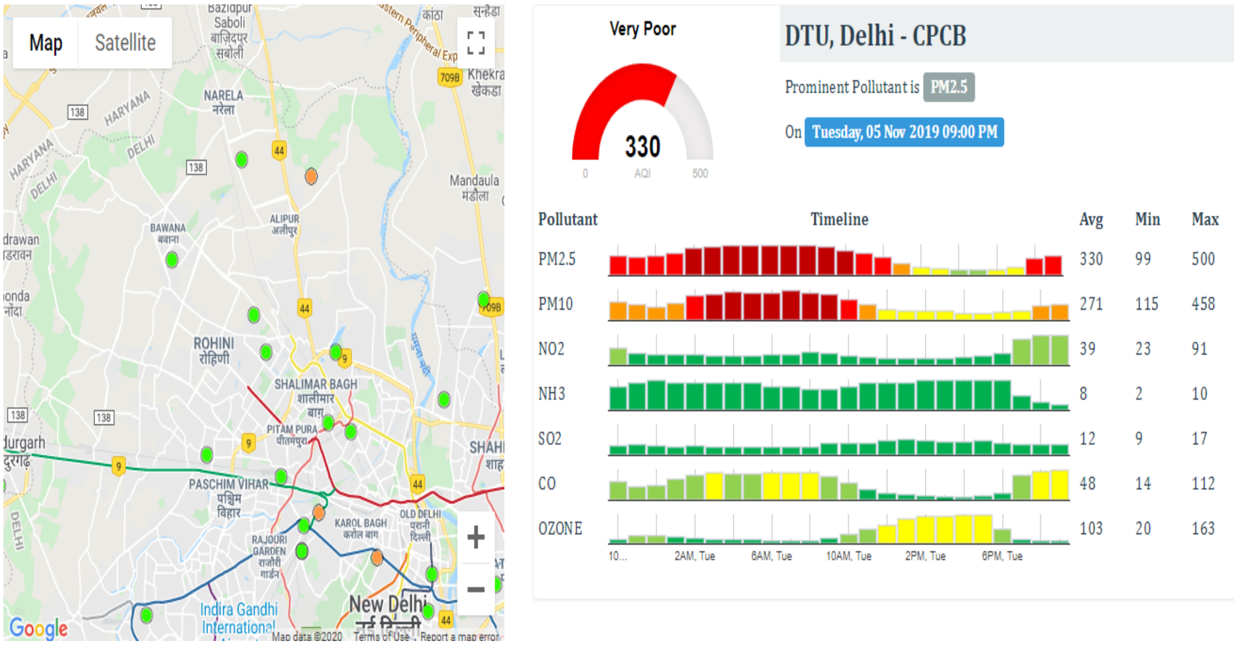

Fig A 2.4.AQI on 5 Nov, 2019

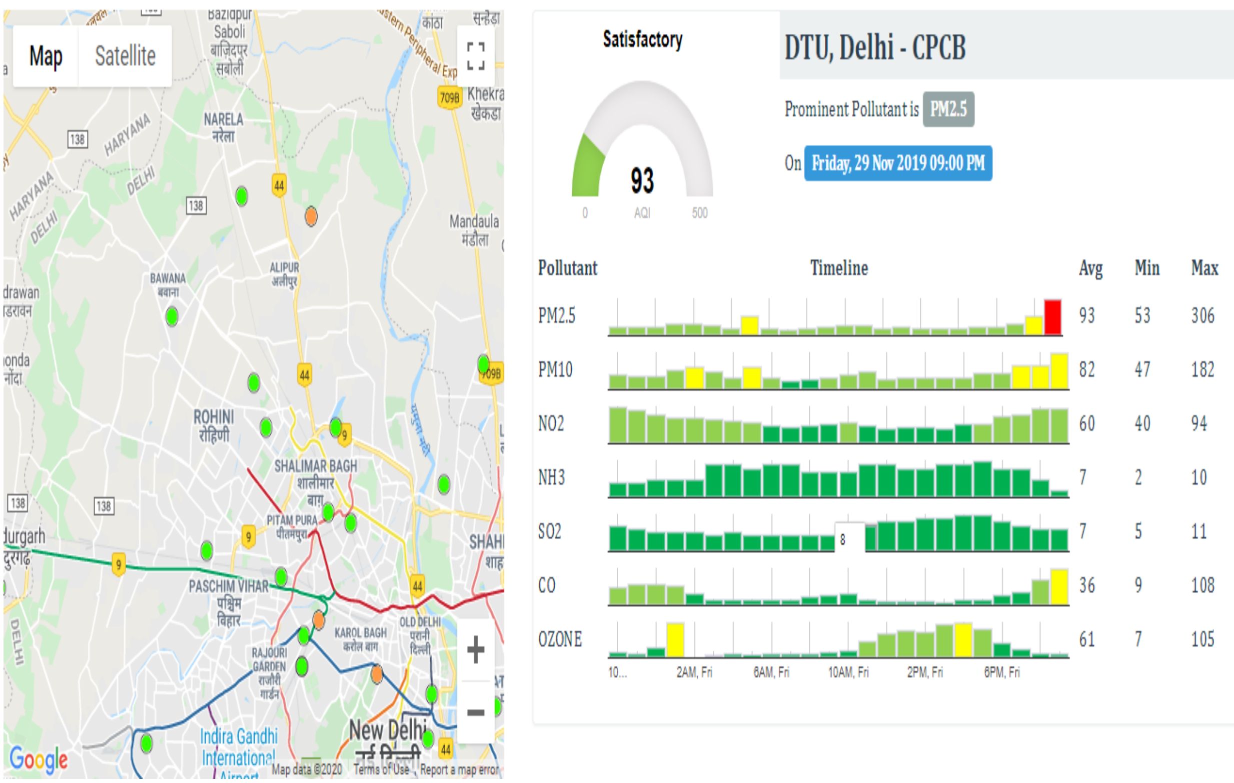

Fig A 2.5.AQI on 29 Nov, 2019

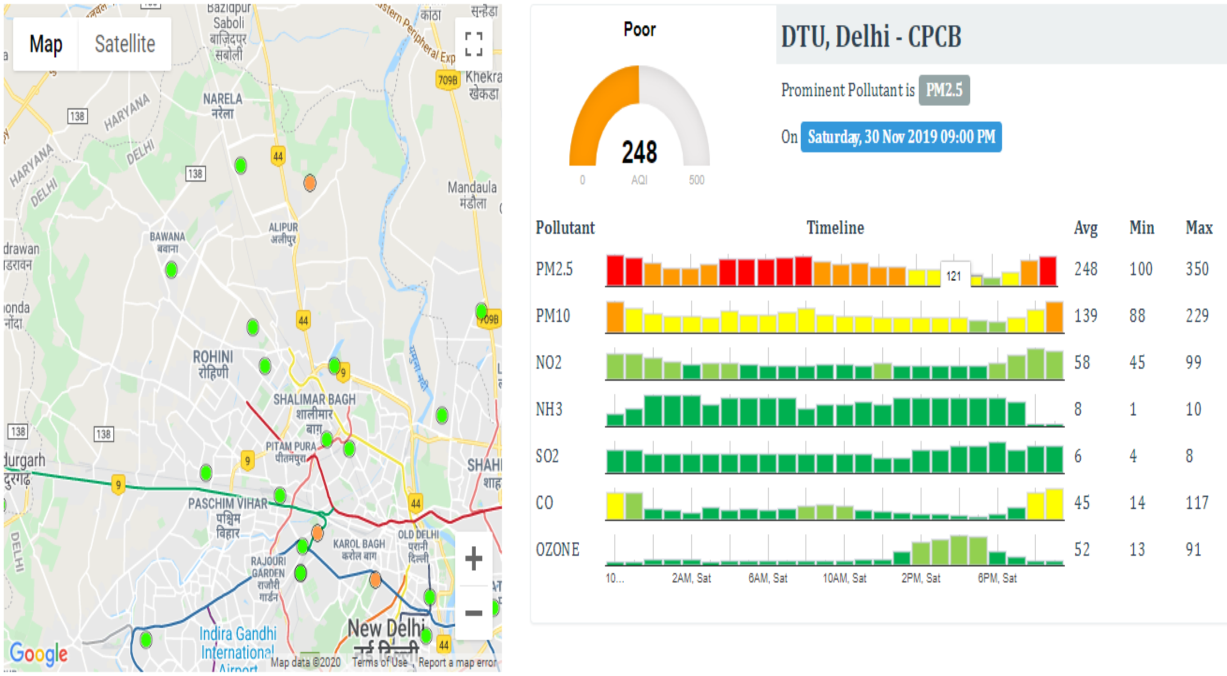

Fig A 2.6.AQI on 30 Nov, 2019

ANNEXURE3. COLLECTED DATA

The data that was collected from the weighing of the used masks is as follows:

Table A 3.1.Data Collected

MASKS	Initial Wt. (gm)	Day1	Day 2	Day 3	Day 4	Day 5	Day 6
MASK A	16.703	16.830	16.843	16.870	16.889	17.010	17.310
MASK B	8.024	8.045	8.091	8.102	8.170	8.235	8.297
MASK C	2.751	2.755	2.764	2.773	2.789	2.797	2.810
MASK D	10.643	10.682	10.695	10.715	10.843	10.891	10.939
MASK E	11.336	11.554	11.719	11.976	12.017	12.113	12.320
MASK F	10.306	10.335	10.342	10.354	10.397	10.407	10.420
MASK G	4.989	4.993	5.009	5.021	5.046	5.060	5.083