A comparative study of indoor and outdoor air quality and associated potential health effects in Gurugram, India

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A comparative study of indoor and outdoor air quality and associated potential health effects in Gurugram, India.

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Abstract. Deteriorating air quality remains a leading reason for global human illness and death. This study aims to investigate and compare inside and outside ambient air quality in 15 locations of Gurugram, India. Research technique adopted comprised of extracting outdoor air quality parameter values via Air Quality Index reporting stations for the entire year 2022. Parallel to that, indoor air quality parameter values of houses close to those monitoring stations were recorded through low-cost IoT based AirCubic sensors (T1595) as $PM_{2.5}$, PM_{10}, relative humidity (RH) and carbon monoxide (CO). After statistical evaluation, it was found that there were significant variations in outdoor and indoor air quality with maximum variations seen in colder season. The study revealed that PM levels were generally lower inside homes than outsides, while CO and RH concentrations were higher indoors. However, these levels often exceeded the acceptable thresholds set by both Indian national and global air quality standards, that could potentially result in harmful health effects, as well as increased risk of short and long-term illnesses, and even death. It may be concluded that more research, extensive air quality monitoring, data sharing, citizen awareness, and better technical and policy inputs are required to maintain healthy air quality for a sustainable lifestyle.

Keywords: AirCubic; air quality index; Delhi; Gurugram; hazard ratio; IoT; relative risk

1. Introduction

India in general and the areas near its capital city New Delhi (known as National Capital Region or NCR) in particular have been regularly graced higher positions as most polluted countries and metropolises respectively [1]. In the year 2022, New Delhi was categorised into one of the worst air quality capital-city globally with India ranking 8th among 131 countries surveyed and 21 out of global 30 cities having acutest air conditions were found in India with 6 of them being in the top 10 of the rankings [2]. In 2019, 0.17 crore fatalities in India had been associated with poor air quality, which translates to ~18% overall mortality of the nation and the combined impact of untimely demise and health issues caused by it resulted in monetary damages to the tune of around US $3000 crores and US $82 crore respectively, which accounted for ~1.4 percentage of Indian GDP; whereas 11.5% that is 53.5 million of the D.A.L.Y. or Disability Adjusted Life Years for the year 2019 were due to bad air quality and elevated PM levels [3]. Poor air quality was 2nd biggest hazard for DALYs with inhaling contaminated outside ambient air contributing ~7 percentage to entire D.A.L.Y and indoor air pollution causing 4.9% [4]. The health issues related with air pollution are well established in the scientific literature. Its effects on heart, lungs, mortality, morbidity, etc. have been studied world over including India [5-8]. According to Epidemiological studies air pollution and ambient PM are a leading cause of increased hospital admission, morbidity and mortality globally [9-11]. The adverse health effects of particulate matter and CO have been validated by studies worldwide [12-15]. As per Global Mortality statistics, 0.5 crore population globally also incorporating 0.15 crore Indians expire before their natural death which is attributable to $PM_{2.5}$ with outside air pollution being fifth largest reason for deaths in India [16]. Gurugram, with an area of 732 km^2, is one of the most historically significant places in India and is a prominent city in the state of Haryana adjacent to Delhi. It is geographically located southwest of New Delhi in the northern Indian region within the latitude and longitude 28.4595° N, 77.0266° E [17]. Its current population is 1,726,452 (931,027 males and 795,425 females). Also known as the Millennium city, Gurugram hosts 252 Fortune 500 companies. More than 45% of Haryana State's total revenue comes from Gurugram City alone and the city's per capita income is the third highest in India. All this rapid development and rise in living standards has come with its own set of problems. Air pollution has seen an alarming rise in recent years, which has led to a lot of health problems among its citizens. There are a number of factors responsible for recent distorted configuration to surrounding air that may be categorized in a number of ways either based upon its source of origin (as natural or anthropogenic), method of origin (as primary or secondary air pollutants), chemical composition (organic or inorganic air pollutants) or state of matter with its size (as particulate also called as PM or gaseous air pollutant). The chief sources of deteriorating air quality in Delhi and Gurugram are vehicular emissions, dust re-suspension, construction related activities, brick kilns, industrial emissions, thermal power plants, biomass and stubble burning, firecrackers, smoking, etc. [18-19]. Delhi and Gurugram also have a very unique geographical location and varied meteorological factors [20-22] making it a hot spot for low air quality if air pollution persists.

Very few studies have been performed in Delhi-NCR that compares the concurrent outdoor and indoor air quality levels to relate them both with adverse health effects. No Risk Assessment model for predicting health effects due to aerosols have been developed for Delhi-NCR including Gurugram. It is imperative to constantly monitor the air quality parameter concentrations to calculate the related health risks at these areas. Key objectives of this research are:

- To perform comparison evaluation study of interior and exterior air quality in select 15 locations in Gurugram for observing seasonal variations.
- To predict the potential health effects at the observed air quality levels theoretically using epidemiological formulas.

There is already a dearth of quality implementation of existing policies related to air pollution control [23, 24]. This study aims to provide reliable data that will assist policy makers in evolving better policies to check and regulate air quality at Delhi-NCR including Gurugram.

2. Methodology

The research approach (figure 1) consisted firstly; a detailed literature analysis related to air pollution at Delhi as well as Gurugram. 15 locations spread all over Gurugram city were selected that met the site inclusion criteria as mentioned in section 2.1. Outdoor air quality data was extracted for $PM_{2.5}$, PM_{10}, CO and Relative Humidity (RH) for the year 2022 from the official websites of Central and Haryana State Pollution Control Boards (CPCB and HSPCB) as well as Air Quality Index (AQI) portal of India. Simultaneously, data for indoor air was extracted for $PM_{2.5}$, PM_{10}, CO and Relative Humidity (RH) from low-cost AirCubic indoor air quality sensor model T1595 [25]. All this data was analysed and has been presented in this paper. Finally, conclusions have been drawn and some recommendations offered to tackle the situation.

2.1 Site inclusion Criteria

A total of 15 houses were selected that were located all over different parts (figure 2) of the city of Gurugram (28.6502° N, 77.3027° E) in India, which has a mix of urban and semi-urban localities. All these locations have official government approved outdoor air quality monitoring stations nearby (within 1 km range). These 15 houses were code identified as I to XV. Indoor air quality was monitored at these places (table 1) using low-cost AirCubic indoor air quality sensor model T1595. Only those houses were selected that did not have any air purifiers and their houseowners were pre-briefed about the research and their consent taken for the research voluntarily.

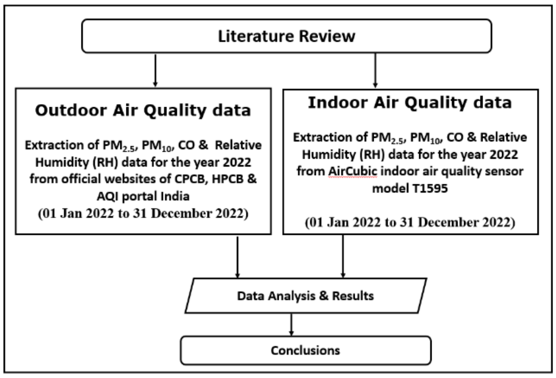

Figure 1. Overall methodology

Figure 2. Location of Sampling points in Gurugram.

Table 1. Sampling locations

Code	Location
I	Arya Nagar, Model Town, Sector 11, Gurugram,
II	Aralias, Sector 42, Gurugram
III	Belvedere Towers, Sec. 24, Gurugram
IV	Carterpuri Village, Sector 23A, Gurugram
V	DLF Park Place sector 54, Gurugram
VI	Heritage One Tower-A, Sector 62, Gurugram
VII	HUDA Office GMDA Sector 44, Gurugram
VIII	Kanhai, Sector 45, Gurugram
IX	Leisure Valley Park, Sector 29, Gurugram
X	Sector 5, Gurugram
XI	Sector 14, Gurugram
XII	Sushant Lok Phase-1, Gurugram
XIII	Tau Devi Lal Biodiversity Park GMDA, Sector 54 A, Gurugram
XIV	The Laburnum, Sector 28, Gurugram
XV	Vatika City, Sector 49, Gurugram

2.2 Device details

The IoT (Internet of Things) low-cost device used in this experiment i.e., AirCubic indoor air quality sensor model T1595 (figure 3) consists of 5 sensors indigenously developed by Juno Terra Technology Private Limited, Delhi, that extracts continuous values for air quality parameters such as $PM_{2.5}$, PM_{10}, CO, CO_2, VOC, CO, relative humidity (RH), temperature and air pressure at set time intervals ranging from per second to per hour as per the study requirements. Of these parameters, $PM_{2.5}$, PM_{10}, CO and RH were included in this study recorded at one-minute intervals. The device also contains a small inlet for the incoming air sample. The IoT device has a built-in Microcontroller with Wi-Fi functionality which sends the continuous stream of data to the cloud storage.

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Figure 3. Indoor air quality sensor model T1595 and its location at a sampling point in Gurugram.

3. Results & discussions

3.1 Annual outdoor PM_{10} & $PM_{2.5}$ values

The yearly outdoor PM_{10} & $PM_{2.5}$ values exceeded the permissible standard values of 100µg/m^3 and 60µg/m^3 respectively for most part of the year (figure 4).

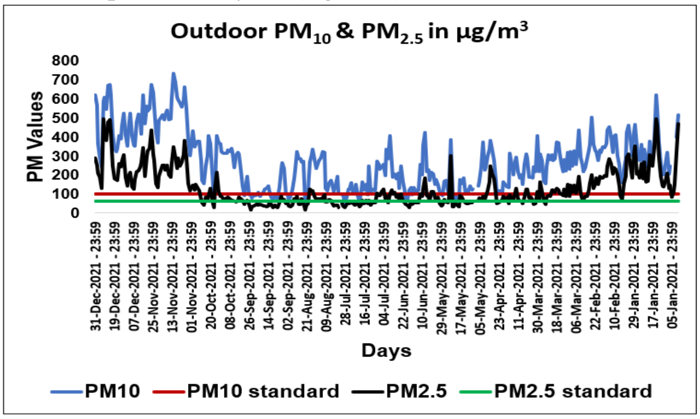


Figure 4. The comparison of $PM_{2.5}$ & PM_{10} with respect to standard values

3.2 Monthly outdoor PM_{10} & $PM_{2.5}$ values

Count of days per month with outdoor PM_{10} & $PM_{2.5}$ levels in different ranges have been shown in (figure 5). It is observed that the greatest number of days were above the permissible limits in the months of winter (November to February) and the least polluted days were seen during the Monsoon season (July to September), as the rains wash away particulate matter from the air.

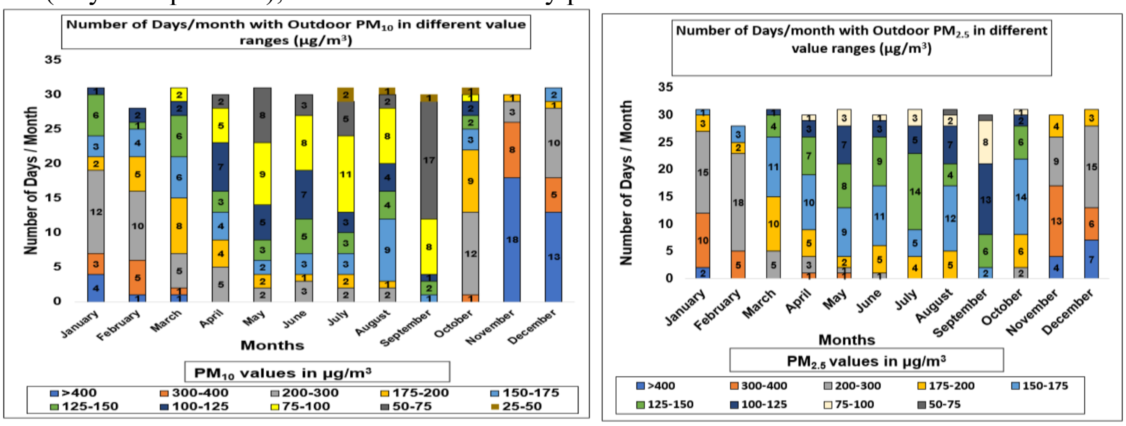


Figure 5. Distribution of outdoor PM_{10} & $PM_{2.5}$ values as count of days per month of the year.

3.3 Annual outdoor PM_{10} & $PM_{2.5}$ values

Annual indoor: outdoor ratios of PM_{10} & $PM_{2.5}$ at all fifteen locations have been shown in (figure 6). It is observed that for locations X, XI and XII this ratio was higher than others. These had the poorest ventilation systems and congested spaces which attributes to such high values.

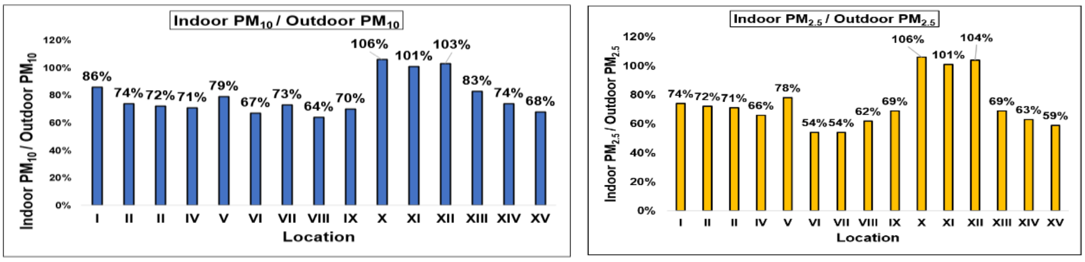


Figure 6. The comparison of PM_{10} indoor vs Outdoor of all 15 locations.

3.4 Annual average PM_{10} & $PM_{2.5}$ values (outdoor &indoor)

Averaging across all locations, indoor PM_{10} and $PM_{2.5}$ in Gurugram were 79% & 73% respectively of the corresponding outdoor air (figure 7).

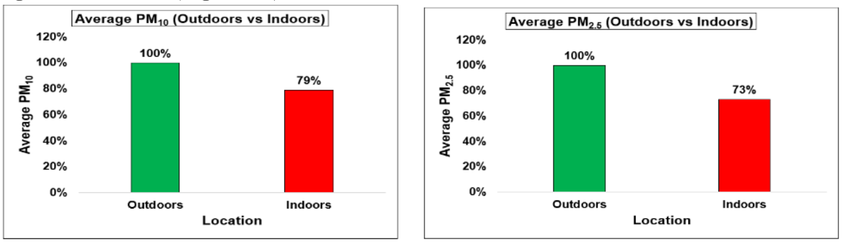
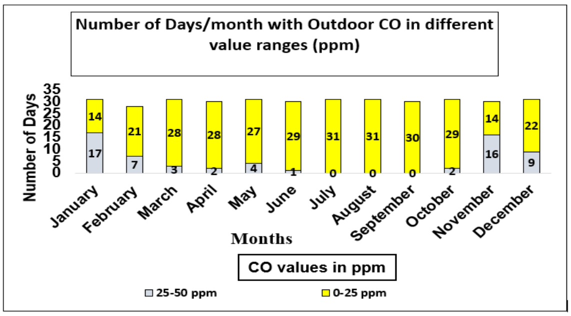


Figure 7. The Average PM_{10} and $PM_{2.5}$ at indoor vs Outdoor locations.

3.5 Annual and monthly average concentration of CO (Indoors vs Outdoors)

The number of days per month with outdoor CO values in different ranges (in ppm) have been shown in (figure 8). It is observed that there were a greater number of high concentration CO days during the winters than other months due to temperature inversion effects, when the weather is cold and calm. It was least during monsoon, as the rains wash away CO from the air. On an average, the CO concentration was 1.19 times more indoors than outdoors at the selected locations (figure 9). The primary reason being poor ventilation.



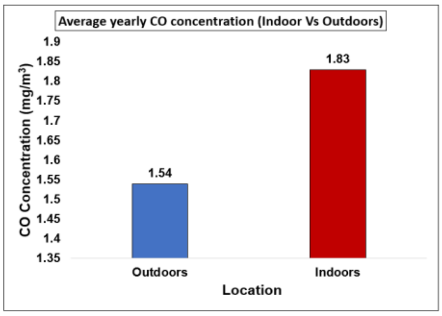


Figure 8. Daily and monthly distribution of CO. **Figure 9.** Average concentration of CO.

3.6 Monthly and annual average outdoor and indoor RH values

The monthly average outdoor RH at all locations have been shown in figure 10. On an average RH was observed more in summer months than in winters. Indoor air is generally dry in colder season. When cold air enters the home, it has less dampness and upon exposure to indoor higher temperature, it lessens its RH. The presence of RH alters the typical accumulation process of PM in nature. The dampness adheres to PM, accruing the surrounding PM levels. As the magnitude of humidity rises, the level of moisture also surges until it reaches a stage of *dry deposition*, which in turn causes drop in airborne PM_{10} levels. This correlates with the air quality observed during the experimental period as the highest RH values were observed during August and September that also reported the lowest PM_{10} concentrations. On an average, the RH values were 1.13 times more indoors than outdoors at the select locations (figure 11). The primary reason being poor ventilation.

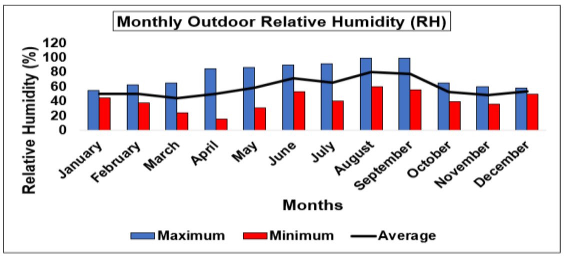


Figure 10. Monthly average outdoor RH.

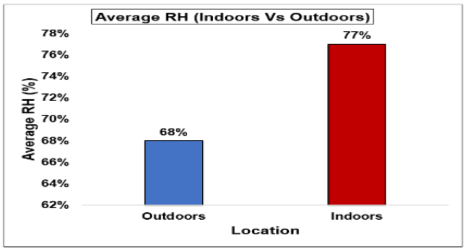


Figure 11. Average RH (Outdoors vs indoors).

4. Theoretical potential health effects at the observed air quality levels

4.1 Hazard ratio (HR) [Outdoor]

Hazard ratio (HR) is defined as the measure of occurrence of a particular event in one group as compared to its occurrence in another group over a definite period of time [26]. Mathematically, it is calculated as,

$$\text{HR} = \frac{\textit{Average concentration } (C)}{\text{Corresponding reference concentration (CR)}}$$

HR: Hazard Ratio; C: Average concentration; CR: Corresponding reference concentration

The hazard ratio for PM_{10}, $PM_{2.5}$ and CO have been calculated and reported in table 3.

Table 2. The table indicates hazard ratio for PM_{10}, $PM_{2.5}$ and CO.

Pollutant	Hazard Ratio
PM_{10}	2.754
$PM_{2.5}$	2.138
CO	0.778

It can be inferred from the above table that PM_{10}, $PM_{2.5}$ and CO have 2.754, 2.138 and 0.778 respectively times potential to cause adverse health effects among residents of Gurugram than those who are exposed to air with air quality within permissible parameter values.

4.2 Potential Health Effects

Relative risk is the ratio of the probability of an event occurring due to an exposure as compared to the probability of the event occurring without it. Cardiorespiratory deaths associated with prolonged inhalation of $PM_{2.5}$ is expressed by the following relative risk function for >30 years old:

$$\text{Relative Risk (RR)} = [(C + 1)/ (C_0 + 1)]^{\beta}$$

Where C and C_o are the Existing and Maximum levels of the pollutant

Suggested β coefficient (95% CI) is 0.15515 (0.0562, 0.2541) as given by Ostro et al., 2004 [27].

This is the recommended relationship presuming the ambient background levels of PM_{10} and $PM_{2.5}$ as 10 and 3 $\mu g/m^3$ respectively.

For Gurugram, outdoor $PM_{2.5}$ have been recorded as high as 999 $\mu g/m^3$. The following table 3 presents theoretical RR values that have been calculated based on the above formula for different ranges of $PM_{2.5}$ values:

Table 3. Calculated theoretical Relative Risk Ranges for different ranges of $PM_{2.5}$

$PM_{2.5}$ value ranges ($\mu g/m^3$)	Calculated Theoretical RR Ranges
0-100	0 - 1.081
101-200	1.081-1.203
201-300	1.203-1.286
301-400	1.286-1.339
401-500	1.339-1.386
501-600	1.386-1.426
601-700	1.426-1.460
701-800	1.460-1.491

801-900	1.491-1.518
901-1000	1.518-1.543

5. Conclusions

5.1 Averaging across all locations, indoor $PM_{2.5}$ and PM_{10} in Gurugram were found to be 73% and 79% of outdoor air respectively.

5.2 The fluctuation in the parameters for air quality showed a greater difference between outdoors and indoors in colder months compared to other months. Hence the role of temperature was quite significant.

5.3 While indoor PM values were lower than outdoor values, indoor levels of RH and CO were higher than outdoor levels.

5.4 The theoretical RR for Cardiopulmonary deaths linked to prolonged $PM_{2.5}$ log linear inhalation for people older than thirty years has been calculated and varies from 0-1.543 for $PM_{2.5}$ values 0-1000 $\mu g/m^3$, which is regularly reached in the winter months.

5.5 The majority of the results for CO, $PM_{2.5}$, and PM_{10} parameters exceeded the acceptable limits set by both Indian and global guidelines, putting individuals at risk for various health issues such as long-term and short-term health problems, diseases, and even death, especially if exposed for extended periods of time.

5.6 Furthermore, as humidity levels rise, the moisture particles gradually increase in mass and eventually reach a level where 'dry deposition' takes place, ultimately lowering the amount of PM_{10} in the air. The highest RH values were observed during August and September that also reported the lowest PM_{10} concentrations.

6. Recommendations

6.1 A pressing requirement exists to establish an extensive network of fixed and movable air quality monitoring units to examine outdoor air quality, as well as small IOT based sensor devices to evaluate indoor air quality.

6.2 The public in general needs to be educated more about the adverse health effects of pollution and make them understand that clean air is not a privilege but a right.

7. Scientific and social contribution of this research

This study is anticipated to inspire legislators, politicians, bureaucrats, and the citizens to set up a greater number of stationary outdoor and IOT based small indoor air quality sensor devices as vital tools for regularly checking their surrounding air quality and plan their schedules accordingly. This will ultimately decrease exposure to contaminants and promote a healthier lifestyle regime.

References

[1] World Health Organization 2016 *Ambient air pollution: A global assessment of exposure and burden of disease* https://apps.who.int/iris/handle/10665/250141

[2] IQAIR 2023 *World's most polluted countries* https://www.iqair.com/world-most-polluted-countries

[3] Pandey et al. 2021 Health and economic impact of air pollution in the states of India: The Global Burden of Disease Study 2019 *The Lancet Planetary Health* **5(1)** 25-38

[4] Indian Council of Medical Research, Public Health Foundation of India, and Institute for Health Metrics and Evaluation 2017 *India: Health of the Nation's States-The India State-Level Disease Burden Initiative* 73

[5] Pope CA, Dockery DW and Schwartz J 1995 Review of epidemiological evidence of health effects of particulate air pollution *Inhalation toxicology* **7(1)** 1-18

[6] Brunekreef B and Holgate ST 2002 Air pollution and health *The Lancet* **360(9341)** 1233-1242

[7] Bhardawaj A, Habib G, Kumar A, Singh S and Nema AK 2017 A review of ultrafine particle-related pollution during vehicular motion, health effects and control *Journal of*

Environmental Science and Public Health **1(04)** 268-288
[8] Bhardawaj A, Habib G, Padhi A, Anand A, Mahala N and Singh BK 2016 Deteriorating air quality and increased health risks in Delhi: The decisions being delayed *IIOAB Journal* **7** 10-15
[9] Dockery et al. 1993 An association between air pollution and mortality in six US cities *New England journal of medicine* **329(24)** 1753-1759
[10] Pope III CA, Bates DV and Raizenne ME 1995 Health effects of particulate air pollution: time for reassessment? *Environmental health perspectives* **103(5)** 472-480
[11] Pope III CA 2004 Air pollution and health-Good news and bad *New England journal of medicine* **351(11)** 1132-1133
[12] Langrish JP and Mills NL 2014 Air pollution and mortality in Europe *The Lancet* **383(9919)** 758-760
[13] Newby et al. 2015 Expert position paper on air pollution and cardiovascular disease *European heart journal* **36(2)** 83-93
[14] Mills et al. 2009 Adverse cardiovascular effects of air pollution *Nature clinical practice cardiovascular medicine* **6(1)** 36-44
[15] Bhagat S, Bhardawaj A, Mittal P, Chandak P, Akhtar M and Sharma, P 2016 Evaluating plastic waste disposal options in Delhi using multi criteria decision analysis *IIOAB Journal* **7(11)** 25-35
[16] Bhardawaj A, Habib G and Singh S 2017 Ambient aerosol induced cardiovascular disease among subjects in monsoon and winter season. *AAAS Annual Meeting, Boston* https://aaas.confex.com/aaas/2017/webprogram/Paper20401.html
[17] Latlong 2023 https://www.latlong.net/place/gurugram-haryana-india-570.html
[18] Mahajan H and Juneja K 2020 Air pollution problem in Delhi *Journal of Critical Reviews* **7(10)** 723-727.
[19] Ahlawat Y, Bhardawaj A and Bhardwaj R 2022 An experimental study on the stability and flow characteristics of mastic asphalt mix using cigarette butt additive *Materials Today Proceedings* **65(2)** 651-661
[20] Upadhyay A, Dey S, Chowdhury S, Kumar R and Goyal P 2020 Tradeoffs between air pollution mitigation and meteorological response in India *Scientific reports* **10(1)** 1-10
[21] Guttikunda SK and Gurjar BR 2012 Role of meteorology in seasonality of air pollution in megacity Delhi, India *Environmental monitoring and assessment* **184(5)** 3199-3211
[22] Kumar P, Khare M, Harrison RM, Bloss WJ, Lewis A, Coe H and Morawska L 2015 New directions: air pollution challenges for developing megacities like Delhi. *Atmospheric Environment* **122** 657-661
[23] Bhardawaj A, Bhardwaj R and Chaudhary AS 2022 Design and development of a model policy document for controlling air pollution in Delhi and NCR of India. *Proc. 25th ETH Int. Conf. on on Combustion Generated Particles (Zurich)* p 74
[24] Ahlawat Y, Bhardawaj A and Bhardwaj R 2022 A critical evaluation of failures in current air pollution control policies in India and proposal of innovative future policy perspectives. *Proc. 25th ETH Int. Conf. on on Combustion Generated Particles (Zurich)* p 60
[25] Chaudhary AS, Bhardawaj A and Bhardwaj R 2022 Comparative assessment of indoor and outdoor air quality at a semi-urban site in Delhi for observing seasonal variations and potential health effects. *Proc. 25th ETH Int. Conf. on on Combustion Generated Particles (Zurich)* p 10 https://www.nanoparticles.ch/2022_ETH-NPC-25.html
[26] Josey KP, Delaney SW, Wu X, Nethery RC, DeSouza P, Braun D and Dominici F 2023 Air Pollution and Mortality at the Intersection of Race and Social Class. *New England Journal of Medicine* **388(15),** 1396-1404
[27] Ostro B 2004 Outdoor air pollution: Assessing the environmental burden of disease at national and local levels *Environmental Burden of Disease* p 23