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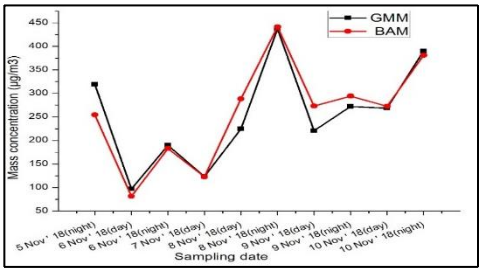

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Contents

From the Editor-in-Chief

Atmospheric poisoning after reopening of industry post lockdown COVID-19

The World Environment day 2020 has witnessed a different environmental scenario. Due to COVID-19, the air quality in India improved substantially, more than 60% improvement over the same month of previous year. However, the lockdown wake-up call was very jarring. Hardly within 2-3 days post lockdown 2.0, beginning May 4, three industrial accidents occurred, one on May 6 and another two on May 7. The May 6 incident happened at Shakti paper mill in Raigarh district of Chhattisgarh where 7 workers had fallen ill after inhaling a poisonous gas leaked at the paper mill. The May 7 accident occurred at the government owned Neyveli Lignite Corporation (NLC) India, thermal power plant in Tamil Nadu's Cuddalore. Eight contract workers suffered serious burn injuries during explosion in the boiler due to pressure. The third severe accident occurred at Vizag based industry, LG Polymers where leak of a poisonous gas styrene killed at least 12 and hospitalized hundreds due to inhalation of this gas from the hazardous clouds of styrene in the atmosphere. People in the area had not heard of styrene and its ill effects before its leak into the atmosphere. Not only the deaths and illness following the leak, but the spread of poisonous gas into the atmosphere causing air pollution which continued affecting the whole environment including air, water, soil, biota, humans, animals, and crops is a cause of greater concern. Styrene which is used in manufacturing of polystyrene plastic and resins is toxic during short-term (acute) and long term (chronic) exposure. The short-term exposure in humans include respiratory problems, irritation of eyes and mucous membrane, gastrointestinal problems etc. The long-term exposure affects central nervous system and causes symptoms such as headache, fatigue, weakness, depression, hearing loss and peripheral neuropathy. Research studies show that the exposure may be linked to various types of cancer including leukemia and lymphoma. Another industrial accident occurred on 3 June in the boiler of an agro-chemical company Yashashvi Rasayan Private Limited at Dahej in Gujarat's Bharuch district. At least 10 workers have died and over 70 received burn injuries. Thick clouds could be seen from Bhavnagar, about 20 Km away. The chemical fumes polluted all the components of the environment. These industrial accidents are not new. We have been affected by similar accidents earlier also. LG Polymer episode is a reminiscent of Bhopal gas tragedy which took a heavy toll of human lives. To avoid recurrence of Bhopal gas like accidents, and to regulate manufacturing, use and handling of hazardous chemicals, the then Union Ministry of Environment and Forests notified two sets of rules: 1. Manufacture, Storage, and Import of Hazardous Chemicals (MSIHC) rules, 1989 2. Chemical Accidents (Emergency Planning, Preparedness and Response (CAEPPR) rules, 1996. Taking a lesson from industrial mishaps that resulted due to haste in starting operations post lockdown 2.0, and looking into the LG Polymer company management's ignoring protocols of proper maintenance before operations, the Central

Pollution Control Board (CPCB) asked the Pollution Boards of states and UTs for compliance of its directives to ensure that industries in India go for safety and hazard audit before starting operations during lockdown 3.0 or post lockdown. In fact, India implemented the Environmental Protection Act, 1986, an umbrella Act, where provisions of all sorts are there for holistic protection of the environment, duties of central and state/UTs, responsibilities to advise and help the industry in operation for prevention of pollution. However, such incidents are not reducing in number and magnitude. The reasons could be many. Perhaps in the Environmental Impact Assessment scheme safety and risk management component is not given due place. There is no post commencement monitoring/audit for compliance of the Terms of References (ToRs) based on which the project appraisal is done, and Environment Clearance is granted. For according consent to operate on year to year basis and for expansion of production, the conditions of various installations and operations must be seriously reviewed. Industry also should have shared responsibility of environmental protection. Even a plethora of environmental laws cannot prevent incidents such as mentioned above if industry is careless in its maintenance and operations. A close perusal of the cause of Bhopal gas tragedy shows that the avoidable accident occurred because a novice supervisor ordered an untrained worker to clean the side pipe of a tank storing methyl isocyanate. The worker did it without inserting the slip-blind to separate the side pipe from the main tank. Water from the pipe on contacting MIC, raised the temperature to 1200^{o} C and blew off the lid throwing a huge amount of MIC gas into the atmosphere. The Shakti paper mill happened while an open recycling chamber was being cleaned before resuming operations. The LG Polymer, Vishakhapatnam industry also occurred due to haste to restart the plant. The gas leak occurred as the pressure built up in the storage tank and increased the temperature to 180 ^{o}C instead of below 20 ^{o}C at which temperature styrene remains in the liquid form. In the Yashashvi Rasayan Private Limited, Nitric acid tanker by mistake was unloaded in the tank of incompatible Dimethyl Sulphate and the exothermic reaction blew off the tanker resulting in a powerful blast. Under such situations, the watchdog institutions of the centre and the states may feel helpless to avert these major industrial accidents. Nonetheless, they should ensure that industry follows good practices such as proper safety measures, constitution of safety committees, proper selection of workforce, enforcement of discipline, safety consciousness among staff, incentives, proper maintenance of machines, equipment and infrastructure, no cost cutting for the required manpower, and safety training which can go a long way in attaining the desired goals. The post COVID-19 challenge is big because the industrialists on the pretext of fighting economic losses may practice cost cutting and may ignore or seek moratorium on environmental restrictions, which may lead to still serious situations.

Prof. C.P. Kaushik

SECRETARY'S REPORT

The Two-Year term of the Executive Committee normally expires in the month of September. However, the existing EC has continued as the elections of the current EC were held in May 18, and it was authorized to hold office till March'20. Due to COVID crisis, an approval for extension of term till Sept. 20 was obtained by e-mail from members.

As decided in its meeting on 25th October 2018, an annual lecture in the memory of Late Prof. G.D. Agrawal was held on 11th October 2019 at Indian National Science Academy, New Delhi. Dr. M. Anandakrishnan, an eminent Educationist and former Chairman, Board of Governers of IIT Kanpur, delivered the first Memorial Lecture in Honor of Late Prof. G.D. Agrawal. Besides him, Dr. Ravi Chopra from PSI Dehradun, Vaidya Rajesh Kotecha, Secretary, Deptt. of Ayush, Govt. of India, Shri M.C. Mehta, well known Environmental Lawyer, Dr. B. Sengupta, former Member Secretary CPCB, Shri Paritosh Tyagi, former Chairman CPCB, Shri Dhunu Roy Environmental Activist & few others shared their impressions on this legendary man.

The entire Northern India comes in grip of severe Air Pollution during October – January every year. The Air Quality in NCR and especially in Delhi become very very poor, causing a great Risk to Human Health. Although several measures are taken and implemented to control the Air Pollution to improve the Air Quality, yet there appears to be no respite. Association felt that Air Quality Experts of the Country should come together and deliberate on the real cause of the problem for deterioration of Air Quality and suggest short term and long term appropriate solutions to ensure good Air Quality in Delhi and its surroundings.

With these objectives, a brain storming workshop was organized at Constitution Club, New Delhi on 30th Nov 2019. Many eminent Air Quality experts like Dr. B. Sengupta, Dr. Rakesh Kumar, Director Neeri, Prof. Virendra Sethi, IIT Bombay, Prof. Mukesh Sharma IITK, Dr. AL Agarwal, former Dy. Director NEERI, Dr. Sumit Sharma TERI, Shri Abhijit Pathak, Scientist CPCB participated. Recommendations of the workshop were sent to CPCB and MOEFCC for their consideration.

Association also partnered with NPL-CSIR lab on 7th Jan 2020 for a discussion on "Criterion for Air Quality Measurement Devices". These discussions were considered very vital as due to rapid advances in technology, newer methods and Instrumentation are getting evolved and India must look at these developments carefully for their adoption into our monitoring network. This workshop also discussed the need for certification of Air Monitoring devices. IAAPC and NPL have partnered in many such events in the past also. A compilation of events organized jointly by NPL and IAAPC is available at the end of this journal.

Association had also planned to organize an International Event on "Air Quality & Climate Change – Planning for sustainable future" during March 2-3,2020. Many National & International experts had confirmed their participation. A professional event management company I-Ten had also joined the Association for organizing the event. However due to delay in receipt of major sponsorships, the event was postponed.

Covid crisis has confronted the entire country since March this year. This is indeed an unexpected & unparalleled crisis that has caused a deep emotional breakdown. Those surviving on their day to day marginal earnings are the worst sufferers. They had rushed back to their native places to be with their families. They lost their jobs and earnings, and this may result into an economic collapse.

However, this crisis also unfolded many sub surfacial issues which were being talked but were being always kept aside due to priority of economic development. For the first time, after many decades, Blue Skies were visible, Chirpings of Birds were heard, our rivers came alive with abundant aquatic life and fresh flowing water. We all learnt to live without motorized transport. We got what we were desperately wanted from our development. Sadly, it came but we never wanted this way. Now it has given us a challenge as to how to restore livelihoods and still maintain this bliss.

Your Association refrained from organizing any public event to comply with social and physical distancing norms. However, it organized two webinars. One, discussion on draft EIA notifications was organized in which more than 350 participants were present, and another to share the memories of Late Prof. G.D. Agrawal in which about 200 participated. The clause by clause comments on draft EIA were prepared by the IAAPC and were sent to MOEFCC for their consideration. ‘A wall of remembrance has been created by a group of well-wishers of GD’ on which memories including Videos can be uploaded by members and others.

With great efforts put in by the Editorial team, the Journal was published in June 2020 covering the backlog of previous years. The present issue which is a combined March & September 2020 issue, is in your hand.

Five members joined the association during September 2019 to August 2020.

Association is planning to hold next event as a “Brain Storming Work-shop” on developing appropriate Guidelines on Air Quality Monitoring requirements & Review of National Ambient Air Quality Standards in September / October 2020. The objective is to prepare a reference guideline document & suggest modified NAAQS.

Association shall continue to actively play its role as a group, to deliberate and evolve scientific opinion on Air Quality issues.

S. K. Gupta

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Some Preliminary Results of Particulate Matter Metrology

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Abstract

The state of air quality is one of the major environmental concerns worldwide. The accuracy and precision of measurements of parameters determining air quality thus becomes significant. To ensure this and the traceability of measurements, quality checks of instruments used is a vital step. Performance evaluation of instruments in accordance with the meteorological conditions at the sampling sites and its calibration using appropriate traceable standards are two important ways to maintain the quality of data generated. In case of particulate matter (PM) pollution, not much progress has been made in India to check the reliability of the real time monitoring instruments used. Also, no reference material has been developed so far for particulate matter metrology. In this context, CSIR-National Physical Laboratory (NPL) has taken few steps to fill this gap which are being presented in this paper.

Keywords: Particulate matter (PM), Certified Reference Material (CRM), β-ray attenuation method

1. Introduction

Extraction of resources to meet the demands of the ever-rising population from nature has put an additional burden on our planet in the past few decades. The developmental activities and increase in the number of industries day by day has harmed the environment poorly across the globe. Deteriorating air quality is one such example among others. Many national and international researches and reports have come up pointing in this direction in recent times. Such researches and reports play a significant role in creating awareness and providing briefs for policy makers to combat and control the emissions. However, one of the major concerns is the uniformity of the data that is being reported in such reports as they are mainly based on the secondary data. Particulate matter (PM) happens to be one of the key contributors to the poor air quality. The particles with size < 2.5 µm ($PM_{2.5}$) are of major importance as they can penetrate deep into alveolar sections of the lungs causing respiratory and cardiovascular diseases. The documented detrimental effects of particulate matter pollution to human health have drawn attention to the need for integrated mitigation strategies, including the establishment of air quality guidelines, continuous and accurate monitoring of PM concentrations and effective control of population exposure. Various agencies such as central and state pollution control boards monitor the air quality at different stations across the country. The methods used in these measurements (sampling to analysis) should be traceable to SI units through an institute called National Metrology Institute (NMI) of the respective country to have comparable results and thus a better monitoring process. This will help in formulating the appropriate pollution control and abatement policies at the regional and national levels.

To ensure and maintain the reliability of the PM measurements, CSIR-NPL, the NMI of India has taken up many research activities in the previous years. Two of such activities, i.e., development of certified reference material (CRM) for particulate matter and performance evaluation of Beta Attenuation Monitor (BAM) in Indian conditions are being discussed in this paper.

2. Performance Evaluation of BAM

According to National Ambient Air Quality Standards (NAAQS) notified by nodal agency Central Pollution Control Board (CPCB), three different methods are to be used in order to monitor the PM concentrations across the country, namely Gravimetric Method (GMM), Beta Attenuation Monitor (BAM) and Tapered Element Oscillating Microbalance (TEOM). BAM and TEOM are the real time measurement methods whereas GMM is the primary method based on the gravimetric measurement of filter used before and after sampling. Real time measurements are favored over the laboratory analysis methods because of their ability to provide continuous measurements with minimal human intervention. Real time methods can provide measurement data on a time scale of minutes whereas the gravimetric method works on a time scale of days. Therefore, the continuous measurements can provide an instant input for policy makers and central agencies to take appropriate mitigating steps in case of severe pollution events.

BAM is the most commonly used real time PM measurement monitor in India by the different monitoring agencies in Continuous Ambient Monitoring System (CAMS). However, some studies have raised the concern of level of reliability of the data produced by it as the technique has certain limitations when used in different weather conditions. The factors such as relative humidity, high mass loading and chemical composition of particulate matter have been reported to affect its performance (Cheng and Tsai, 1997; Lazaridis *et al.,* 2005; Shin *et al.,* 2011). BAM either over-estimate or under-estimate the PM mass concentration levels since the humidity (30 to >95%) and temperature (minus degree to >45 °C) varies widely across the country depending on season and region. This leads to significant variation in measurement data when compared with the reference method (GMM). The major factors that are reported to cause inconsistency in PM concentrations include (1) the cutoff aerodynamic diameter and the penetration curve of the inlet (Ranade *et al.,* 1990; Tsai, 1995) (2) heavy particle deposition on the impaction surface or inner surface of instrument which may reduce particle penetration (John *et al.,* 1991) (3) the deliquescence of aerosols (Meng *et al.,* 1995; Pilinis and Seinfeld, 1989) and (4) the evaporation loss of volatile species of aerosols (Zhang and McMurry, 1987, 1992; Cheng and Tsai, 1997). Variations in the aerosol chemical composition affects the water content of particles and thus induce differences between BAM and GMM measurements. Water content of aerosols depends on the ability of the particles to hold water under given RH conditions, i.e. their hygroscopicity. Also, the water content has been reported to be governed by the relative abundance of inorganic salts in aerosols as inorganic particles are more hygroscopic in nature than the organic particles (Aggarwal *et al.*, 2007). This leads to overestimation in mass measurements. This further indicates that performance of BAM is affected differently by both low and high levels of RH. In operation, the inlet line of BAM is heated up to a temperature of 30˚C before the sample reaches the filter tape to reduce the relative humidity to below 60%. This feature minimizes the water content of particles to lower the bias from high RH, but it may also cause a loss of volatile and semi-volatile component (such as NH_4NO_3) of particulate matter present in the ambient air sample, thus underestimating the mass concentration. But during high ambient RH conditions (60% - 90%), the heating of inlet at this temperature is not enough to evaporate water in aerosols leading to high mass measurements (Shin *et al.*, 2012). These differences can significantly affect quantitative agreement between the BAM and the GMM measurements. Therefore, there is a need to explore these areas and find a solution to overcome bias in BAM measurements.

At CSIR-NPL, we performed a comparative study for measuring $PM_{2.5}$ mass concentrations by BAM and Gravimetric method in the month of November 2018. Simultaneous day-night sampling was carried out at the rooftop of Apex Metrology Building, CSIR-NPL. Samples for gravimetric method were collected on

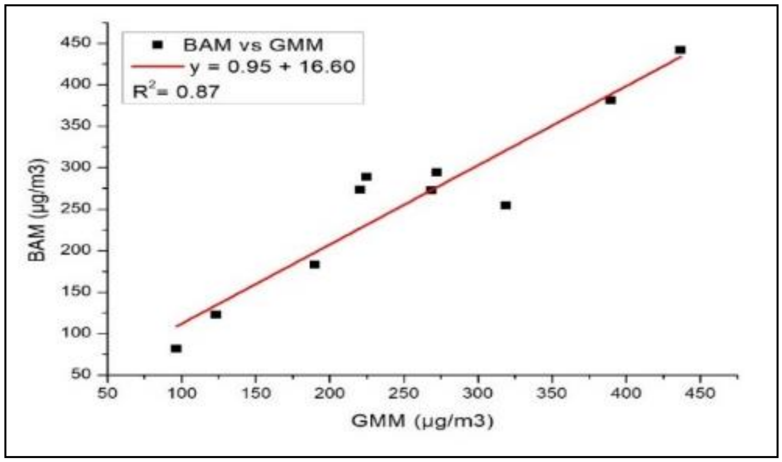

Figure 1: Comparison of $PM_{2.5}$ concentration between BAM and GMM

(a)

(b)

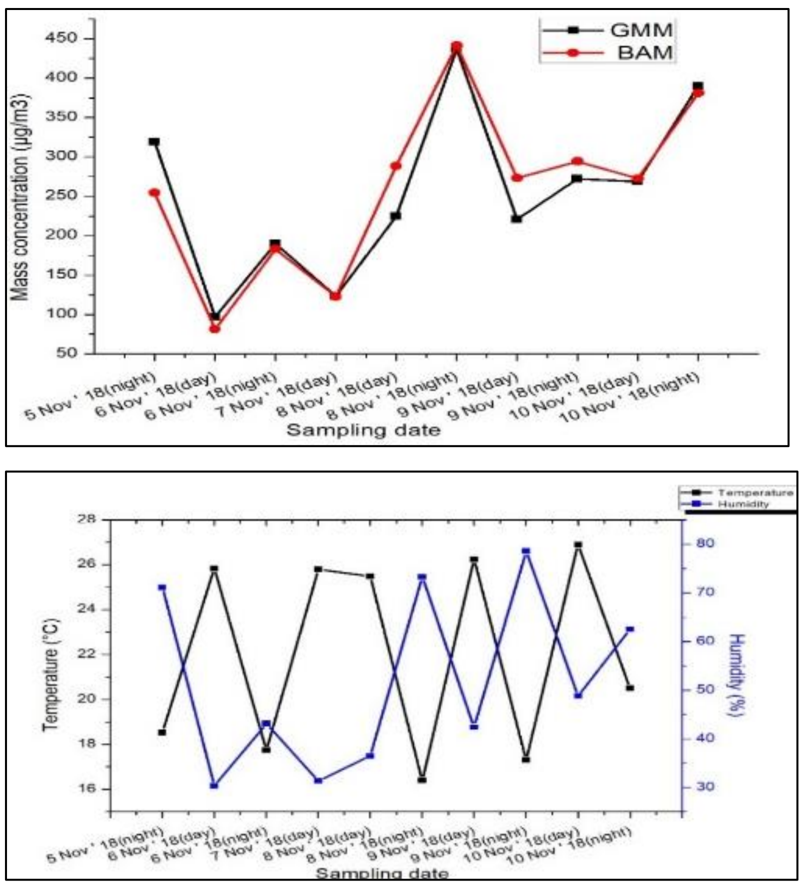

Figure 2: (a) Mass concentration of $PM_{2.5}$ measured by BAM and GMM; (b) temperature and humidity on the days of sampling

pre-baked (at 450˚ C for 4.5 hours) quartz fiber filters using the high-volume sampler (Tisch Environmental, USA) at a flow rate of 1130 LPM. The filters were weighed before and after sampling using a digital microbalance (Model: 1700i, Sartorius), the difference of which was used to calculate the $PM_{2.5}$ mass concentration. The BAM (Model: MEZUS 610, Kentek Environmental Technology, Korea) with a flow rate of 16.67 LPM was run simultaneously and for the same duration as that of high-volume sampler. The meteorological parameters i.e. temperature and humidity were also recorded during the entire sampling duration.

The results show that BAM and gravimetric measurements of $PM_{2.5}$ are correlated at low ambient $PM_{2.5}$ concentrations with estimated Pearson coefficient~0.9 (Fig.1). The variability at high ambient $PM_{2.5}$ concentration was found potentially dependent on the high particle mass loading and high relative humidity at night, showing the biasness in BAM measurements (Fig 2). Changing gaseous concentrations in Indian condition, i.e. SO_2, NH_3, NO_x and O_3, play a major role in the formation of secondary particles and hence affect BAM measurements as secondary particles are hygroscopic in nature and can retain water. Therefore, detailed understanding of the other parameters that affect the measurements under Indian conditions are also necessary to ensure optimal application of the instrument and accurate interpretation of the results obtained from it.

3. Development of Certified Reference Material for Particulate Matter

The degrading air quality across the globe have instilled a vast research scope in this field. Since air pollution is a very sensitive issue owing to its harmful health effects on humans and environment, accurate monitoring and measurements become an important aspect of control strategies. Maintaining quality and reliability in the data produced from a laboratory requires certain tools such as use of calibration standards and certified reference materials (Piascik *et al.,* 2010). CRM is reference material that has been characterized by a metrologically valid procedure for one or more specified properties, accompanied by a certificate that provides the value of the specified property, its associated uncertainty, and a statement of metrological traceability. CRMs are required to ensure the quality, reliability and inter-comparability of the analytical data generated from any analytical process or instrument operation (Aggarwal *et al.,* 2013, Mori *et al.,* 2008). Also, the use of CRMs ensures the data generated to be at par and acceptable at national and international levels. The instruments used in quantifying the characteristics of airborne particulate matter can be calibrated or quality assured using CRMs of other materials but the use of a representative matrix CRM of the measurand is much more helpful in ensuring data quality and comparability. Accuracy of air pollution studies holds great importance since the control and abatement strategies depend largely on them. Also, such studies provide inputs for governmental action in severe pollution events to take appropriate steps.

Few of the NMIs of the world have been engaged in developing particulate matter CRM since 1970s. As a result, several of them are available with different certified properties of particulate matter. National Institute of Standards and Technology (NIST), USA; National Institute of Environmental Studies (NIES), Japan; Institute for Reference Materials and Measurements (IRMM), Belgium are three such NMIs that have been able to develop and provide such a facility to maintain data quality and meet international standards. Some of the available CRMs produced by these three NMIs specifically for use in atmospheric particulate study are summarized in Table 1.

India, being ranked as one of the polluted countries in terms of air quality has not developed any CRM for particulate matter as of now or any other air pollutant as a matter of fact. A wide variation has been observed in the air quality data from different sources in our country leading to misperception among the scientific fraternity, public and policy makers. In order to minimize this ambiguity, it is necessary to develop appropriate quality control tools. CRMs are one such tool to ensure the measurement data quality and laboratory performance. Currently, no suitable CRM is available representing Indian ambient conditions that certifies the contents of particulate matter. Therefore, at CSIR-NPL, we are working actively to fill this gap.

Table 1: Currently available CRMs representing airborne particulate matter

CRM No.	Certifying NMI	Matrix	Certified properties	Reference
1648a	NIST	Urban Particulate matter	PAHs, Nitro-PAHs, PCB congeners, chlorinated pesticides, inorganic elements	NIST, 2015
1649b	NIST	Urban atmospheric particulate matter	PAHs, Nitro-PAHs, PCB congeners, chlorinated pesticides, poly-chlorinated dibenzo-p-dioxins, dibenzofurans, inorganic constituents, particle size	NIST, 2016
CRM 28	NIES	Urban aerosols	Inorganic elements, PAHs	Mori *et al.*, 2008
ERM-CZ100	IRMM	PM_{10}-like fine dust	PAHs	Piascik *et al.*, 2010
ERM-CZ120	IRMM	PM_{10}-like fine dust	Arsenic, Cadmium, Nickel, Lead	Piascik *et al.*, 2010
RM 8785	NIST	Urban dust	Total carbon, elemental carbon, organic carbon	Klouda *et al.*, 2005
SRM 2786	NIST	Urban	PAHs, nitrated PAHs, trace elements, BDE congeners	Schantz *et al.*, 2016
SRM 2787	NIST	Urban	PAHs, nitrated PAHs, trace elements, BDE congeners	Schantz *et al.*, 2016
Vehicle exhaust particulates	NIES	Vehicular exhaust	Inorganic elements	Okamoto, 1987

However, developing a particulate matter is a challenging task as compared to other materials. One of the biggest challenges is the collection of bulk amounts of starting material. For example, it took 10 years to collect 3 kg of material by NIES, Japan to develop NIES CRM 28 (Mori *et al.*, 2008). Since the material is collected over different seasons and weather conditions, there might be an issue with the homogeneity in the composition of material while certification. Storage and quality maintenance over the years after certification are among other challenges being faced in CRM development. Although, development of CRM is a tedious process, but it is important to develop it especially for a country like India where the air quality issues are on a rise and measurement accuracy should be a prime concern.

A collection facility has been set up for collection of particulate matter at the rooftop of CSIR-NPL. The instrument can collect the airborne particulate matter in powder form. It is based on the principle of impaction and cyclone both. The instrument consists of an inlet, a cyclone assembly, backup filter holder, flow meter, pump and a control unit. The inlet has a provision of attaching an impaction surface to segregate the coarse (>2.5 µm) and fine (< 2.5 µm) fraction of particles. The impaction surface can be removed to collect TSP (Total Suspended Particulate Matter). The particles that enter the inlet, are segregated into coarse and fine. The coarse particles get stuck on the impaction surface while the finer ones travel to the cyclone assembly where due to centrifugal force, the particles separate from the air stream and after hitting the walls of cyclone gets collected in the container attached at the bottom. The air stream then travels through a backup assembly where a filter is placed to collect any remaining ultrafine fraction of the particulate matter. The instrument works at a flow rate of 1200 LPM and has high collection efficiency, however, the amount of material collected depends on the prevailing environmental conditions. The facility is functional since November 2017.

Conclusion

Air quality has become one of the prime concerns in the recent past because of its visible impacts on human health and environment. The first and the major step of any air pollution study or a control and abatement exercise is the accurate measurement of the existing air quality. CSIR-NPL India is actively engaged in ensuring the quality of data by taking up new research initiatives and establishing new facilities. Two such activities are described in this paper. Performance evaluation of BAM will certainly help to bring about and better understand the instrument's limitations in Indian conditions. This will further aid in improving the system to be better suited to country's ambient conditions. The development of CRM would prove beneficial for monitoring agencies and researchers working in this domain. Maintaining and communicating data quality and accuracy in analytical results will become easier by use of developed CRM. Also, the CRM will help in ensuring the performance of instruments used in the analytical procedures.

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References

1. Aggarwal, S. G., Kumar, S., Mandal, P., Sarangi, B., Singh, K., Pokhariyal, J., Mishra, S. K., Agarwal, S., Sinha, D., Singh S., Sharma C. and Gupta P.K. (2013). Traceability issue in PM 2.5 and PM 10 measurements. *Mapan*, *28*(3), 153-166.
2. Aggarwal, S. G., Mochida, M., Kitamori, Y., & Kawamura, K. (2007). Chemical closure study on hygroscopic properties of urban aerosol particles in Sapporo, Japan. *Environmental science & technology*, *41*(20), 6920-6925.
3. Cheng, Y. H., & Tsai, C. J. (1997). Evaporation loss of ammonium nitrate particles during filter sampling. *Journal of Aerosol Science*, *28*(8), 1553-1567.
4. John, W., Winklmayr, W., & Wang, H. C. (1991). Particle deagglomeration and reentrainment in a PM_{10} sampler. *Aerosol Science and Technology*, *14*(2), 165-176

5. Klouda, G. A., Filliben, J. J., Parish, H. J., Chow, J. C., Watson, J. G., and Cary, R. A. (2005). Reference material 8785: Air particulate matter on filter media. *Aerosol science and technology*, *39*(2), 173-183.
6. Lazaridis, M., Spyridak, A., Solberg, S., Smolik, J., Zdımal, V., Eleftheriadis, K., Aleksanropoulou, V., Hov, O., Georgopoulos, P.G. (2005). Mesoscale modeling of combined aerosol and photo-oxidant processes in the Eastern Mediterranean. *Atmos. Chem. Phys*. 5, 927e940.
7. Meng, Z., Seinfeld, J. H., Saxena, P., & Kim, Y. P. (1995). Contribution of water to particulate mass in the south coast air basin. *Aerosol Science and Technology*, *22*(1), 111-123.
8. Mori, I., Sun, Z., Ukachi, M., Nagano, K., McLeod, C. W., Cox, A. G., and Nishikawa, M. (2008). Development and certification of the new NIES CRM 28: urban aerosols for the determination of multielements. *Analytical and bioanalytical chemistry*, *391*(6), 1997-2003.
9. NIST (2015). Certificate of Analysis: Standard Reference material 1648a, Urban Particulate Matter, National Institute of Standards and Technology, Gaithesburg, MD.
10. NIST (2016). Certificate of Analysis: Standard Reference material (SRM) 1649b, Urban Dust, National Institute of Standards and Technology, Gaithesburg, MD.
11. Okamoto, K. (1987). Environmental standard materials NIES No. 8—automobile-exhaust particles. *Kankyokenkyu*, *66*, 124-133.
12. Piascik M., Perez Przyk E., and Held A. (2010). The certification of the mass fractions of Arsenic, cadmium, Nickel and Lead in Fine Dust (PM_{10}-like matrix): Certified Reference Material ERM-CZ120. Luxembourg, European Union.
13. Piascik M., Perez Przyk E., and Held A. (2010). The certification of the mass fractions of selected Polycyclic Aromatic Hydrocarbons (PAHs) in Fine Dust (PM_{10}-like matrix): Certified Reference Material ERM-CZ100. Luxembourg, European Union.
14. Pilinis, C., Seinfeld, J. H., & Grosjean, D. (1989). Water content of atmospheric aerosols. *Atmospheric Environment (1967)*, *23*(7), 1601-1606.
15. Ranade, M. B., Woods, M. C., Chen, F. L., Purdue, L. J., & Rehme, K. A. (1990). Wind tunnel evaluation of PM_{10} samplers. *Aerosol Science and Technology*, *13*(1), 54-71.
16. Schantz, M. M., Cleveland, D., Heckert, N. A., Kucklick, J. R., Leigh, S. D., Long, S. E., and Porter, B. J. (2016). Development of two fine particulate matter standard reference materials (<4 μm and <10 μm) for the determination of organic and inorganic constituents. *Analytical and bioanalytical chemistry*, *408*(16), 4257-4266.
17. Shin, S. E., Jung, C. H., & Kim, Y. P. (2011). Analysis of the measurement difference for the PM10 concentrations between beta-ray absorption and gravimetric methods at Gosan. *Aerosol and Air Quality Research*, *11*(7), 846-853.
18. Shin, S. E., Jung, C. H., & Kim, Y. P. (2012). Estimation of the optimal heated inlet air temperature for the beta-ray absorption method: analysis of the PM10 concentration difference by different methods in coastal areas. *Advances in environmental research*, *1*(1), 69-82.
19. Tsai, C. J. (1995). A field study of three collocated ambient PM_{10} samplers. *Particle & particle systems characterization*, *12*(1), 10-15.
20. Zhang, X. Q., & McMurry, P. H. (1987). Theoretical analysis of evaporative losses from impactor and filter deposits. *Atmospheric Environment (1967)*, *21*(8), 1779-1789
21. Zhang, X., & McMurry, P. H. (1992). Evaporative losses of fine particulate nitrates during sampling. *Atmospheric Environment. Part A. General Topics*, *26*(18), 3305-331

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Impact of Environmental and Climatic Factors on Monuments

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Abstract

Monuments all over the world are being impacted by rapidly changing environmental and climatic factors. Moreover, global projections of a further rise in temperatures and extreme events have been made by IPCC and other Global and National Centres using hierarchy of modeling studies. There is need to take an integrated approach for conservation and safety of these world heritage properties. An attempt has been made to assess the impacts of the deteriorating factors and suitable measures for incorporation into disaster risk reduction strategies.

Key words: Monuments, Environmental, Climate, Pollution

1.0 Introduction

Cultural heritage monuments are being continuously impacted from natural and anthropogenic factors and resulting in damage and changing their original state. The environmental factors like temperature, humidity, precipitation, extreme events (extreme winds, storms, tornados, frost, extreme precipitations, flooding, flash floods, heat waves, drought, pollution peaks etc.), air pollution, climate change etc. have both slow and rapid impacts on the Built Cultural Heritage viz. the Monuments scattered throughout India and the world. Relative humidity and temperature changes deteriorate stone and ceramic because a slight change may result in salts crystallizing and resulting weathering. Increased temperatures result in increased dryness, droughts and possibly fires which may destruct organic materials and several non-organic ones. Biological activities impact the rate of deterioration and reduce monument's aesthetic qualities and color. It is observed that rapid climatic changes in recent last decades have caused more problems to the monuments than previous centuries or millennia since their existence. The global mean temperature is likely to rise further between 2.9°C and 3.4°C by 2100 relative to pre-industrial levels Inter-governmental Panel on Climate Change (IPCC, 2018) and will impact monuments. In India also, mean surface air temperature during 2016 – 2045 is projected to rise by 1.08°C to 1.44 °C relative to 1976-2005. Further, it may rise by 1.35°C, 2.41°C and 4.19°C under RCP 2.6, RCP 4.5 and RCP 8.5 scenarios, respectively during 2066-2095 (Fig. 1) (Krishnan and Sanjay 2017). Air pollution is another important factor in degradation of surfaces of historical buildings and monuments. Corrosion caused by chemicals and soiling caused by particles may result in economic losses and destruction of cultural heritage. A recent study led by the Italian Institute for Environmental Protection and Research and the Institute for Conservation and Restoration of Heritage shows that in Rome about 3600 cultural heritage made of calcareous stone (limestone) and 60 cultural heritage objects made of bronze are at risk of deterioration (UNCEE 2015). UNESCO (2008) has listed 14 primary factors**,** encompassing each a number of secondary factors which are threat to monuments in different countries of the world (Table 1). Further, potential impacts have also been delineated.

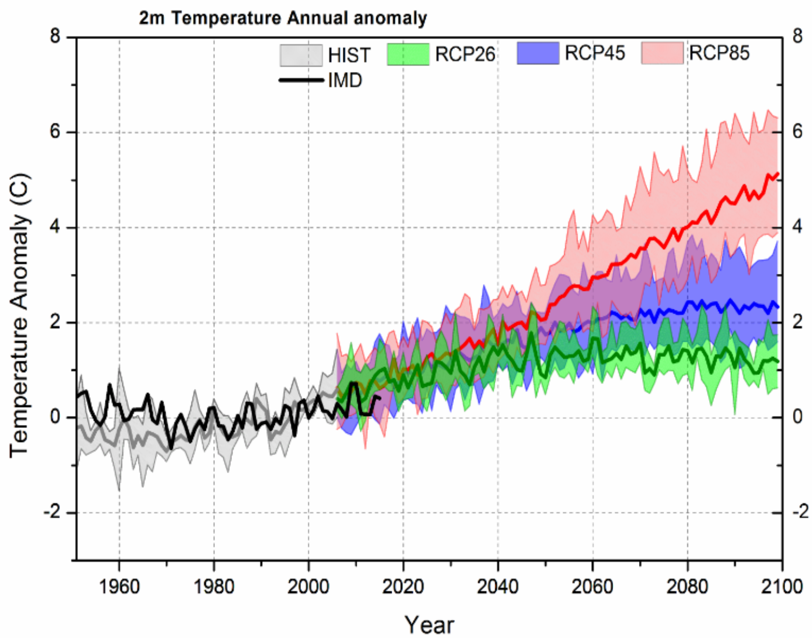

Fig. 1: Projected temperature anomaly over India

The problem is similar in India also. Though, many Indian cities are known for their heritage monuments, but impact of rising air pollution has not been measured systematically. However, pollution levels in the vicinity of 138 heritage monuments in 39 cities cities were measured to assess the gravity of the problem. The results indicate that particulate matter pollution around monuments was within the national ambient air standard in only six cities viz. Shimla, Hassan, Mangalore, Mysore, Kottayam and Madurai. In was found up to four times higher than the national ambient air quality standards in remaining cities. The world famous monuments like Red Fort and Qutub Minar in Delhi, Charminar in Hyderabad, Bara Imambara in Lucknow etc. are in the most polluted areas of these cities. The government has not enforced any traffic management plan around most monuments, which are in congested parts of cities, except around Taj Mahal trapezium (HT 2013). Many of the monuments are in critical conditions and need extensive diagnostics for proper management of conservation/rehabilitation works and their safety for both movable and immovable heritage. As such, an attempt has been made to assess the impact of environmental and climatic factors on monuments so as to plan effective management strategies for their preservation and safety.

2. Environmental Impacts

The process of deterioration of materials induced by outdoor environmental factors is a complex interplay of the effects of climate, local meteorological characteristics, and biological and chemical processes resulting from the impact of pollutants and natural constituents from the surrounding environment. Monuments are impacted by both direct and indirect effects of environment. The direct effects are caused by variation in soil/ moisture and/or desertification, flooding and surface runoff, extreme weather events, coastal erosion, freeze and thaw- glacier variation, formation of salts, quality & typology of the biological environment of the area and its flora/fauna, variation in temperature. Greenhouse gases emissions, corrosion and earth recession etc.

Table: 1 Threats to world heritage properties

SN	Threat/ factors	Sector
1	Buildings and Development	Housing, Commercial development, Industrial areas, Major visitor accommodation and associated infrastructure , Interpretative and visitation facilities
2	Transportation Infrastructure	Ground transport infrastructure, Air transport infrastructure, Marine transport infrastructure, Effects arising from use of transportation infrastructure
3	Utilities or Service Infrastructure	Water infrastructure, Renewable energy facilities, Non-renewable energy facilities, localised utilities, Major linear utilities
4	Pollution	Pollution of marine waters, Ground water pollution, Surface water pollution, Air pollution, Solid waste, Input of excess energy
5	Biological resource use/ modification	Fishing/ collecting aquatic resources, Aquaculture, Land conversion, Livestock grazing, Crop production, Commercial wild plant collection, Subsistence wild plant collection, Commercial hunting, Forestry /wood production
6	Physical resource	Mining, Quarrying, Oil and gas, Water extraction
7	Local conditions affecting physical fabric	Wind, RH, Temperature, Radiation/light, Dust, Water (Rain/Water table), Pests
8	Social/cultural uses of heritage	Ritual/spiritual/religious and associative uses, Society's valuing of heritage, Indigenous hunting, gathering and collecting, Changes in traditional ways of life and knowledge system, Identity, social cohesion, changes in local population and community, Impacts of tourism/visitor/recreation,
9	Other human activities	Illegal activities, Deliberate destruction of heritage, Military training, War, Terrorism, Civil unrest
10	Climate change and severe weather events	Storms, Flooding, Drought, Desertification, Changes to oceanic waters, Temperature change, Other climate change impacts
11	Sudden ecological or geological events	Volcanic eruption, Earthquake, Tsunami/tidal wave, Avalanche / landslide Erosion and siltation/deposition, Fire (wildfires)
12	Invasive/alien species or hyper-abundant species	Translocated species, Invasive/alien terrestrial species, Invasive / alien freshwater species, Invasive/alien marine species, Hyper-abundant species, Modified genetic material
13	Management and institutional factors	Management System/Management Plan, Legal framework, Low impact research/monitoring activities, Governance, High impact research/monitoring activities, Management activities, Financial resources, Human resources
14	Other factors	Any other factor not covered in above list

Indirect effects of climate change include migration (permanent/ temporary), conflicts, changes in value systems, politics, changes in production and consumption related to agriculture, industry, urbanization, settlements, deforestation, changes in polluting elements etc (ICOMOS 2012). Environmental deterioration of materials is mainly caused by total deposition. It is estimated that dry deposition ranges from 20% to 60% while wet deposition varies from 80% to 40% of the total deposition. The gaseous pollutants that cause the most damage to construction materials are oxides of sulphur, but other pollutants like carbon dioxide, nitrogen oxides and salts from sea spray also contribute in deterioration. Atmospheric oxidants such as ozone, atomic oxygen and different free radicals generated during photochemical reactions are responsible for the formation of sulphuric and nitric acids. Air pollution has continuously increased with industrialization. Eras of pollution are depicted in Fig. 2.

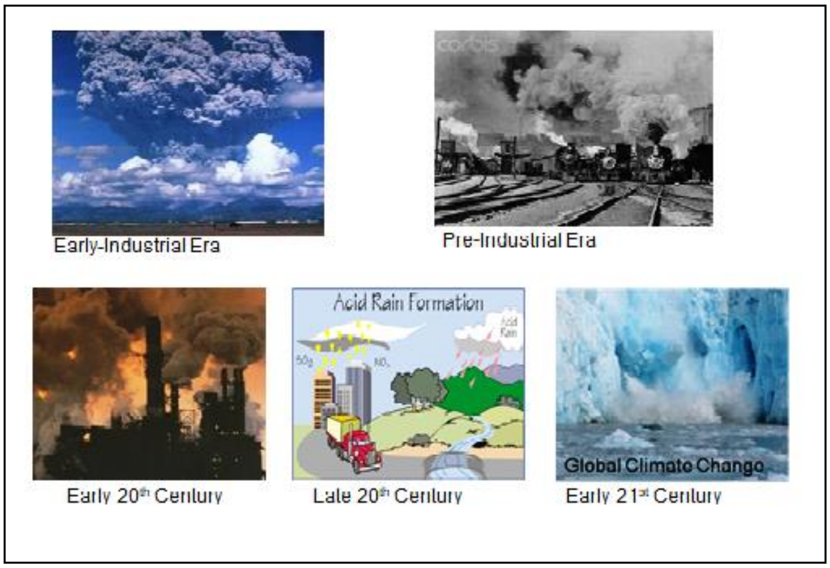

Fig. 2: Eras of Air pollution

Air pollution estimates are made at global and national level. A Sand and Dust Storm Warning and Assessment System (SDS-WAS) of World Meteorological Organisation focus on enhancing the ability of countries to deliver timely and quality forecasts of sand and dust storms, observations of aerosols: sand and dust and information and knowledge to users through an international partnership of research and operational experts and users as under

- Global Coordination: Three Regional Nodes (The North Africa, The Europe and The Middle East Node, (East) Asian Node and Pan-American Node) exchange information and enhance collaboration. The West Asian Node will also be established in near future.
- First Operation Centre viz. The Barcelona Dust Forecast Centre opened in Spain in 2014.
- Trust fund and Steering Committee: to ensure the global coordination activity

In India, air pollution is measured by various organisations / institutes like Central Pollution Control Board, State Pollution Control Board, Universities, IMD, and NGOs etc. IMD has established a dedicated networks of Skyradiometes (20) , Aethalometers (25 stations) and Nephelometer (12) in addition to air quality monitoring systems in the country to characterise the optical and chemical properties of aerosols and resulting air quality and climate impacts. Based on threshold values for Aerosol Optical Depth (AOD) and Angstrom Exponent (AE) five dominant aerosol types i.e., Mostly dust (MD), polluted continental (PC;

dominant anthropogenic aerosols with dust), anthropogenic aerosol (AA; mainly coming from urban/industrialized regions around the measuring site, as well as from vehicular emissions), biomass burning (BB; mainly coming through biomass/crop residue burning),and mixed type (MT) in Indo-Gangetic Region are depicted in Fig. 3 (Tiwari *et al*, 2016). The estimation of aerosol chemical composition helps in quantifying their impacts on monuments.

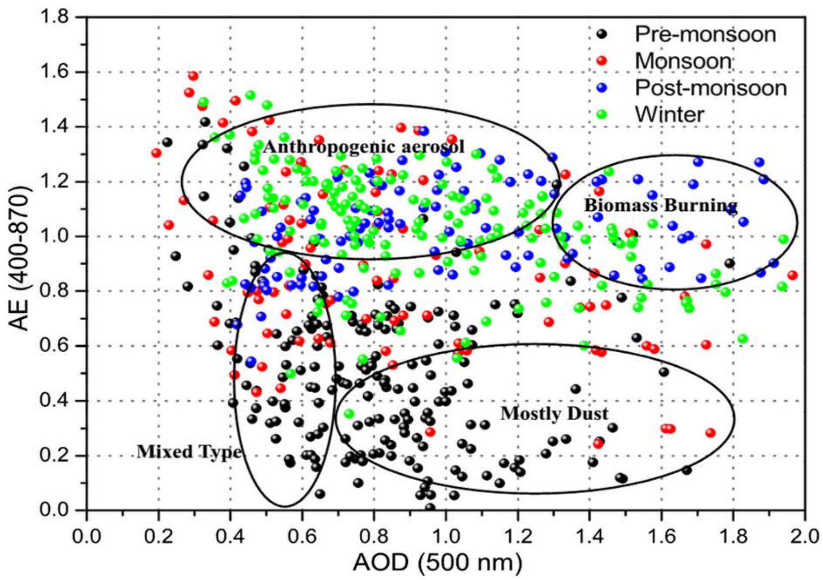

Fig 3: Variation of aerosols in different seasons in India (Tiwari et al 2016)

Atmospheric pollution is an accelerating factor in the material deterioration of the buildings of historical importance. The study of the corrosive effects of gaseous SO2, NOx, O3, HNO3 and acid rainfall etc. have crucial impact on the heritage buildings and structure (Chapoulie et al. 2008; Aulinas et al. 2009). Taj Mahal is built is going to be yellowish in colour which is due to SO2 (Sulphur di oxide) emitted from the Mathura refinery, resulting in formation of acid rain which later on corrodes the marble surface by dissolving the CaCO3 (calcium carbonate) present in the marble (Pandey & Kumar. 2015). The deposition of gaseous and particulate atmospheric pollutants known to have a destructive effect on the calcareous stones [Nava et al. 2010; Urosevic et al. 2012] seem to be originated from the contamination by atmospheric pollutants emitted by industrial sources and vehicular traffic, particularly sulphur dioxide and by the marine sprays. Burning fossil fuels increases the concentration of NOx and SO2- in the atmosphere, the agents most harmful to masonry [Bityukova 2006; Massey 1999].

The surface level soil moisture content modifies the Land surface Temperature (LST) and vegetation cover. Changes in soil moisture content can alter the soil thermal properties and evapotranspiration. It is known that rise in the soil moisture leads to rise in the soil thermal capacity, conductivity and inertia thereby slowing the rise in the LST. In addition, surface heat fluxes such as the Latent Heat Flux (LHF) and Sensible Heat Flux (SHF) get modified (Jiang et al, 2015). This process of changing the moisture content over the last few years also affected our historical Monuments. It is well known that soil moisture for the environment and climate system is played an important role. Soil moisture influences hydrological and agricultural processes, runoff generation, drought development and many other processes. It also impacts on the climate system through atmospheric feedbacks.

Soil moisture is a source of water for evapotranspiration over the continents, and is involved in both the water and the energy cycles. Soil moisture was recognised as an Essential Climate Variable (ECV) in 2010 as known more precisely AS Climate Change Initiative (CCI). The data sets utilized for the study are combined data sets of global volumetric soil moisture (m3 /m3) at 0.250 x 0.250 and downloaded from European Space Agency (ESA) global web-site data (https://earth.esa.int/eogateway/). The combined data sets are generated by blending the active and passive products which were created by using scatterometer and radiometer soil moisture products (Dorigo et al., 2019, Gruber et al., 2019). The data sets used in this study are volumetric soil moisture represents content of liquid water in a surface soil layer of 2 to 5 cm depth are available since the year 1978 . Authors created a mean climatology of volumetric soil moisture (1978-2018) for Indian region from the global data sets and then brought the departure from normal for the year 2018. Positive departure values signify the increase in the volumetric soil moisture over the area and vice versa. The Fig. 4 shows the appreciable change in the soil moisture especially around the historical monument location areas. Hence the appreciable change of volumetric soil moisture content is also one of the main contributors of degradation along with meteorological /hydrological tracers.

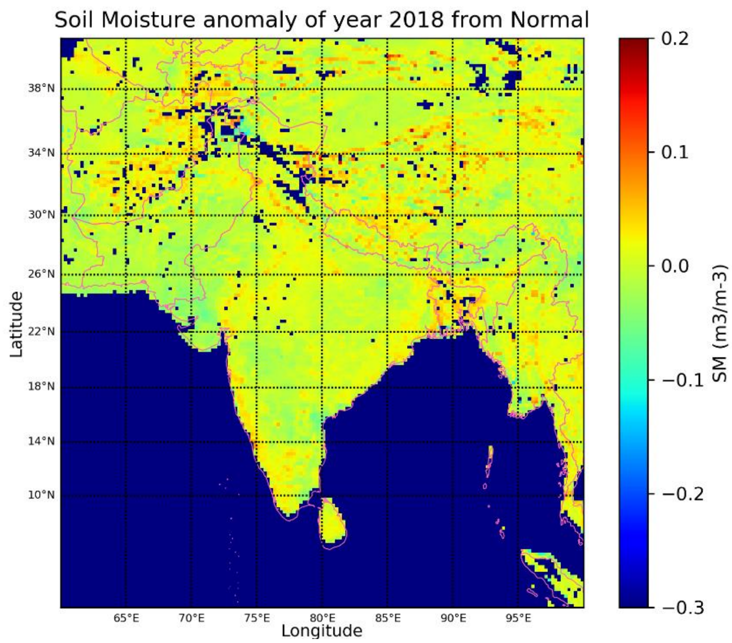

Fig. 4: Year 2018 Soil moisture departure from Normal (1978-2018)

The global Copernicus Atmosphere Monitoring Service (CAMS) reanalysis datasets of total column of sulphur dioxide [kg /m^2] have been utilized in this study are downloaded through European Centre for Medium Range Weather Forecasting (ECMWF) global web portal. The CAMS reanalysis data sets was produced using 4DVar data assimilation in CY42R1 of ECMWF's Integrated Forecast System (IFS), with 60 hybrid sigma/pressure (model) levels in the vertical, with the top level at 0.1 hPa. Atmospheric data are available on these levels and they are also interpolated to 25 pressure, 10 potential temperature and 1 potential vorticity level(s).

The mean of sulphur dioxide (SO_2) over Indian region (2003-2019) is generated from the global data file of 0.75 degree resolution (Raoult et al 2017). This pollutant contributes to acid deposition and has adverse effects on buildings, aquatic ecosystems of rivers, lakes, vegetation and inflaming the respiratory tracts in humans. In this way we can say of the key contributors of historical monument degradation. The mean total integrated concentration of SO2 over Indo Gangetic Plains (IGP) and some pockets of South West and North West India show appreciable increase in comparison to other parts of India. Most of the historical monuments are situated around on those areas. Hence, Fig. 5 represents the causes of degradation of historical monuments from decades.

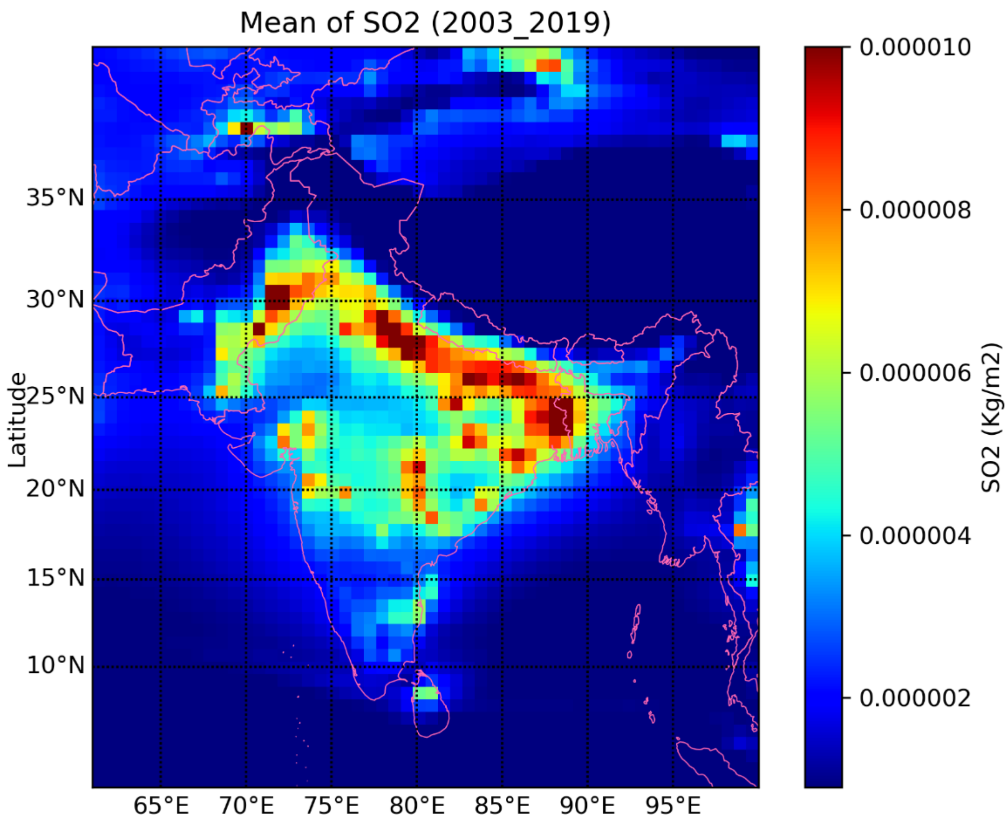

Fig. 5: Integrated sulphur dioxide data (2013-2019)

3. Protection of cultural heritage from disasters

There is need to protect Cultural Heritage including from disasters by incorporating potential opportunities in Disaster Risk reduction plans for

- Improving the quality of life
- Saving lives and reducing those impacted
- Saving Structures and Sites
- Increasing economic value and opportunity
- Increases communities' resilience

Traditional knowledge needs to be used which include

- Local building techniques,
- Materials,

- Methods
- Preventing/mitigating/responding to/recovering from disasters.
- Tried/tested over centuries
- Proven effective in addressing various disasters
- Look locally and internationally.

Cultural heritage tourism including religious and adventure tourism has become a significant revenue stream. European Cultural Heritage generates over 340.000 million EUR annually, (10% of EU GDP) and employs ~10m citizens. Investing in DRR of cultural heritage will help in protecting the local economy, livelihoods and safety (EU 2013). A culture of '*prevention over recovery*' having numerous benefits, including saving lives and protecting our cultural heritage should be our goal.

4. Acknowledgements

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References

1. Aulinas. M., Garcia-Valles, M., Gimeno, D., Fernandez-Turiel, JL., Ruggieri. F., Pugès, M., (2009), Weathering patinas on the medieval (S. XIV) stained glass windows of the Pedralbes Monastery (Barcelona, Spain), Environ Sci Pollut Res., doi:10.1007/s11356- 008-0078.
2. Bityukova, L., (2006), Air Pollution Effect on the Decay of Carbonate Building Stones in Old Town of Tallinn, Water Air and Soil Pollution, 172, 239-271.
3. Chapoulie, R., Cazenave, S., Duttine, M., (2008), Laser cleaning of historical limestone buildings in Bordeaux. Appraisal using cathodoluminescence and electron paramagnetic resonance, Environ Sci Pollut Res, 15(3), 237–243.
4. Dorigo, W., Wagner, W., Gruber, A., Scanlon, T., Hahn, S., Kidd, R., Paulik, C., Reimer, C., Van der Schalie, R., Preimesberger, W., and De Jeu, R.(2019), ESA Soil Moisture Climate Change Initiative (Soil_Moisture_cci): Version 04.4 data collection, Centre for Environmental Data Analysis, https://doi.org/10.5285/dce27a397eaf47e797050c220972ca0e.
5. EU, 2013, EU Research - Cultural Heritage.
6. Gruber, A, Tracy, S.,Robin, V. d. S., Wolfgan, W. and Wouter, D., (2019). Evolution of the ESA CCI Soil Moisture climate data records and their underlying merging methodology, Earth Syst. Sci. Data, 11, 717–739, https://doi.org/10.5194/essd-11-717-2019
7. HT, 2013, Bad air gnawing at our monuments, https://www.hindustantimes.com/ delhi/bad-air-gnawing-at-our-monuments/story-ML0Q6nVQmsGpzPL7FCyQqO.html
8. ICIMOS, (2012), Climate Change and its Impact on Preservation Management of Archaeological Sites.
9. IPCC, (2018), Summary for Policymakers. In: *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to* the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. WMO, Geneva, Switzerland.

10. Jiang, Y., Fu, P. & Weng, Q., (2015). Assessing the impacts of urbanization-associated land use/cover change on land surface temperature and surface moisture: A case study in the midwestern United States, Remote Sens., 7, 4880–4898.
11. Krishnan, R. and Sanjay, J., (2017), Climate Change Over India-As Interim Report, http://cccr.tropmet.res.in/home/reports.jsp
12. Massey, S.W., (1999), The effects of ozone and NOx on the deterioration of calcareous stone, Science of Total Environment, 227, 109-121.
13. Nava, S., Becherini, F., Bernardi, A., Bonazza, A., Chiari, M., García-Orellana, I., Lucarelli, F., Ludwig, N., Migliori, A., Sabbioni, C., Udisti, R., Valli, G., Vecchi, R., (2010), An Integrated Approach to Assess Air Pollution Threats to Cultural Heritage in a Semi-confined Environment: The Case Study of M. Dalimi ScienceLib Editions Mersenne : Volume 5 , N ° 130510 ISSN 2111-4706 15 Michelozzo's Courtyard in Florence (Italy), Science of the Total Environment 408 (6), 1403- 1413.
14. Pandey, A.K. and Kumar, V., (2015), Impact of Environmental Pollution on Historical Monuments of India: Conservation Problems and Remedial Measures. Journal of Applied Geochemistry, 17 (1), 50-55.
15. Raoult, B, Bergeron, Angel, C. L. A., T Jean-Noël, T., and Dee, D. D., (2017), Climate service develops user-friendly data store, ECMWF, News Letter, No. 151. 22-27.
16. Tiwari S., Dumka, U.C., Kaskaoutis, D.G., Kirpa Ram, Panicker, A.S., Srivastava, M.K., Tiwari, S., Attri, S.D., Soni, V.K. and Pandey, A.K., (2016), Aerosol chemical characterization and role of carbonaceous aerosol on radiative effect over Varanasi in central Indo-Gangetic Plain, Atmospheric Environment, 125 (B), 437-449.
17. UNCEE, (2015), https://www.unece.org/info/media/news/environment/2015/air-pollution-puts-cultural-heritage-at-risk/air-pollution-puts-cultural-heritage-at-risk.html
18. UNESCO, (2008), 'Climate Change and World Heritage. Report on Predicting and Managing the Impacts of Climate Change on World Heritage and Strategy to Assist States Parties to Implement Appropriate Management Responses' World Heritage Reports 22.
19. Urosevic, M., Yebra-Rodríguez, A., Sebastián-Pardo, E., Cardell, C., (2012), "Black Soiling of an Architectural Limestone During Two-year Term Exposure to Urban Air in the City of Granada (S Spain)." Science of the Total Environment, 414, 564-575.

Evaluation of Air Pollution Tolerance Index and Anticipated Performance Index of trees in and around the stone quarrying region of Mahendragarh, Haryana.

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Abstract

Mining activity is responsible for the release of various pollutants to environment and especially to the atmosphere. Trees can play an important role to control pollutants of air and improve the quality of air. The present study aimed at determination of the Air Pollution Tolerance Index (APTI) of different trees in the mining area of Mahendragarh, Haryana. Representative leaf samples were collected from thirteen plant species growing in and around Bakhrija stone quarry. The plant species considered for the sampling are *Azadirachta indica* (Neem), *Syzygium cumini* (Jamun), *Millettia pinnata (Karanja)*, *Dalberga sissoo* (Sheesham), *Albizia lebeck* (Siras), *Ficus benghalensis* (Bargad) *and Melia azedarach* (Bakain). The samples were subjected to extraction following which analysis was carried out to determine the physical and biochemical parameter *viz.* the pH, relative water content (RWC), Total Chlorophyll (*TCh*), and Ascorbic acid content (AAC). Using the obtained values, the APTI was calculated for classifying the samples into four categories namely tolerant, moderately tolerant, intermediate, and sensitive species with respect to their ability to withstand the effect of pollutants. Based on APTI, *Millettia pinnata* was the only tolerant species; *Melia azedarach, Syzygium cumini*, *Azadirechta indica* were observed to be moderately to intermediate tolerant; and *Dalbergia sisoo* and *Ficus benghalensis* belonged to the intermediate tolerant category. Based on API, *Ficus benghalensis*, *Syzygium cumini* and *Dalbergia sisoo* were categorized as good; *Melia azedarach*, and, *Azadirechta indica* as moderate; and *Albizia lebeck* as very poor/unsuitable. Effective measures such as plantation of tolerant native species with good API are recommended to develop effective green belts around the stone quarries.

Keywords: Air Pollution Tolerance Index (APTI), Anticipated Performance Index (API), mining, Mahendragarh, Green belt**.**

Introduction

Air pollution poses a major threat to the various compartments of the environment. The rapid ascent in the air pollutants has been attributed to population boom, urban development and Industrial revolution (Vailshery *et al.,* 2013). Industries and vehicles are major contributors to air pollution and no chemical or physical technique has been seen to improve the air quality. Earlier, the purpose of planting trees was purely aesthetic however this perception was quickly reviewed to achieve the dual possibilities – bioaesthetics and abatement of pollution be it air or noise (Pathak *et al.*,2011). Plants being an integral part of the environment, play different roles depending upon their susceptibility (Shannigrahi and Agrawal, 1996) *vis-à-vis* the pollutants released in the air. The effectiveness of green belt to barricade and hold back the aerial pollutants rely on various factors such as size, shape, texture, moisture level, nature of the pollutant (gas or particulate) and the part of the plant involved in their activity. (Ingold, 1971). Plants can curb air pollution in two ways: directly through the leaves or indirectly by increasing the acidity of the soil (Kumar 2013). The atmospheric particulate matter undergoes dry deposition, the leaves provide for a large surface area which facilitates the deposition, concentration and the incorporation of the pollutants within itself thereby bringing down the level of pollutants in the atmosphere (Rawat and Banerjee, 1996; Escobedo *et al.,* 2008). For the gaseous pollutants, gas transfers from the atmosphere before ending up into the stomatal pores stimulating intracellular reactions resulting in damage to the plant tissue (Currie and Bass (2008); Jim and Chen (2009). The plants which are abundantly found in the study area are observed to be prime receptors of the air pollutants (Liu *et al.,* 2008). Often the changes at the stomatal level, disruption of membranes, modifications in catalytic reactions, biochemical interferences and death of plants are reported. It is vital to identify and subsequently categorize the plant species with respect to their capacity to resist air pollution.

The sensitive plants act as bioindicators of air pollution contrary to the tolerant species which serves as sink for the abatement of pollution. APTI and API coupled together can be used as a tool for suitability of trees since these are calculated from biological and socio-economic parameters. A suitable biological method of planting trees to ameliorate the air quality around urban and industrial areas has been widely studied and suggested (Prajapathi and Tripathi 2008; Rai 2013). There have been a number of studies to determine the effectiveness of trees /green belts in controlling air pollution around the industrial settings, highways and urban areas. The emissions from marble processing plants have a significant influence on the foliage depending upon their leaf structure and sensitivity level (Noor *et al.,* 2017). Another study undertaken by Shannigrahi *et al.,* (2004) highlighted the economic and aesthetic importance of trees for curtaining pollutants in industrial/urban areas. From the perspective of air pollution abatement, the keystone plants evaluated as best for upkeep and expansion of a better environment find their place in the green belt in and around an urban area (Prajapathi and Tripathi, 2008). Moreover, plants have been seen to possess properties helpful to evaluate the stress of vehicular pollution and hence with such features, frondescence are essential for the purpose of improving the air quality along roadsides (Jyothi and Daya 2010). Besides, an evaluation of the APTI of plants in sensitive area namely an educational institution by Deepika *et al.,* (2016), established that species with broader leaves and thick canopy had higher tolerance compared to species with narrow and cylindrical canopies, which can consequently be adopted. The present study was carried out at Bakhrija stone quarry in Mahendragarh, Haryana with the aim to determine the APTI and the API of the plants species growing in and around the study area.

Materials and methods

Study Area

Cocooned by the districts of Rajasthan in the South and East and Bhiwani and Rewari districts of Haryana in the North and West direction, lies Mahendragarh, one of the third highly populated district of Haryana at a north latitude 27°47’ to 28°26’ and east longitude 75°56’ to 76°51’, spread across an area of 1899 square Kilometers, the district has seven major stone quarries. Renowned for mining of minerals of utmost importance, Bakhrija stone mine is located near the village Bakhrija, Tehsil Narnaul, between 27°55′1″ to 27°54′6″ North latitude and 76°03′28.34″ to 76°03′27.56″ East longitude. The annual rate of production of stone and associated minerals is 77.56 MT. Extraction of carbonate minerals, mica, limestone and garnet are few of the materials extracted from the study area. The stone along with associated minor minerals serves as masonry stone, while the mineral rejects of (~ 1 to 2 %) are used to make haul roads. With the objective to assess the role of plants in arresting air pollutants, the present study was undertaken to investigate the suitability of trees growing in the mining area.

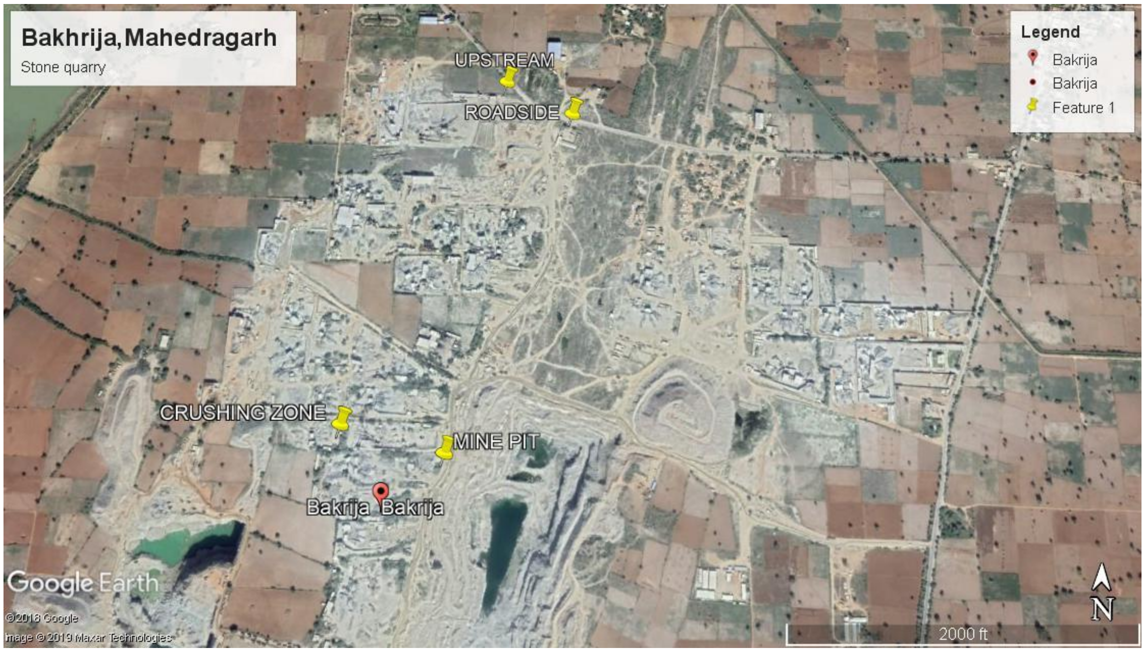

Fig. 1. Location of sampling sites (Upstream, Crushing zone, Mining pit and Roadside) in Bakhrija Stone Quarry (Source: Google Earth).

Collection of samples

Leaf samples were collected from four identified locations namely the crushing zone (C), the mine/pit (M), on the upstream side of the mine (U) and along the roadside areas (R) during the month of June 2019. The plants species sampled belonged to *Azadirachta indica* (Neem), *Syzygium cumini* (Jamun), *Millettia pinnata (Karanja)*, *Dalberga sissoo* (Sheesham), *Albizia lebeck* (Siras), *Ficus benghalensis* (Bargad) *and Melia azedarach* (Bakain). Representative samples of mature leaves were collected and stored in clear zip lock bags at 4°C during the transfer to the laboratory.

Analysis of samples

The leaf samples were subjected to physical and biochemical analysis for determining the pH of cell sap, Relative Water Content (RWC), Chlorophyll concentration (TCh) and Ascorbic Acid (AA) concentration as per the standard methods. The pH of the leaf extract was determined by the method reported by Agbiare and Esiefsrienrhe (2009). Fresh mature leaves were plucked, 0.5 grams weighed leaves were ground and homogenized in 10 ml of deionized water. The extract was centrifuged at 5000 rpm for 10 minutes. The supernatant obtained was used to measure the pH with digital pH meter (HANNA Make HI96107 Model).For RWC, the method as suggested by Singh (1977) was used. The fresh weight (FW) of the samples was noted; and leaf samples were then immersed into water overnight before being blotted down dry and noting down the turgid weight (TW). The samples were then dried in a hot air oven overnight at 70°C and the dry weight (DW) of the same were noted to calculate the RWC.

$$\textit{Relative Water Content (RWC)} = [(FW-DW) / (TW-DW)] * 100$$

The Total Chlorophyll content (*TCh*) was carried out as per the method described by Arnon (1949). Five hundred milligrams of representative samples were blended followed by extraction with 10 ml of 80 percent acetone. The samples were then centrifuged at 5000 rpm for 10 minutes. The optical density of the supernatant was determined with the help of Visible Spectrophotometer at 645 and 663 nm for chlorophyll a and b respectively. The concentration of TCh was calculated as follows:

$$TCh = 20.2\ (\text{O.D}_{645}) + 8.02\ (\text{O.D}_{663})$$

$$\textit{Chlorophyll 'a'}\ (\text{mg/g}) = \frac{\{12.3 * \text{O.D } 663 - 0.86 * \text{O.D } 645\}}{1000 * W} * \text{V}$$

$$\textit{Chlorophyll 'b'}\ (\text{mg/g}) = \frac{\{19.3 * \text{O.D } 645 - 3.6 * \text{O.D } 663\}}{1000 * W} * \text{V}$$

Where, O.D 645 = optical density at 645 nm; O.D 663 = Optical density at 663 nm ;V = Final volume of leaf extract ;W = Dry weight of leaf .

Ascorbic Acid Content (mg/g) was determined using the method reported by Ballentine (1941). For Ascorbic Acid analysis, 2.5 g of fresh leaves were weighed and ground in a mortar and pestle. To the mixture, 30 ml of 0.03 M H_2SO_4, 20 ml distilled water and 0.5 g Oxalic acid was added. The mixture was stirred for about 20 minutes in shaker and immediately centrifuged at 5000 rpm for 10 minutes to obtain the leaf extract. Titration of the supernatant was carried out against 0.001 N Iodine solution using 5 % starch as indicator.

$$\text{AAC (mg/l)} = \frac{N * V * EW}{Volume\ of\ extract}$$

$$\text{AAC (mg/l)} = \frac{\left\{\text{AAC}\left(\frac{\text{mg}}{\text{l}}\right) * 1000\right\}}{1000}$$

Where, N = Normality of titrant; V = Volume of sample (ml); Volume of extract in ml; E W is equivalent weight of Ascorbic Acid.

Calculation of APTI and API

APTI is evaluated as proposed by Singh & Rao (1983) to assess the tolerance of the plants against pollution. The mathematical expression is as follows:

$$APTI = \frac{[A(T + P) + R]}{10}$$

The ascorbic acid content in mg g^{-1} of fresh weight; T is the Total Chlorophyll Content in mg g^{-1} of fresh weight; P is the pH of the leaf extract and R is the Relative Water Content (RWC) in percentage.

The classification of plants based on APTI is done using the criteria as given below.

Category	Criterion for Assessment
Tolerant	APTI > Mean APTI + SD
Moderately Tolerant	Mean API < APTI < Mean APTI + SD
Intermediate	Mean APTI – SD < APTI < Mean APTI
Sensitive	APTI < Mean APTI – SD

Anticipated Performance Index (API)

The APTI values are limited to biochemical parameters whereas the API is a more useful tool when it comes to air pollution reduction and other ecological and economic services as well offered by the plant species since it is based on relevant biological and socio – economic characters (Ogunkunle et al. 2015) such as the plant habit, canopy structure, type of plant, laminar structure and economic values.

Table 1. Gradation of plant species based on air pollution tolerance index (APTI) twinned with biological parameters and socioeconomic importance.

Grading character	Pattern of assessment	Grade allotted
a) Tolerance (APTI)		
	0 – 9.1	+
	9.1 – 18.0	++
	18.1 – 27.0	+++
	27.1 – 36.0	++++
	36.1 – 45.0	+++++
b) Biological and Socio-Economic		
i. Plant Habit	Small	-
	Medium	+
	Large	++
ii. Canopy structure	Sparse/Irregular/Globular	-
	Spreading crown /open/semi dense	+
	Spreading dense	++
iii. Type of plant	Deciduous	+
	Evergreen	++
iv. Laminar structure	Small	-
Size	Medium	+
	Large	-
Texture	smooth	+
	Curvaceous	++
Hardiness	Delineate	-
	Hardy	+
v. Economic Value	Less than three uses	-
	Three or more uses	+
	Five or more uses	++

Maximum grades that can be scored by a plant = 16

Based on the criteria, the plants are assigned different grades (+ or -), therefore helping in categorizing the plants according to their performance. Thus, with the help of obtained assessment and category, suitable plants can be recommended for developing a more reliable green belt to attenuate the pollution level (Prajapati and Tripathi 2008).

Table 2. Classification of tree species contrary to API

Grade	Score (%)	Assessment category
0	Up to 30	Not recommended
1	31 – 40	Very poor
2	41 – 50	Poor
3	51 – 60	Moderate
4	61 – 70	Good
5	71 – 80	Very good
6	81 – 90	Excellent
7	91 – 100	Best

Results and discussion

The pH, RWC, chlorophyll and ascorbic acid concentrations of the trees obtained after the chemical analysis is given in the Table 3. The description of the individual parameters is as given below.

pH

The pH of the leaves was found to be slightly acidic in range with a mean value of 6.51. The maximum pH of 6.9 was noted for *Millettia pinnata* near the crusher while a minimum pH of 5.96 was recorded for *Syzygium cumini* equally found near the crusher. Studies have proved that a low pH of cell sap indicates sensitivity to air pollutants. Contrarily, high pH of the leaf extract is believed to help in reducing the sensitivity when exposed to acidic pollutants (Aggarwal 1986; Agbiare and Esiefarienhe 2009; Prajapati 2008).

Table 3. Air Pollution Tolerance Index (APTI) of the tress growing in Bakhrija stone quarry, Mahendragarh, Haryana.

SN	Plant species	Location	pH	Relative water content (%)	Total Chlorophyll (mg g^{-1} fresh wt)	Ascorbic Acid (mg g^{-1} dry wt)	APTI	Inference
1.	*Syzygium cumini*	C	6.0	75	2.77	2.53	10	IT
2.	*Azadirachta indica*	C	6.7	86	0.70	3.28	14	IT
3.	*Millettia pinnata*	C	6.9	62	1.36	9.30	14	IT
4.	*Melia azedarach*	C	6.5	68	11.13	7.13	19	MT
5.	*A. lebbeck*	C	6.7	58	10.36	5.35	15	IT
6.	*Azadirachta indica*	M	6.0	78	9.49	3.49	13	IT
7.	*Syzygium cumini*	M	6.8	84	12.34	5.34	19	MT

8.	*Millettia pinnata*	M	6.4	53	21.70	13.7	44	T
9.	*Millettia pinnata*	U	6.9	74	11.90	2.90	13	IT
10.	*Azadirachta indica*	U	6.5	67	15.66	5.66	19	MT
11.	*Azadirachta indica*	R	5.9	70	18.91	7.91	27	MT
12.	*Dalbergia sissoo*	R	6.7	73	15.18	3.18	14	IT
13.	*Ficus benghalensis*	R	6.7	82	15.66	2.66	14	IT

Where T- Tolerant; MT- Moderately Tolerant; IT- Intermediate Tolerant;

Relative Water Content (%)

The RWC of the plants was found to be lying in the range of 52.8 % (*Millettia pinnata)* to 85.8 % (*Azadirachta indica). Azadirachta indica,* one of the most prominent plant in the study area had wide range of RWC with minimum of 66.9 % and the highest RWC of 85.8 %. The minimum was recorded at the upstream of the mine while the maximum RWC was recorded near the crusher. Water is a crucial element for maintaining a normal and healthy state in plants. In pollutants infested state, usually the plant faces stress and under such conditions, the rate of transpiration is escalated and it usually triggers drought like conditions. A study carried by Swami et al (2004) linked reduced RWC with pollutants' manifestation. High RWC is often a measure of the permeability of the cells; usually a permeable cell tends to lose water and nutrients resulting in premature ageing of leaves (Agrawal and Tiwari 1997). In the present study, relatively lower water content in some regions/species may be attributed to low permeability of leaves owing to deposition of dust which blocks the stomatal pores. Higher RWC is known to be beneficial during drought; plants exhibit boosted up resistance (Dedio, 1975). Hence, plants with high RWC tend to depict tolerance towards the polluting substances in the ecosystem (Jyothi and Daya 2010).

Chlorophyll content

The mean total chlorophyll (*TCh)* was estimated to be 1.12 mg g^{-1} FW. The minimum of 0.70 mg g^{-1} FW was recorded for *Azadirachta indica* at two locations – near the crusher and along the roadside. The maximum of 2.77 mg g^{-1} FW was recorded for *Syzygium cumini* located in vicinity of the crusher. The total chlorophyll content acts as an indicator for growth, development and photosynthesis related activities and the chlorophyll content is likely to depict variation depending on species, age of leaf, pollution level and other biotic and abiotic conditions (Katiyar and Dubey 2001). The degeneration of chlorophyll content is a proof of deterioration of the air quality (Ninave *et al.,* 2001). Also, it can be seen that in plants with higher dust deposition, the *TCh* Content is low. The dust particles form a coat therefore blocking the path of sunlight from reaching the plant and as a result, the pigmentation process is impeded. Injuries at the frondescence level when subjected to alkaline dust deposition, yellowing of leaves, premature fall of leaves, stunted growth are few of the effects reported.

Ascorbic Acid Content

The mean ascorbic acid content was found to be 5.57 mg g^{-1}, ranging from a minimum of 2.53 mg g^{-1} for *Syzygium cumini* near the crusher to a maximum of 13.70 mg g^{-1} for *Millettia pinnata* found near the mine. Ascorbic acid, an antioxidant plays a major role in the healthy development of the plants. It is also known to have an effect on the defense mechanisms of the plants. High level of Ascorbic Acid is associated with high level of pollution while low level of it can be correlated with the weakening of the defense of the plants. High level of AA is beneficial for safeguarding thylakoid membrane from damage arising from oxidation reactions in limited water conditions (Tambussi *et al.,* 2000). Ascorbic acid increases the resistance of plants against pollutants alongside scavenging reactive oxidizing species (ROS) (Hippeli and Elstner 1996) formation of which takes place in mineral-deficiency like situation.The activity of Ascorbic acid is pH dependent. The Ascorbic acid content of plants is often more at higher pH and lesser at low pH. Therefore, leaf extract with higher pH are more tolerant to air pollution (Singh and Verma 2007).

As per APTI, *Millettia pinnata* was having the highest APTI value and was found to be rooted in the vicinity of the mine. The equation proposed by the Singh and Rao (1983) was applied and it was ultimately concluded that *M. pinnata* belong the tolerant category. Also, *M. azedarach* and *S. cumini* each having APTI values of 19 and located at the crusher and the mine respectively belonged to the moderately tolerant category. Likewise, *A. indica* having an APTI value of 19 at the upstream side and a value of 27 along the roadside **(Figure 2)** were also found to belong to the moderately tolerant category. Rest of the species, distributed sparsely in the four locations namely near the crusher, mine, upstream region and the roadside belonged to the intermediate category.

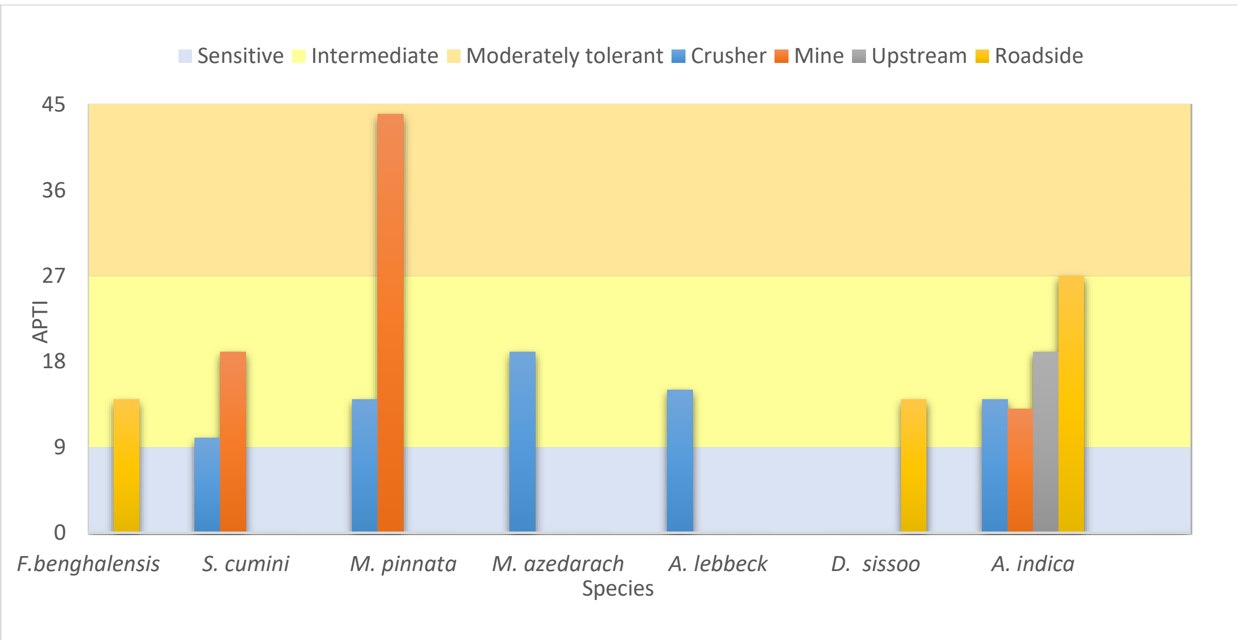

Fig. 2. Categorization of tree species against APTI for different locations.

The grading pattern (**Table 2**) of the plant species were carried out according to the biological and other socio-economic parameters tabulated (**Table 1**). Additionally, **Table 4** summarizes the different species, the anticipated performance and their assessment with respect to air pollution abatement. The best performers among the representative samples collected were found to be *Syzygium cumini*, *Millettia pinnata*, *Dalbergia sissoo* and *Ficus benghalensis* with an Anticipated Performance grade of 4 (very good category) while *Azadirachta indica* and *Melia azedarach* displayed slightly less tolerance with an API grade of 3 (Moderate category). A very poor performance was recorded for *A. lebbeck* therefore not recommended for the green belt development.

Table 4. Evaluation of API of plant species based on their APTI values and some other biological and socio-economic characters

Plant species	APTI	Tree Habit	Canopy structure	Type of tree	Size	Texture	Economic Importance	Hardness	Total Plus	% score	API Grade	Assessment
S. cumini	++	++	++	+	+	-	+	+	10	62.50	4	Good
A. indica	++	++	+	+	-	-	++	+	9	56.25	3	Moderate
M. pinnata	++	+	++	+	++	-	++	+	11	68.75	4	Good
M. azedarach	+++	+	+	+	-	-	++	+	9	56.25	3	Moderate
A. lebbeck	++	+	+	-	+	-	+	-	6	37.50	1	Very poor
D. sissoo	++	++	++	+	+	+	+	+	11	68.75	4	Good
F. benghalensis	++	++	+	+	++	+	+	+	11	68.75	4	Good

Conclusion

The deterioration of the air quality is a major concern due to its likelihood of affecting the flora and fauna as well as extending the damages to the nearby regions. The results of this study divulge that the dust emission from the stone quarry certainly influence the plants found in the area. It can be concluded that tolerance of the plants is dependent on factors such as the location and level of exposure which in turn havesome effects on the biological and physiological parameters hence varying sensitivity level could be seen. The plants are believed to eliminate the pollutants in the air by absorbing or aiding in the deposition over the surface. The APTI and API of the plant species suggest that the vegetation comprising of *Syzygium cumini, Millettia pinnata, Dalbergia sissoo and Ficus benghalensis* are highly recommended while the plantation of *Azadirachta indica* and *Melia azedarach* could further be enhanced. Contrarily, *A. lebbeck* could serve as bioindicator of pollution as a sensitive species.

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References

1. Agarwal, S.K (1986). A new distributional function of foliar phenol concentration in the evaluation of plants for their air pollution tolerance index. Acta Ecologica, 8(2): 29-36.
2. Agbaire, P.O. and Esiefarienrhe, E. (2009). Air pollution tolerance indices (APTI) of some plants around Otorogun gas plant in Delta State, Nigeria. J. Appl. Sci. Environ. Manag. 13(1): 11-14.
3. Agrawal, S., and Tiwari, S. (1997). Susceptibility level of few plants on basis of air pollution tolerance index. Indian Forester, 123: 319–322.
4. Arnon, D.I. (1949). Copper enzymes in isolated chloroplasts polyphenol oxidase in *Beta vulgaris.* Plant Physiology, 2: 1-15.
5. Babu, G.B., Parveen, S.N., Kumar, K.N., and Reddy, M.S. (2013). Evaluation of Air Pollution Tolerance Indices of Plant Species Growing in the Vicinity of Cement Industry and Yogi Vemana University Campus. Indian Journal of Advances in Chemical Science, 2: 16–20.
6. Ballentine, R. (1941). Determination of ascorbic acid in citrus fruit juices. Analytical Chemistry (Industrial & Engineering Chemistry Analytical Edition), 13(2): 89.
7. Currie, B.A., Bass, B. (2008). Estimates of air pollution mitigation with green plants and green roofs using the UFORE model. Urban Ecosystem, 11: 409–422
8. Dedio, W. (1975). Water relations in wheat leaves as screening tests for drought resistance. Canadian Journal of Plant Science, 55: 369–378.
9. Deepika, Gour, P., Haritash, A.K. (2016). Air pollution tolerance of trees in an educational institute in Delhi. International Journal of Environmental Science, 6: 979–986
10. Escobedo, F.J., Wagner, J.E. and Nowak, D.J. (2008). Analyzing the cost effectiveness of Santiago, Chile's policy of using urban forest to improve air quality. Journal of Environmental Management, 86: 148 - 157.
11. Hippeli, S., Elstner, E.F. (1996). Mechanisms of oxygen activation during plant stress: biochemical effects of air pollutants. Journal of Plant Physiology, 148: 249–57.
12. Ingold, C.T. (1971). Fungal Spores: Their Liberation and Dispersal. Clarendon Press: Oxford, UK
13. Jim, C., Chen, W.Y. (2008). Assessing the ecosystem service of air pollutant removal by urban trees in Guangzhou (China). Journal of Environmental Management, 88: 665-676.
14. Jyothi, S.J., and Jaya, D. (2010). Evaluation of air pollution tolerance index of selected plant species along roadsides in Thiruvananthapuram, Kerala. Journal of Environmental Biology, 31: 379–386
15. Katiyar, V. and Dubey, P.S. (2001). Sulphur dioxide sensitivity on two stage of leaf development in a few tropical tree species. Indian Journal of Environmental Toxicology, 11: 78-81.
16. Kumar, M. and Nandini, N. (2013). Identification and Evaluation of Air Pollution Tolerance Index of Selected Avenue Tree Species of Urban Bangalore, India. International Journal of Emerging Technology and Computer Application Science, 13: 388-390.
17. Liu, Y.J. and Ding, H. (2008). Variation in air pollution tolerance index of plants near a steel factory: Implications for landscape-plant species selection for industrial areas. WSEAS Transactions of Environmental Development, 4: 24-32.
18. Ninave, S.Y., Chaudhri, P.R., Gajghate D.G., and Tarar, J.L. (2001). Foliar biochemical features of plants as indicators of air pollution. Bulletin of Environmental Contamination and Toxicology, 67: 133-140.
19. Noor, M.J., Sultana, S., Fatima, S., Ahmad, M., Zafar, M., Sarfraz, M., and Ashraf, M.A. (2017). Retraction note to: estimation of anticipated performance index and air pollution tolerance index

and of vegetation around the marble industrial areas of Potwar region: bioindicators of plant pollution response. Environmental Geochemistry and Health, 39(3):705-705

20. Odilara, C.A., Egwaikhide, P.A, Esekhegbe, A, Emua, S.A. (2006): Air pollution tolerance indices (APTI) of some plant species around llupeju industrial area, Lagos. Journal of Engineering, Science and Application (4): 97-101.
21. Ogunkunle, C.O., Suleiman, L.B., Oyedeji, S., Awotoye, O.O., Fatoba, P.O. (2015). Assessing the air pollution tolerance index and anticipated performance index of some tree species for biomonitoring environmental health. Agroforestry Systems, 89(3): 447-454.
22. Pathak, V., Tripathi, B.D., and Mishra, V.K. (2011). Evaluation of anticipated performance index of some tree species for green belt development to mitigate traffic generated noise. Urban Forestry and Urban Greening, 10: 61-66.
23. Prajapati, S.K., and Tripathi, B.D. (2008). Anticipated performance Index of some tree species considered for green belt development in and around an urban area: a case study of Varanasi city, Indian Journal of Environmental Management, 88:1343-1349.
24. Rai, P.K. (2013). Environmental magnetic studies of particulates with special reference to biomagnetic monitoring using roadside plant leaves. Atmospheric Environment, 72:113-129.
25. Rao, P.S., Gavane, A.G., Ankam, S.S., Ansari, M.F., Pandit, V.I., and Nema, P. (2004). Performance evaluation of a green belt in a petroleum refinery: a case study. Ecological Engineering, 23: 77-84
26. Rawat, J.S., Banerjee, S.P. (1996). Urban forestry for improvement of environment. Journal of Energy Environment Monitoring, 12 (2): 109–116.
27. Shannigrahi, A.S., and Agrawal, K.M. (1996). An overview on optimal greenbelt development for industrial project. Indian Journal of Environmental Protection, 17 (4): 253–261.
28. Shannigrahi, A.S., Fukushima, T., and Sharma, R.C. (2004). Anticipated air pollution tolerance of some plant species considered for green belt development in and around an industrial/urban area in India: an overview, International Journal of Environmental Studies, 61 (2): 125–137.
29. Singh A. (1977). Practical Plant Physiology, Kalyani Publishers, New Delhi.
30. Singh, S.K., and Rao, D.N. (1983). Evaluation of plants for their tolerance to air pollution. In: Proceedings Symposium on Air Pollution Control, vol.1. Indian Association for Air Pollution Control, New Delhi, India: 218–224.
31. Singh, S.N. and Verma A. (2007). Phytoremediation of Air Pollutants: A Review. In: Environmental Bioremediation Technology, Singh, S.N. and R.D. Tripathi (Eds.). Springer, Berlin Heidelberg: 293-314
32. Swami, A., Bhatt, D., and Joshi, P (2004). Effects of automobile pollution on sal (*Shorea robusta*) and Rohini (*Mallotus phillipinensis*) at Asarori, Dehradun. Himalayan Journal of Environmental Zoology, 18: 57–61.
33. Tambussi, E.A., Bartoli, C.G., Beltrano, J., Guiamet, J.J., and Araus J.L. (2000). Oxidative damage to thylakoid proteins in water-stressed leaves of wheat (*Triticum aestivum*), Physiologia Plantarum, 108: 398-404.
34. Vailshery, L.S., Jaganmohan, M., and Nagendra H. (2013). Effect of street trees on microclimate and air pollution in a tropical city. Urban Forestry & Urban Greening, 12: 408-415

Assessment of Best Available Technologies (BAT) to mitigate Mercury Pollution in Ambient Air- Approach to implement the Minamata Convention on Mercury

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Abstract

Atmospheric pollution has been a global concern in terms of its impacts on the health of humans, animals and the environment. Traces of mercury present in the ambient air has led the world to talk about mercury pollution in the environment that consequently resulted in the introduction of the Minamata Convention (MC) on Mercury, an international treaty on mercury with 128 signatories currently. It was signed on 10th October 2013 in Japan that became effective from 16th August 2017. The Minamata Convention is a global treaty that aims to protect human health and the environment from anthropogenic emissions of mercury and its compounds. The MC recognizes mercury as a pollutant of global concern considering mercury to be capable of long-range transport, to be persistent, and to bioaccumulate, which ultimately results in elevated human exposure levels associated with a range of negative health effects. The main concern of the convention is the health impacts of mercury on the human beings and to regulate its emissions by noting its sources. In addition to this, chemistry of mercury and its compounds, long-range transport, prevention and control technologies relating to mercury are the other concerns of the convention. Initially, Mercury, also known as Quicksilver, had been noted for developing public health disasters in Minamata Bay, Japan. Broadly, it exists in two chemical forms, namely, inorganic mercury and organic mercury. The most common form of mercury contributing to the atmosphere due to anthropogenic activities is gaseous elemental mercury. The target organ for inhaled mercury vapor is primarily the brain. Toxicity varies with dosage, large acute exposures to elemental mercury vapor induce severe pneumonitis, that in extreme cases are often fatal. The paper discusses the best available techniques to regulate the mercury concentration in ambient air and mentions the concentration of mercury removal by various control techniques.

Keywords: Minamata Convention on mercury, mercury pollution, best available techniques, ambient air.

Introduction

Mercury, being a heavy metal of notable toxicity, noted for developing public health disasters in Minamata Bay, Japan [1]. It exists in numerous chemical forms such as inorganic mercury, that includes metallic mercury and mercury vapor (Hg^0) and mercurous (Hg_2^{++}) or mercuric (Hg^{++}) salts; and organic mercury, which includes compounds in which mercury is bonded to a structure containing carbon atoms (methyl, ethyl, phenyl, or similar groups) [2]. Inhaled elemental mercury vapor, for example, is easily absorbed through mucus membranes and the lungs and rapidly oxidized to other forms (but not so quickly as to prevent considerable deposition of elemental mercury within the brain). Methyl mercury easily gets absorbed through the gut and gets deposited in many tissues, but never crosses the blood-brain barrier as efficiently as elemental mercury; but, on getting into the brain it's more and more demethylated to elemental mercury [3]. The target organ for inhaled mercury vapor is primarily the brain. Mercurous and mercuric salts principally harm the gut lining and kidney, while methyl mercury is widely distributed throughout the body. Toxicity varies with dosage: large acute exposures to elemental mercury vapor induce severe pneumonitis, that in extreme cases are often fatal [3]. This paper is intended to review revealed knowledge on best available techniques to mitigate mercury pollution in ambient air since it has been one of the most concerned matter and one must focus on controlling and reducing emissions of mercury released from various sources [4]. As per UNEP, 2013, the most common form of mercury contributing to atmosphere due to anthropogenic activities is gaseous elemental mercury. The remaining emissions are in the form of gaseous oxidized mercury. Oxidised forms of mercury have a shorter atmospheric lifetime than gaseous elemental mercury and are deposited to land or water bodies more rapidly after their release (UNEP, Global Mercury Assessment, 2003). Elemental mercury in the ambient air can undergo transformation into oxidized mercury that is more readily deposited but, once deposited, can be transformed under certain circumstances into organic compounds by bacteria in the environment [4]. Many countries are already concerned about the toxicity of mercury in the environment and are aware of the risks on health and ecology due to which they have accepted it as a priority to control the pollutant [5]. An emission inventory of mercury indicates that mercury in Asian countries accounts for more than 50% of global anthropogenic emissions of mercury [25]. They have stated that the mercury and carbon monoxide ratio give the satisfactory indication of the Asian industrial flow [6].

Implementing measures to manage mercury emissions can, however, typically involve some value [4]. Detailing of control technologies for Mercury include pre-treatment, recovery and treatment technologies for the reduction of Mercury emissions from the number of well-known sources; whether natural or anthropogenic [7]. In case of atmosphere, the total contribution of mercury annually is estimated to be around 5500 to 8900 ton/yr. out of which 3,780 to 6,350 ton/yr. is said to be contributed by natural sources such as from oceans, forest fires, volcanoes etc. [8]. The major anthropogenic generators of mercury include dental use and amalgam, paint and pesticides, mercury mining and production, Artisanal and small-scale gold and silver mining, chlor-alkali plants etc. of which different treatment facilities already exist like incinerators, landfill treatment and wastewater treatment processes [8]. When mercury is released in the atmosphere by any means, planktons and other small fishes becomes the target and it gets accumulated in them as methyl mercury. Ultimately, this is termed as bio-accumulation and bio-magnification as its concentration gets magnified when larger fishes eat smaller ones. Similarly, the concentration goes up the food chain [9].

Legal framework for mercury pollution control

Regulation and working of the actions depend on the regularised framework that lead to its success. Therefore, before going into the mercury pollution techniques it is important to see how it is managed internationally as well as at national level.

International level

In United States, there is a systematic framework for handling the issues of mercury emitting from different sources. Federal and state statutes are responsible for the easy and smooth regulation of mercury such as United States Environmental Protection Agency (USEPA) is responsible for controlling of mercury emissions from pesticides, US Food and Drug Administration (FDA) regulates presence of mercury in cosmetics, food and dental products. The Occupational Safety and Health Administration (OSHA) regulates exposure of atmospheric mercury at workplaces [10]. Apart from this, Clean Air Act (CAA), Clean Water Act (CWA) and Resource Conservation and Recovery Act (RCRA) are some of the statutes accountable for developing the regulations in order to control the emissions of mercury. As per Environment Protection

Agency (EPA), mercury-specific laws namely, Mercury-containing Rechargeable Battery Management Act of 1996 and Mercury export ban Act of 2008 that basically intends to reduce the availability, usage as well as disposal of mercury based-items. International Agency for Research on Cancer (IARC) addresses the health effects of mercury on human health in addition to other carcinogenic chemicals. International Programme on Chemical Safety (IPCS) addresses the environmental and health impacts of mercury and suggest the appropriate precautionary measures [10].

National level

According to 42nd Amendment of the Indian constitution, regulation of toxic metals has extensively dealt. Pollution Control Boards (PCB) have actively adopted the various control measures under the concerned topic.

***Table 1*: Environmental Legislations related to Mercury in India**

S. No.	Legislations	Objectives	Remarks
1	The Environment (Protection) Act/ Rules, 1986	Act provides for the protection and improvement of environment by giving Central Government powers to take measures whereas Rules regulate environmental pollution, with power given to Central & State Pollution Control Boards.	Mercury is included in the standards of all the major emitting industries, but there are no regulations or standard for thermal power plants emitting mercury in the air.
2	The Water (Prevention & Control of Pollution) Act, 1974 (amendment 1988)	To provide for the prevention, control and abatement of water pollution, and the establishment of central and state boards to implement that objective.	It specifies areas affected by water pollution in the country and prohibits the use of streams or wells for disposal of polluting matter but doesn't concern with the disposal of sludge.
3	The Water (Prevention & Control of Pollution) Cess Act/ Rules, 1978	Act was primarily intended to levy and collect a cess for the abatement of pollution whereas rule specifies quantity of water to be consumed by industries.	Rule specifies the maximum quantity of water to be used for the production of caustic soda by mercury cell process.
4	The Hazardous and other wastes (Management & Transboundary movement) Rules, 2016	To establish a control mechanism for the management of hazardous wastes.	Mercury is included in the waste category.
5	The Manufacture, Storage and Import of Hazardous Chemical Rules, 1989 (amendment 2000)	Formed to regulate hazardous chemicals in the country	Chemicals are included according to the degree of toxicity
6	The Solid Wastes Management Rules, 2016	Regulates municipal solid waste	Standards set for mercury in groundwater, composts and leachate

7	The Central Insecticides Act, 1968	Regulates the import, manufacture, sale transport, distribution and use of insecticides to prevent risk to people and animals	Prohibits the import of most mercury based agro-chemicals
Source: Central Pollution Control Board. Dec. 2009. *Mercury - environmental implications & toxicity, Parivesh Publication.*			

The Minamata convention on mercury

The Minamata convention on mercury is an international treaty signed on 10th October, 2013 in Japan that became effective from 16th August, 2017 in order to protect the environment and human health from untreatable effects of mercury poisoning. The convention consists of 35 Articles and 5 Annexes. The story lies behind the Minamata disease which was firstly diagnosed in two young girls in the year 1956 [22] in Minamata Bay, Japan. This happened due to the presence of a contaminant, known as, methyl mercury $[CH_3Hg]^+$ in the wastewater discharged from a chemical industry [22]. The disease spread all over in infants, children and adults that shifted the world's focus on mercury poisoning. The agreement focused on reducing the mercury pollution world-wide by addressing the entire life cycle of mercury and controlling its various sources [18]. The Minamata Convention follows and builds on the basis of Rotterdam, Basel and Stockholm conventions. Therefore, altogether it contributes to a comprehensive global system for regulation of hazardous substances. Following are the concerned topics of the convention that have been taken care of in addition to a global assessment of mercury and its compounds:

1. Chemistry of mercury and its compounds;
2. Health effects;
3. Sources;
4. Long-range transport;
5. Prevention and control technologies.

The problem of mercury pollution was recognized due to its significant neurological and adverse health impacts particularly in infants and unborn children. Worldwide transport of mercury led to this decision of taking global action to address the problem of mercury pollution from various identified sources. According to the Article 16, namely, health impacts, countries are encouraged to promote the development and implementation of preventive programs on occupational exposure to the mercury, identifying the population at risk, setting treatment facilities and establish institutional health care monitoring facilities.

Mercury, a hazardous substance has prolonged persistence in the environment. It has the ability to accumulate in the body of living organisms that poses negative impacts on them. The strategy of developing the legal norms to withstand the mercury-free environment has resulted in strengthening the national capabilities for the management of mercury. In 2009, the governing council of the United Nations Environment Programme (UNEP) established an Inter-Governmental Negotiating Committee (INC) to construct a legally-binding tool for efficient and effective management of mercury [19].

National assessment of the situation

India signed the convention on 30th September, 2014 and participated actively in all the sessions of INC. The convention gives the flexibility in adapting the national development plans in order to control the emissions of mercury by setting the reducing levels. Also, the Mercury wastes and contaminated sites are regulated by setting the environmentally sound measures. For example, controlling of newly borne atmospheric emissions of mercury governed by the convention must be done using best available technology (BAT) and best environmental practices (BEP) [20]. National implementation plans and strategies were developed by the parties to meet the objective of the convention including public awareness and education, Research & Development (R&D), information exchange facilitation etc. [20]. Primarily, mercury is used in the manufacture of thermometers, batteries, thermostat switches, lighting equipment and pharmaceuticals. In India, import of mercury was reported to be 228.19 tons in 2015-16 mainly from Japan, Singapore, USA, Indonesia and Mexico.

As per general emission standards in the country, concentration of mercury must not exceed beyond 0.2 mg/Nm^3. On the other hand, standards for concentration of mercury and its compounds in cement plant with co-processing of wastes is 0.05 mg/Nm^3 and for chlor-alkali industry (from hydrogen gas holder stack) is 0.2 mg/m^3. In dental practices, 2 tons per annum of mercury is used in the country. 99% of producers in chlor-alkali industry have been shifted to membrane cell technology (cleaner technology), recommended by Charter on Corporate Responsibility for Environmental Protection (CREP).

Table 2: Mercury emission standards in India

S.No.	Industries	Source of Emissions	Standards
1	Chlor-alkali (Caustic soda)	Mercury (from hydrogen gas holder stack)	0.2 mg/Nm^3
2	Thermal Power Plant (TPP)	from Stacks of Coal-fired power plants	0.03 mg/Nm^3
		Coal-fired industrial boilers	0.2 mg/Nm^3
3	Cement Plant with co-processing of waste	from Stack	0.05 mg/Nm^3
4	Cement clinker production facilities	from Stack	0.2 mg/Nm^3
5	Smelting and roasting processes used in production of non-ferrous metals (only lead, zinc, copper, and industrial gold)	from Stack	0.2 mg/Nm^3
6	Waste incineration	From stack with flue gas	0.05 mg/Nm^3
Source: CPCB Ambient Air Quality Emission Standards			

In India, according to Environment (Protection) Act, 1986, there is prohibition of mercury mining activities and fortunately there is no primary mining of mercury has been reported. Mercury used in case of gold mining located in the fields of Kolar and Hatti in the state of Karnataka through cyanide process was also discontinued. Artisanal and small-scale gold mining is considered as insignificant, because it is commonly not practiced in the country. According to E-waste (Management) Rules, 2016 states the permissible limits of mercury used in fluorescent lamps. Provisions of Drugs and cosmetics Act, 1940 and rules 1945 prohibit the manufacture and import of mercury used in cosmetics. Mercury used in pesticides, biocides and topical antiseptics have been prohibited by Ministry of Agriculture and Farmer's welfare but the use of methoxy ethyl mercuric chloride (MEMC) in fungicides are still in practice for seed treatment in potato and sugarcane only.

Chemistry of atmospheric mercury

Mercury is found freely in nature. It is mainly present as Cinnabar ore (HgS) which is a bright red crystalline solid. Mercury is a lustrous liquid metal that can even sink in water. It is mobile and so it is used in thermometers and blood pressure instruments. It is malleable, ductile and can solidifies at -39 ^{0}C that can be cut with a knife. Mercury is an excellent conductor of electricity.

Three most important species of mercury are as follows:

1. Elemental mercury (Hg): Mercurous (Hg^0), low solubility in water.
2. Divalent inorganic mercury: Mercuric (Hg^{2+}), more soluble in water.
3. Methyl mercury [CH3Hg+ or MeHg]: It is toxic and is strongly bio-accumulated in living organisms.

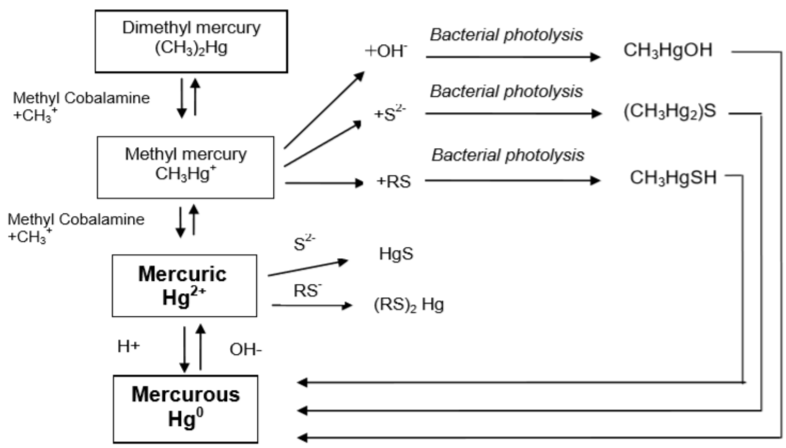


Figure 1: **Environmental chemistry of mercury in environment**

Source: Central Pollution Control Board. Dec. 2009. *Mercury - environmental implications & toxicity, Parivesh.*

Reactive gaseous mercury (RGM) that consists Hg (I) & Hg(II) compounds and particle bound mercury (PHg) are reactive forms of mercury that are deposited in the atmosphere near the emission source and are said to have short lifetime. In Northern Hemisphere, the global concentration of mercury is found to be 1.5 to 1.7 ng/m^3 and in Southern Hemisphere, 1.1 to 1.3 ng/m^3 [21].

Techniques for controlling mercury emission

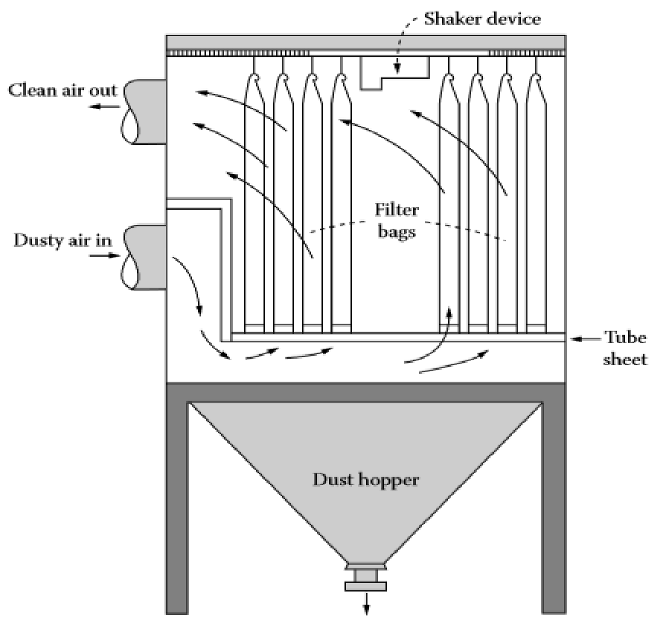
The extent of control of mercury is dependent on its chemical nature as well as on its form that is oxidised or elemental. Oxidised mercury is usually captured in dust-cleaning devices such as bag filters and electrostatic precipitators (ESP) but elemental mercury does not. Therefore, to remove the atmospheric mercury efficiently, it becomes necessary to enhance by oxidising the gaseous mercury [11]. There are numerous technologies for controlling Mercury and following are the few controlling devices/techniques of primary particulates e.g. asbestos and heavy metals:

- Bag filters
- Electrostatic precipitator (ESP)
- Wet scrubbers

- Activated carbon
- Coconut pith

Bag filters

It is one of the effective mechanism or the particulate collector with almost 99% efficiency that consists of fabric filter bags, inlet, outlet, shaker device and a dust hopper. The filter bag is usually made of a material i.e. fabric which gives the support for the filtering mechanism. When air comes in, it passes through these filters and eventually comes out as a clean air through outlet. The particulates get attached on the surface of the filters and are removed via dust hoppers simply. The thin layer of particles or rather a filter cake that settles on the filter surface is known as precoat [12].



It works efficiently when the passed gas is not too hot and wet. Often working can be enhanced by using it with the combination of dry or semi-dry sorbent injection [11]. The instantaneous flow rate through the filter [13] is described by the following equation:

$$V_s = \frac{(P_1 - P_3)}{\mu[(\Delta x/k)_{\text{cake}} + (\Delta x/k)_{\text{f.m.}}]} = \frac{Q}{A_{\text{filter}}}$$

The Δx / k terms are called the cake resistance and the cloth resistance [13].

***Fig 2*. Single compartment baghouse filter.**

Source: Griffin R.D. (2007). *Principles of Air Quality Management.* Second Edition. Boca Raton: Taylor & Francis Group, *pg*. 170.

For the efficient removal of mercury, gaseous form must be oxidised so that it could bind to particles [11]. Although, when the gas steam is cooled to the dew point of the specific material, some metals and toxic air pollutants might form condensable particulate fume. Therefore, its operation must be at temperatures above the dew point so that the metal compound is passed leaving behind the toxic metals [12].Mercury removal has been observed better by fabric filters as compared to that of electrostatic precipitator. Their performance has been recorded by observing the results before and after the passing of the flue gas. The location for taking the samples was at five coal-fired power plants [15].

Electrostatic Precipitator (ESP)

Electrostatic precipitators use electrostatic forces for the separation of dust particles from exhaust gases. Main factors that affect the collection efficiency are particle size distribution and electricity resistivity [11] in addition to the temperature, moisture content and flow rate. Toxic metals are significantly controlled by wet ESPs as compared to that of dry ESPs [12]. Operation of a wet ESP takes place with the help of water vapour saturated air streams i.e. humidity is 100% [11]. The working principle is based on electrical ionisation and charging of particles or droplets in the steam. The charged particles migrate towards the concerned electrode after passing through an electrical field. Ultimately, collected particulates are removed mechanically or washed online with a water solution.

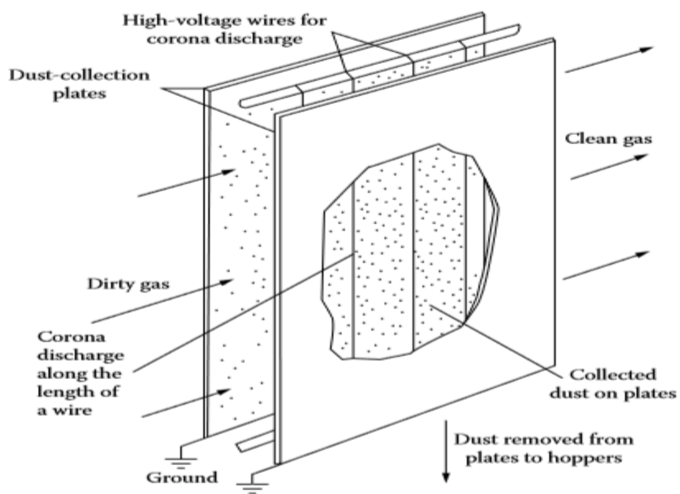
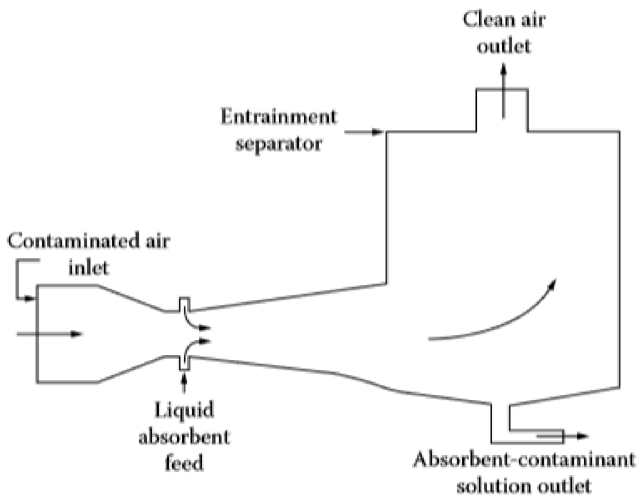


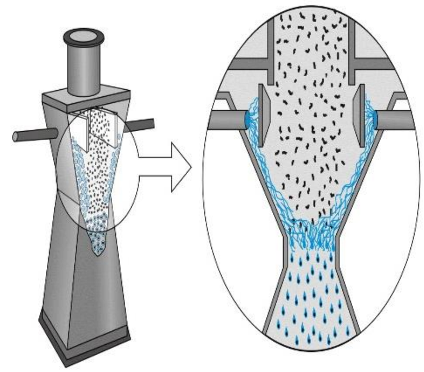
Fig. 3: Single-stage Electrostatic precipitator

Wet Scrubber

Wet scrubber provides control for gaseous emissions by the process of chemical absorption. The efficiency of dust removal is said to be 98% but the final concentration of dust is relatively high i.e. over 5 mg/Nm^3 [11]. Common types of wet scrubber are as follows:

- Spray chambers
- Plate (tray) chambers
- Centrifugal
- Dynamic (Wet fan)
- Venturi





Source: Griffin R.D. (2007). *Principles of Air Quality Management.* Second Edition. Boca Raton: Taylor & Francis Group, pg.172.

Venturi scrubbers use liquid steam to remove particles. Gas laden with particulate matter passes through a short tube with flared ends and a constricted middle. This constriction causes the gas steam to speed up when the pressure is increased. The difference in velocity and pressure resulting from the constriction causes the particles and water to mix and combine. The reduced velocity at the expanded section of the throat allows the droplets of water containing the particles to drop out of the gas stream. Absorption of elemental mercury can be improved by the addition of activated carbon or sulfur compounds to the scrubber liquor (Miller et al., 2014). To limit the risk of mercury that is posed to human health, the Environmental Protection Agency (EPA) has announced that it will alter or regulate the mercury emissions and other toxics in the atmosphere from coal and oil-fired power plants [14].

Activated carbon

It is an effective sorbent for mercury capture from flue gas and it is temperature dependent. Therefore, when temperature decreases, removal become effective (below 175^0C) [11]. It can be injected to the upstream of dust-cleaning devices. Although, it may pose a risk of fire and explosion due to its bad quality so dilution of carbon with inert material is suggested.

***Table 2*: Minimum expected performances of activated carbon techniques for mercury removal expressed as hourly average mercury concentrations**

Control techniques	**Mercury content after cleaning (mg/m^3)**
Carbon filter	<0.01
Sulfur-impregnated carbon filter	<0.01
Carbon injection + dust separator	<0.05
Injection of brominated activated carbon + dust separated	0.001
Source: Guidance document on best available techniques for controlling emissions of heavy metals and their compounds, annex II (ECE/EB.AIR/116,2013)	

Coconut pith

Coconut pith has very good adsorption capacity of elemental mercury. The adsorption capacity in case of activated carbon is observed to be much lower as compared to coconut pith with a difference of almost 3,023 µg/g of adsorption capacity. Therefore, this indicates that coconut pith can replace activated carbon effectively [24].

Conclusion

Mercury capture by various dust-abatement techniques such as Electrostatic precipitators (ESPs), activated carbon, wet scrubbers etc. poses great help towards the protection of human health which is a main objective of the international agreement, the Minamata Convention on Mercury. The agreement has been a great success in the country and more or less, all over globe. India alone has cut-down mercury pollution to a significant level by prohibition of mercury mining activities, setting permissible limits for mercury in fluorescent lamps, prohibition of manufacture and import of mercury used in cosmetics etc. Also, shifting of mercury thermometers to digital thermometers and blood pressure instruments has been a great achievement in reducing the use of mercury. Almost all the chlor-alkali industries have been shifted to a cleaner technology i.e. membrane cell technology. Mostly, elemental mercury is not captured by these dust-cleaning devices. The remedy of this problem lies in oxidation of gaseous mercury. To improve the efficiency of removal of mercury, oxidising agents such as halogens may be added or injected to the flue gas. The same can be achieved by using activated carbon impregnated in addition to halogens or sulphur.

Concerning the management of mercury emissions associated with coal burning and other sources in India, an important step would be to identify the regions and industries that are leading in atmospheric mercury emission levels for successful implementation of the Minamata Convention on Mercury. Mercury management action plans need to be implemented for selected industries along with a national roadmap that facilitates the development of a National Action Plan for the Minamata Convention. A sound and effective management of mercury pollution in India would be a complement to ongoing efforts to achieve the Sustainable Development Goals.

References:

1. Environmental Health Department, Ministry of the Environment, Minamata disease: The History and Measures, Ministry of the Environment, Government of Japan, Tokyo, Japan, 2002.
2. Bernhoft, R.A., 2012. Mercury toxicity and treatment: a review of the literature. *Journal of environmental and public health*, *2012*.
3. M. Berlin, R. K. Zalups, and B. A. Fowler, "Mercury," in Handbook on the Toxicology of Metals, G. F. Nordberg, B. A. Fowler, M. Nordberg, and L. T. Friberg, Eds., chapter 33, Elsevier, New York, NY, USA, 3rd edition, 2007.
4. United Nations Environment Program, COP1/7
5. Wu, D., Zhang, S. and Zhu, T., 2011. Controlling mercury emission for China's coal fired electricity plants: an economic analysis. *Energy Procedia*, *5*, pp.1439-1454.
6. Mukherjee, A.B., Bhattacharya, P., Sarkar, A. and Zevenhoven, R., 2009. Mercury emissions from industrial sources in India and its effects in the environment. In *Mercury fate and transport in the global atmosphere* (pp. 81-112). Springer, Boston, MA.
7. Rhee, S.W., 2015. Control of mercury emissions: policies, technologies, and future trends. *Energy Emiss Control Technol*, *4*, pp.1-15.
8. Mason RP, Choi AL, Fitzgerald WF, et al. Mercury biogeochemical cycling in the ocean and policy implications. Environ Res. 2012; 119:101–11.

9. Lambert, K.F., Evers, D.C., Warner, K.A., King, S.L. and Selin, N.E., 2012. Integrating mercury science and policy in the marine context: Challenges and opportunities. *Environmental research*, *119*, pp.132-142.
10. Makhijani S.D, Lal R.B and Sharma C.S., 2009. Mercury - environmental implications & toxicity.
11. Conference of the Parties to the Minamata Convention on Mercury, UNEP/MC/COP.1/7., 2017.
12. Griffin R.D. (2007). *Principles of Air Quality Management.* Second Edition. Boca Raton: Taylor & Francis Group, pg.169-172.
13. Nevers N.D. (1995). *Air Pollution Control Engineering*. Second Edition. Long Grove: Waveland Press, pg.250-298.
14. Xie, R., Duan, Y., Cao, Y., Li, L.C., Kellie, S., Pan, W.P., Riley, J.T., Ho, K., Chu, P. and Metha, A., 2002. *Mercury speciation and concentrations at esp in a 100mwe coal-fired power plant*. In *Abstr. Pap. Am. Chem. Soc* (Vol. 224, p. U574).
15. Wang, Y.J., Duan, Y.F., Yang, L.G., Jiang, Y.M., Wu, C.J., Qian, W.A.N.G. and Yang, X.H., 2008. Comparison of mercury removal characteristic between fabric filter and electrostatic precipitators of coal-fired power plants. *Journal of Fuel Chemistry and Technology*, *36*(1), pp.23-29.
16. Granite, E.J. and Pennline, H.W., 2002. Photochemical removal of mercury from flue gas. *Industrial & Engineering Chemistry Research*, *41*(22), pp.5470-5476.
17. Lin, C.J. and Pehkonen, S.O., 1999. The chemistry of atmospheric mercury: a review. *Atmospheric environment*, *33*(13), pp.2067-2079.
18. Mackey, T.K., Contreras, J.T. and Liang, B.A., 2014. The Minamata Convention on Mercury: Attempting to address the global controversy of dental amalgam use and mercury waste disposal. *Science of the total environment*, *472*, pp.125-129.
19. Selin, H., 2014. Global environmental law and treaty-making on hazardous substances: the Minamata Convention and mercury abatement. *Global Environmental Politics*, *14*(1), pp.1-19.
20. Evers, D.C., Keane, S.E., Basu, N. and Buck, D., 2016. Evaluating the effectiveness of the Minamata Convention on Mercury: Principles and recommendations for next steps. *Science of the Total Environment*, *569*, pp.888-903.
21. Steffen, A., Douglas, T., Amyot, M., Ariya, P., Aspmo, K., Berg, T., Bottenheim, J., Brooks, S., Cobbett, F., Dastoor, A. and Dommergue, A., 2008. A synthesis of atmospheric mercury depletion event chemistry in the atmosphere and snow. *Atmospheric Chemistry and Physics*, *8*(6), pp.1445-1482.
22. Kessler, R., 2013. The Minamata Convention on Mercury: a first step toward protecting future generations.
23. UN Environment (2016) *Guidance on best available techniques and best environmental practices*: UN Environment.
24. Johari, K., Saman, N., Song, S.T., Chin, C.S., Kong, H. and Mat, H., 2016. Adsorption enhancement of elemental mercury by various surface modified coconut husk as eco-friendly low-cost adsorbents. *International Biodeterioration & Biodegradation*, *109*, pp.45-52.
25. Jaffe, D., Prestbo, E., Swartzendruber, P., Weiss-Penzias, P., et al. 2005. Export of atmospheric mercury from Asia. *Atmos. Environ. 39,* 3029-3038.
26. [http://www.cpcbenvis.nic.in/scanned%20reports/PCL%204%20Environmental%20Standards.pdf [Accessed 10 March 2019].

Impact assessment of vehicular pollution

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Abstract

All Indian cities have witnessed very high rise in traffic on their transport corridors. Inside city limit, many residential habitats, commercial shops, hospitals and schools are located along these roads. Therefore, it is imperative to assess the carrying capacity of these roads and also assess the impact of vehicular exhaust on surrounding community so that management plans could be formulated. Vikas Marg is one of the most prominent arterial road connecting East Delhi to Central Delhi. Traffic study has been done at two locations on 12th November 2018. The observed daily traffic volume on this road varies from 140115 to 84775 Passenger Carrying Unit (PCU). The morning peak hourly traffic volume was found to vary from 15066 to 13896 PCU and evening traffic volume was found to vary from 13832 to 13016 PCU. This is far above the carrying capacity of 5400 PCU as per guidelines of Indian Road Congress. Emission factors developed by Automotive Research Association of India was applied to calculate the air pollution load. The concentration on Particulate Matter varied from 1.9 to 1.4 kg/km, Carbon monoxide from 72.6 to 48.6 kg/km, oxides of nitrogen from 37.8 to 27.9 kg/km and Hydrocarbons from 27.6 to 23.4 kg/km. In order to have an idea of the magnitude of impact of vehicular exhaust on the vicinity, modelling was done using CALINE4 software for 7000 vehicles per hour. The applied emission factors are as follows: 0.015 g/km for PM, 1.0 g/km for CO and 0.5 g/km for NO_2. It was observed that the incremental concentration of PM at 25 m distance from the centre of road is 24.5 µg/m^3 for 1 m/s wind speed and 8.0 µg/m^3 for 3 m/s wind speed. The incremental concentration of CO at 25 m distance is 0.4 ppm for 1 m/s wind speed and 0.1 ppm for 3 m/s wind speed. The incremental concentration of NO_2 at 25 m distance is 0.06 ppm for 1 m/s wind speed and 0.02 ppm for 3 m/s wind speed. Traffic congestion and high air pollution during peak hours in this road stretch is due to violation of guidelines on fringe conditions for which this road was designed, particularly with reference to no frontage access, no parked vehicles, no standing vehicles and no cross traffic. Adherence to the guidelines and recommendations stipulated by the Indian Road Congress would significantly reduce the traffic congestion at peak hours as well as air pollution due to vehicular exhaust.

Key words

Carrying Capacity of Urban Road, Indian Road Congress Guidelines IRC: 106-1990, CALINE4, Impact Assessment of Vehicular Pollution

Introduction

Urban roads in Metropolitan towns of India have a heterogeneous mix of traffic. These include the pedestrians, slow moving and fast moving vehicles and public transport vehicles. The space occupied by each of these vehicles, acceleration and deceleration and speed is variable. Unlike rural roads, the hourly variation of traffic on urban roads has at least two distinct peaks; namely during the morning and evening hours of the day. Further traffic fluctuates more on the urban road than on rural roads. The urban peak hour traffic constitutes about 8-10% of the total daily traffic depending on various factors including the importance of the road in the network.

Estimation of carrying capacity of urban roads, impact of vehicular exhaust on surrounding habitation and delineation of appropriate management plan to mitigate the adverse impacts are not given the desired focus in Environmental Impact Assessment process in India. As per environmental regulation, certain category of building projects and township development projects requires environmental clearance and for this purpose traffic impact assessment and management plan are required to be assessed by the Central or State Level Expert Appraisal Committees. It has been observed that the traffic impact assessment is carried out and assessed at a cursory level. This is unfortunate from the point of view of human health. One such example is the East Kidwai Nagar Redevelopment Project near AIIMS and Safdarjung Hospital Delhi (Development of 1.35 million m^2 area; building of 4700 apartments of various types, school, commercial complex, etc). Traffic congestion (near INA market) is already visible resulting in increase in air pollution levels. It is worth mentioning here that AIIMS crossing used to be the second most air polluted intersections in Delhi (after ITO) during 1990 – 2000 and several actions has been implemented during 1995 – 2005 to reduce the air pollution at AIIMS intersection. Compare this with development of Common Wealth Games village complex in East Delhi during 2007-2010. Proper traffic impact assessment report resulted in implementation of traffic management plan (construction of a new flyover, wide roads with two entry-exit points and developing a wide dense green barrier between the road and the complex), therefore traffic congestion and air pollution was not observed.

According to the Guidelines for Capacity of Urban Roads in Plain Areas by the Indian Road Congress (IRC: 106-1990), capacity analysis of road is fundamental for planning, design and operation of roads. It provides the basis for determining the number of traffic lanes to be provided for different road sections having regard to volume, composition and other parameters of traffic. For an existing road network, the capacity analysis provides a means of assessing the traffic carrying ability of the road and suggest short and long term improvement plans for smooth traffic flow. The new code of practice for design of urban roads (Part-I elaborates various norms and standards for urban road cross section design) was prepared by the Ministry of Urban Development through the Institute of Urban Transport in association with the Transportation Research and Injury Prevention Program. There are two basic variations from the IRC codes, which are introduced by MOUD codes, namely; i) IRC Codes uses different values for speed limit and design speed, while the new code requires the road to be designed for the intended speed limit on the road; and ii) Lane width has been linked to speed limit on the road, that is, for lower speed limit lane width has been reduced. IRC uses the same lane width irrespective of the intended speed on the road.

Capacity or Design Service Volume is the maximum hourly volume at which vehicle can reasonably be expected to transfer a point or uniform section of a lane or roadway during a given period. Capacity standards are fixed normally in relation to the Level of Service (LOS) adopted for design. The LOS depends on factors, such as speed and travel time, freedom to manoeuvre, traffic interruptions, comfort, convenience and safety. Six LOS are recognized commonly designated from A (general level of comfort and convenience is excellent) to F (general level of comfort and convenience is very poor). Considering the need for smooth traffic flow, it has been recommended that normally LOS-C be adopted for design of Urban Roads. At this level volume of traffic will be around 0.7 times the maximum capacity and this is taken as the Design Service Volume.

In this paper an attempt has been made to estimate the capacity of urban roads by observing the daily, peak and non-peak traffic volume count, vehicle classification, calculation of air pollution load and modelling the incremental air pollution.

Methodology

Vikas Marg is one of the most prominent arterial road connecting East Delhi to Central Delhi. It connects New Delhi Railway Station to East Delhi via ITO. Traffic volume count and vehicle classification has been carried out at two locations on Shakarpur – Laxmi Nagar section of Vikas Marg (observation & video) on 12th November 2018. The locations chosen for monitoring are near Laxmi Nagar Metro Station and Preet Vihar Metro station. Six sub arterial roads join this Arterial road between location 1 and 2. Dense human habitation and commercial activities exists on both sides of the Arterial Road. This road is banned for movement of heavy transport vehicles and carts, tongas, cycle rikshaws. Separate street and footpath exists on both sides of Arterial road that provides frontal access to the habitation and shops. Two main traffic intersections and few frontal access points exists on this stretch of arterial road (L1 and L2). The road section and monitoring locations are marked in Figure 1. The road characteristics is given in Table 1.

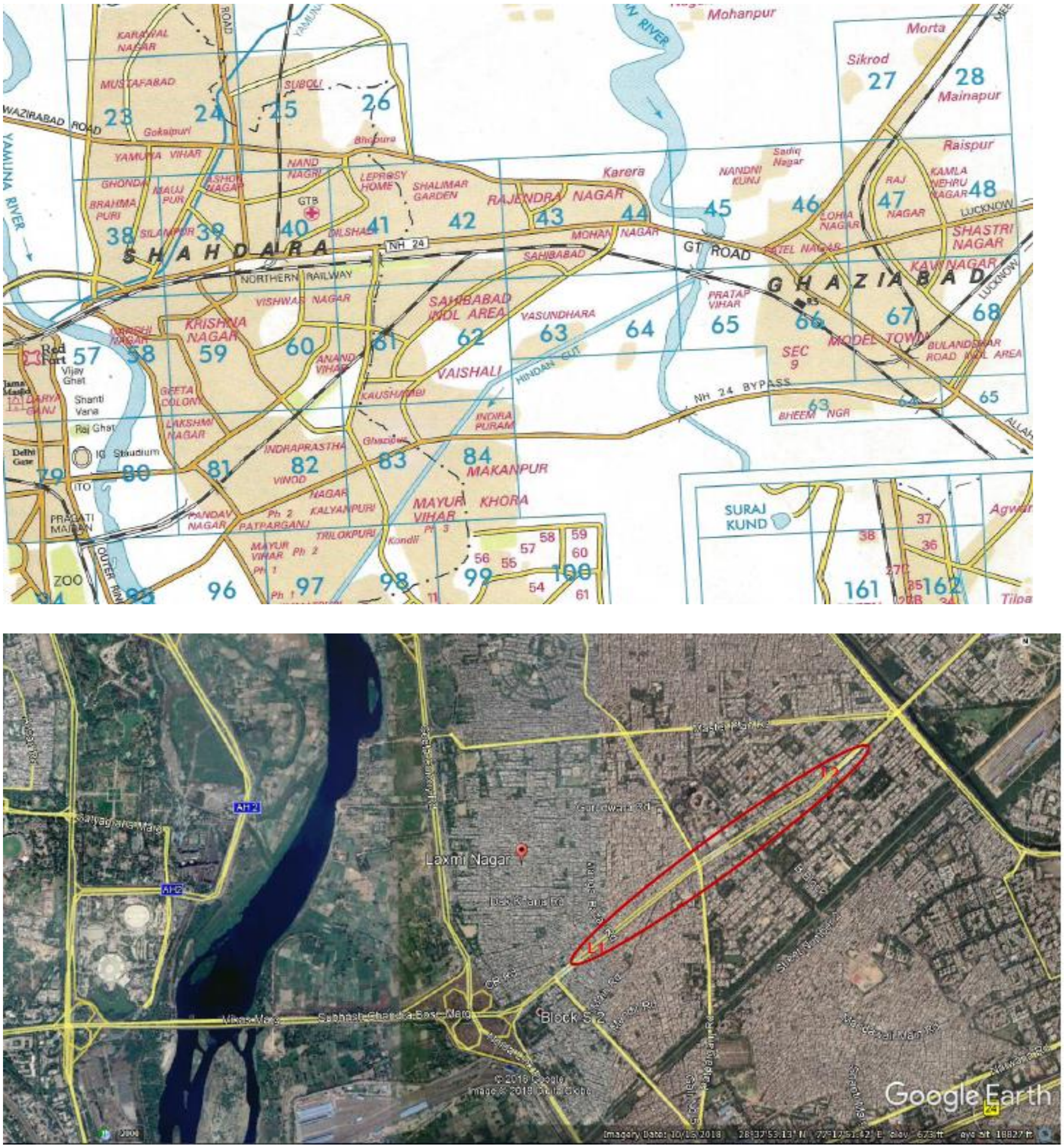

Figure 1: Vikas Marg (80) and Location of Traffic Study

Table 1: Vikas Marg Road Characteristics

1	Pavement for pedestrian movement	Available on both sides of carriageway
2	Carriage width (3-lane+3-lane)	15 m + 15 m (Two-way)
3	Road type & condition	Divided with median, Asphalted, good condition
4	Lane markings, zebra crossing, bus stop	Available
5	Signages	Standard signages available
6	Traffic control type	Normal traffic signal (with Timer at intersections)

The traffic volume count and vehicle classification were done on 12th November 2018 Monday at two locations (marked L1 and L2). The results of vehicle count are given in Table 2 and Table 3.

Table 2: Traffic Volume Count: Location 1- Near Laxmi Nagar Metro Station

Time	2 -Wheeler	3-Wheeler	Car/Jeep	Bus/Truck
8:00 AM to 10:00 AM	6750	3560	12610	600
10:00 AM to 6:00 PM	5220	2950	8560	486
6:00 PM to 8:00 PM	7140	3280	11320	560
8:00 PM to 8:00 AM	3150	760	5160	220
Total	22260	10550	37650	1866

Table 3: Traffic Volume Count Location 2-Near Preet Vihar Metro Station

Time	2 -Wheeler	3-Wheeler	Car/Jeep	Bus/ Truck
8:00 AM to 10:00 AM	7620	3740	13660	655
10:00 AM to 6:00 PM	5890	3110	9210	520
6:00 PM to 8:00 PM	6980	3420	12560	605
8:00 PM to 8:00 AM	3450	880	54220	262
Total	23940	11150	89650	2042

Passenger Car Unit (PCU) factors developed by Indian Road Congress has been applied to estimate the PCU and compare them with the recommended Design Service Volume for such type of Urban Road (IRC 106 1990). The PCU Factors are given in Table 4. The estimated PCUs at both the locations are given in Table 5. The peak hour traffic low during peak hours in the morning and evening is shown in Table 6. The design service volume (in PCU/hour) recommended by IRC: 106-1990 is given in Table 7. When compared with the recommended standard, it is seen that the standard of 5400 PCU is exceeded by almost triple, resulting in Level of Service (LOS) - F (general level of comfort and convenience is very poor).

Table 4. PCU Factors for Different Class of Vehicles in Urban Road (IRC 106 1990)

S.No.	Type of Vehicles	Equivalent PCU Factors (%age composition of vehicle type in traffic stream)	
		5%	10% and above
1.	Two-wheelers	0.5	0.75
2.	Car, Jeep, Taxi, Utility Vehicles	1.0	1.0
3.	Auto Rikshaw (3-wheeler)	1.2	2.0
4.	Bus and Truck	2.2	5.0

Table 5: Estimated Daily PCUs on Location 1 and 2 of Vikas Marg

S.No.	Type of Vehicles	Location 1	Location 2
1.	Two-wheelers	16695	17955
2.	Three-wheelers	21110	22300
3.	Car	37650	89650
4.	Bus	7000	7460
5.	Truck	2330	2750
6.	Total PCU	84775	140115

Table 6: Estimated Peak Hour Traffic on Location 1 and 2

S.No.	Type of Vehicles	Location 1		Location 2	
		Morning	Evening	Morning	Evening
1.	Two-wheelers	2531	2676	2858	2618
2.	Three-wheelers (Auto Rikshaw)	3560	3280	3740	3420
3.	Car, Jeep, Taxi, Utility Vehicles	7455	6830	6830	6280
4.	Bus and Truck	1500	1400	1638	1513
5.	Total Peak PCU	13896	13016	15066	13831
6.	Recommended Design Service Volume (IRC106-1990)	5400	5400	5400	5400

Table 7: Recommended Design Service Volumes in PCU per Hour

Type of Road/ Carriageway	Total Design Service Volumes for Different Categories of Urban Road		
	Arterial Road	Sub-Arterial Road	Collector Road
2-lane (1-way)	2400	1900	1400
2-lane (2-way)	1500	1200	900
4-lane divided road (2-way)	3800	2900	
4-lane undivided road (2-way)	3000	2400	1800
6-lane divided road (2-way)	5400	4300	
6-lane undivided road (2-way)	4800	3800	
8-lane divided road (2 way)	7200		
Arterial road: Roads with no frontal access, no standing vehicles, very little cross traffic Sub-arterial road: Roads with frontal access but no standing vehicles and high capacity intersections Collector road: Roads with free frontage access, parked vehicles and heavy cross traffic			

Estimation of vehicular pollution load of Carbon Monoxide, Hydrocarbon, Oxides of Nitrogen, Carbon Dioxide and Particulate Matter has been done using the emission factors developed by Automotive Research Association of India for various classes of vehicles. The Emission Factors are given in Table 8. The vehicular emission load at the two locations were calculated using the Emission Factors and results are shown in Table 9 and Table 10.

Table 8: Emission Factors for Indian Vehicles (ARAI-2007 in g/km)

Type of Vehicle	**CO**	**HC**	**NOx**	**CO_2**	**PM**
Scooter 4s (post 2005) Bajaj, Honda, Kinetic, TVS, etc	0.4	0.15	0.25	42.06	0.015
Motorcycle 4s (post 2005) Bullet, Karisma, etc	0.72	0.52	0.15	45.6	0.013
Three-wheeler CNG 4s (post 2000) Bajaj	1.0	0.26	0.5	77.7	0.015
Car Diesel (post 2005)Indigo, Scoda, Hyundai, Ford, etc	0.06	0.08	0.28	148.76	0.015
Car Petrol (post 2005) Indigo, Icon, Hyundai, Ascent, Ford, Honda, Maruti, etc	0.84	0.12	0.09	172.95	0.002
Car CNG (post 2000) Maruti, Omni, Lancer, etc	0.06	0.36	0.01	131.91	0.002
HCV-Bus CNG (post 2000) Tata	3.72	3.75	6.21	806.5	0.044
HCV-Diesel Truck (post 2000) Telco, Volvo, Leyland, etc	6.0	0.37	9.3	762.39	1.24

Table 9: Location 1 – Estimated Daily Vehicular Emission Load (g/km)

Type of Vehicle	**CO**	**HC**	**NOx**	**CO_2**	**PM**
Scooter 4s (post 2005) Bajaj, Honda, Kinetic, TVS, etc	1781	668	1113	187251	67
Motorcycle 4s (post 2005) Bullet, Karisma, etc	12822	9260	2671	812045	232
Three-wheeler CNG 4s (post 2000) Bajaj	10550	2743	5275	819735	158
Car Diesel (post 2005) Indigo, Scoda, Hyundai, Ford, etc	904	1205	4217	2240326	226
Car Petrol (post 2005) Indigo, Icon, Hyundai, Ascent, Ford, Honda, Maruti, etc	14232	2033	1525	2930205	34
Car CNG (post 2000) Maruti, Omni, Lancer, etc	339	2033	56	744962	11
HCV-Bus CNG (post 2000) Tata	5208	5250	8694	1129100	62
HCV-Diesel Truck (post 2000) Telco, Volvo, Leyland	2796	172	4334	355274	578
Total Load (kg/km)	48.6	23.4	27.9	9.2 t/km	1.4

Table 10: Location 2 – Estimated Daily Vehicular Emission Load (g/km)

Type of Vehicle	**CO**	**HC**	**NOx**	**CO_2**	**PM**
Scooter 4s (post 2005) Bajaj, Honda, Kinetic, TVS, etc	1915	718	1197	201383	72
Motorcycle 4s (post 2005) Bullet, Karisma, etc	13789	9959	2873	873331	249
Three-wheeler CNG 4s (post 2000) Bajaj	11150	2899	5575	866355	167
Car Diesel (post 2005) Indigo, Scoda, Hyundai, Ford, etc	2152	2869	10041	5334534	538
Car Petrol (post 2005) Indigo, Icon, Hyundai, Ascent, Ford, Honda, Maruti, etc	33888	4841	3631	6977235	81
Car CNG (post 2000) Maruti, Omni, Lancer, etc	807	4841	134	1773860	27
HCV-Bus CNG (post 2000) Tata	5550	5595	9265	1203298	66
HCV-Diesel Truck (post 2000) Telco, Volvo, Leyland	3300	204	5115	419315	682
Total Load (kg/km)	72.6	27.6	37.8	17.6 t/km	1.9

Impact assessment of vehicular pollution has been carried using the software developed by California Department of Transportation, CALINE4 - Dispersion Model for Predicting Air Pollutant Concentrations

Near Roadways. The model is based on Gaussian diffusion equation and employs a mixing zone concept to characterize dispersion of pollutants over roadway. Given source strength, metrology and site geometry, the model can predict pollutant concentration for receptors located within 500 m of roadway. Urban CBD was considered for Aerodynamic Roughness Coefficient. Ground based inversion (Mixing Height – 10 m and Mixing Depth – 10 m) has been considered for all the recognized stability classes (1 to 7); most unstable, neutral and most stable. Worst case wind direction has been modelled by calculating 1-hr average CO and $PM_{2.5}$ concentrations at the receptors (5 m and 25 m distance from road). 7000 vehicle movement per hour was considered. Emission factor considered for modelling of $PM_{2.5}$ was 0.015 g/km, for NO_2 was 0.5 g/km and CO was 1.0 g/km. The modelled results are shown in Table 11.

Table 11: Incremental Ground Level Concentration of Air Pollutants

Wind Speed	Pollutant	Incremental concentration (Hourly average values)	Receptor distance from edge of road
1 m/s	CO	1.7 ppm 0.4 ppm	5 m 25m
3 m/s	CO	0.6 ppm 0.1 ppm	5 m 25 m
1 m/s	NO_2	0.2 ppm 0.06 ppm	5 m 25 m
3 m/s	NO_2	0.08 ppm 0.02 ppm	5 m 25 m
1 m/s	PM	99 µg/m^3 24.5 µg/m^3	5 m 25 m
3 m/s	PM	36.8 µg/m^3 8.0 µg/m^3	5 m 25 m

Note: concentration in µg/m^3 = ppm x 1000 x Molecular weight ÷ 24.45

Result and Discussion

The observed daily traffic volume on Vikas Marg road varied from 140115 to 84775 Passenger Carrying Unit (PCU). The morning peak hourly traffic volume varied from 15066 to 13896 and evening traffic volume varies from 13832 to 13016 PCU. This is much above the carrying capacity of 5400 PCU stipulated in the Guidelines by Indian Road Congress. The vehicular pollution load of Particulate Matter varied from 1.9 to 1.4 kg/km, Carbon monoxide from 72.6 to 48.6 kg/km, oxides of nitrogen from 37.8 to 27.9 kg/km and Hydrocarbon from 27.6 to 23.4 kg/km. The incremental concentration of PM at 25m distance from the centre of road was 24.5 µg/m^3 for 1 m/s wind speed and 8.0 µg/m^3 for 3 m/s wind speed. The incremental concentration of CO at 25m distance from the centre of road was 0.4 ppm for 1 m/s wind speed and 0.1 ppm for 3 m/s wind speed. The incremental concentration of NO_2 at 25m distance from the centre of road was 0.6 ppm for 1 m/s wind speed and 0.02 for 3 m/s wind speed.

The main reasons for traffic congestion and high air pollution during peak hours at this road stretch was violation of designed fringe conditions, particularly with reference to no frontage access, no parked vehicles, no standing vehicles and no cross traffic. Compliance of Indian Road Congress (IRC:106-1990) guidelines would solve the traffic congestion and reduce air pollution.
Following recommendations are suggested:

a) No on-street, on lane parking: Remove all parking from this arterial road. Implement no vehicle standing policy. Increase drop points for passengers at suitable locations.

b) Reduction of roadside friction: Remove all illegal commercial establishments, hawkers, through control of non-conforming landuse.
c) No cycle rickshaw: prohibit cycle rickshaw movement and allow only e-rickshaw to ply.
d) Provision of adequate facilities for pedestrians: Keep footpath free from vehicles parking.
e) Banning certain conflicting movements during peak hours: Control cross traffic & side street traffic by regulating the gaps in medians and kerbs
f) Improving traffic discipline: Create education and awareness for lane driving, no overtaking, and no U turn.
g) Encourage use of GPS Navigational Systems (Google Maps) by motorists and passengers

References

1. CR Patel, GJ Joshi, Capacity and LOS for Urban Arterial Road in Indian Mixed Traffic Condition, Procedia – Social and Behavioural Sciences, 48, 2012 p 527-534
2. Indian Road Congress, Guidelines for Capacity of Urban Roads in Plain Terrain, IRC106, 1990
3. Indian Road Congress, Guidelines for Capacity of Roads in Rural Areas, IRC64, 1990
4. Ministry of Urban Development, Govt of India, Code of Practice for Design of Urban Road, Part 1 to Part V, October 2013
5. Public Works Department, Govt of Delhi, Urban Road Manual, 2nd Edition, December 2014
6. S.Velmurugan, et al, Critical Evaluation of Roadway Capacity of Multi Level High Speed Corridors Under Heterogenous Traffic Conditions, Paper No. 566, J of Indian Road Congress, Oct-Dec 2010
7. V. Suresh, G Umadevi, Empirical Methods of Capacity Estimation of Urban Roads, Global Journal of Research in Engineering: J General Engineering, Volume 14, Issue 3, Version 1 2014

Analysis of Ambient Air Quality Pre- and During Lockdowns due to COVID -19A Case Study of Hapur (NCR Town), Uttar Pradesh

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Abstract

The present study deals with the assessment of ambient air quality trend analysis at Hapur, a town near the capital city Delhi, with respect to the concentration of different pollutants viz. $PM_{2.5}$, PM_{10}, carbon mono oxide (CO), Sulphur dioxide (SO_2) and Nitrogen dioxide (NO_2) levels during different lockdown periods as compared to covid-19 pre--lockdown. The daily data of the pollutants on hourly average basis was retrieved from the CPCB website, Delhi. This study mainly focuses on the extent of air pollution and air quality index for a period before lockdown between 01 March 2020 to 22 March 2020, including one day of Janata curfew (22 March 2020); first lockdown (25 March 2020 -13 April 2020); second lockdown (15 April 2020 – 03 May 2020); third lockdown (04 May 2020 – 17 May 2020) and fourth lockdown (18 May 2020 – 31 May 2020).There was little improvement in air quality during lockdown first (wrt AQI, PM10 & PM2.5) and fourth (wrt CO during 16-24 hour) as compared to 21 days of the pre-lockdown period. On March 22, 2020; the day of Janata curfew, AQI was moderate in Hapur, which remained moderate and little improved in lockdown first but again increased in consecutive lockdowns. The range of $PM_{2.5}$ concentration in pre-lockdown and lockdown 1, 2, 3, 4 was reported as 14–98$\mu g/m^3$, 19–60 $\mu g/m^3$, 18-74 $\mu g/m^3$, 22–65 $\mu g/m^3$, and 13–73 $\mu g/m^3$ respectively with exceedance of standard limit between 4.7% to 28.5% of days . The range of PM_{10} concentration in pre-lockdown, and lockdown 1, 2, 3, 4 was reported as 22- 211 $\mu g/m^3$, 36-222 $\mu g/m^3$, 62 -310 $\mu g/m^3$,73-220 $\mu g/m^3$, and 18 -233 $\mu g/m^3$ respectively with exceedance of standard limit between 52.38% to 84.21% of days . The range of SO_2 concentration in pre-lockdown, and lockdown 1, 2, 3, 4 was reported as 1-16 $\mu g/m^3$, 6-11 $\mu g/m^3$, 4-13$\mu g/m^3$, 3-11 $\mu g/m^3$, and 2-7 $\mu g/m^3$ respectively. The range of NO2 concentration in pre-lockdown, and lockdown 1, 2, 3, 4 was reported as 35-72 $\mu g/m^3$, 42 -69 $\mu g/m^3$,42 -67 $\mu g/m^3$,45-63 $\mu g/m^3$, and 48-69 $\mu g/m^3$ respectively. No significant effect of lockdown was observed in SO_2 & NO_2 and no violation of standard limit observed throughout the study. The 8 hourly CO concentration was analyzed and it was found exceeding the standard limit ranging from nil % (4th lock down in time interval 16:00 to 24.00hrs) to 47.62% % (1st lock down in time interval 00.00 to 08.00 hrs).The ratio of $PM_{2.5}$ and PM_{10} is also calculated to analyze the impact of fine particles in the composition of particulate matter due to lockdowns, which is observed ranging between 0.3 and 0.6. The results displayed reduced levels during lockdown-1, in comparison to others during the study period, which can be seen from the percentage of days they exceeding the standard limits for different pollutants. This case study disclosed unique findings unlike big cities as no much impact of lockdown 2,3 & 4 probably due to pollution generated from transport, vehicular movement, industries, construction and demolition activities, biomass and excessive burning, road dust which was curbed down due to the lockdown 1 restrictions and as result air quality was improved. Under the nationwide lockdown, the good air quality index was observed globally. The government may think over the prevailing healthy air post covid-19 and may formulate a good policy to mitigate the air pollution including revisiting criteria of fixing NAAQS for PM10, PM2.5 & AQI, which violate safe levels even in a smaller town during lockdown period, then how we can expect

these may be controlled during normal period. Further, at least one-day heavy vehicle-free, one-day car-free, odd and even day type of consideration twice a month and up to week long complete lockdowns during peak pollution periods in winter season may be needed to reduce or combat the pollution besides augmenting public transport rather than private vehicles, promoting non-motorized & e- mobility, vacuum cleaning of roads, preventing dust from construction/demolition activities and total ban on burning of waste refuge & plant leaves etc.

Keywords: Particulate Matter, Janata- curfew, Covid-19, Lockdown, Air Quality, Air Quality Index, Air Pollution.

Introduction

The rampant increase in vehicles and construction work in urban areas contributes considerably to pollution due to the generation of several pollutants (Shrivastava, et al, 2018; CPCB, 2010). In 2015 Singh and Grover reported that due to expeditious urbanization huge areas of vegetation is being replaced with concrete buildings, Highways and stunted surfaces (Singh et al, 2015).Vehicles, road dust, and cooking using solid fuel are the key urban sources of air pollution. According to Khandar and Kosankar, 2014, the number of motor vehicles ranged from 72.7 million in 2004 to ~141.8 million and suggested that the transport sector is the main source contributing ~90% of total emissions in India (Khandar et al, 2014). Shrivastava et al., 2013, have revealed that there is a direct relationship between the road transport system and air pollution in urban areas (Shrivastava, et al, 2013). Gurjar et al. (2016) studied the air pollution trends and increased NOx and decreased SOx was observed in all the megacities. This could be due to the increased numbers of vehicles registered (Gurjar, et. al., 2016; Ambasht, et. al., 2006). Wong *et al*., paper evidenced that this is a big issue in densely populated urban areas of India (Wong et al, 2010). According to the World Health Organization (WHO), each year, more than 4 million people die early because of outdoor air pollution. The main culprits are fine particles with diameters of 2.5 micrometers or less ($PM_{2.5}$). These can penetrate deep into the lungs, heart and bloodstream, where they cause diseases and cancers (Xiangdong et al, 2019).A study carried out by Lawrence and Fatima in 2014 at Lucknow has reported the average levels of PM_{10} and $PM_{2.5}$ were above the acceptable limits laid down by WHO (World Health Organization) at densely populated and roadside sites with 189μg/m^3($PM_{2.5,}$ 76 μg/m^3) and 226 μg/m^3 ($PM_{2.5,}$ 91 μg/m^3) respectively (Lawrence et al, 2014)..Dhere et al. in 2008 reported that the SPM, SO_2, and NOx concentrations were quite higher than those stipulated by the standard National limit of India (Dhere et al, 2008; Gurjar, et. al., 2016). The average annual emission of suspended particulate matter (SPM) found at the waste disposal site in Pune was 1708 μg/m^3 while the average annual emission of SO_2&NOxat landfills were 285 μg/m^3 and 234 μg/m^{3}respectively. Sharma *et al*. have reported that the highest contribution to the estimated average values of PM_{10} comes from particulate organic matter (24%) with other matters such as soil/crustal matter (16%), light-absorbing carbon (4%) ammonium nitrate (6%), aged sea salt (5%), and ammonium sulphate (7%). Delhi receives a sector-wise contribution to PM_{10} mass was mainly from secondary aerosols (21.7%), soil dust (20.7%), fossil fuel combustion (17.4%), vehicle emissions (16.8%), and biomass burning (13.4%) (Sharma et al, 2014). Gupta, 2008., According to WHO report- (1992), ambient air pollution levels exceed the WHO standards in many of metropolitan cities in India and total of thirteen Indian cities are amongst twenty most polluted cities of the world in terms of the particulate matter air pollution ("Ambient Air Pollution Database", World Health Organization, May 2014) (Gupta U., 2008). Five parameters namely $PM_{2.5}$, PM_{10}, SO_2, NO_2, and CO have been selected for the present study because Hapur is receiving a heavy load of pollution from numerous sources and necessary to analyse the extent of pollution in Hapur and further to take step to minimize the bad air. Many heath issues are only due to pollution (CPCB, 2009; Jain et al, 2016; WHO, 1992; Jamwal 2006; Tyagi et al, 2016) and many researches are going on to find the solution. Among them, cardiovascular causes have been estimated to be responsible for more than two thirds of the considerable mortality attributed to air pollution. Multiple biological mechanisms are responsible; however, oxidative stress is a prominent observation at many levels of the cardiovascular impairment induced by pollutant exposure (Miller M.R., 2020). The present study is one small step to stop pollution in small city like Hapur.

Materials and Methods

Study area

Hapur was recently established as a district in NCR zone of Uttar Pradesh and carved out from Ghaziabad district with a population of 1,281,272 (2016). Hapur is located at 28.72°N 77.78°E.It has an average elevation of 213 meters(699 feet). It is bound on the north by Meerut, in the south by Bulandshahar, while Ghaziabad and Amroha form the western and eastern limits. There are 4 blocks namely Hapur, Garhmukteshwar, Simbhauli and Dhauluna and 3 Tehsils namely Hapur, Garhmukteshwar and Dhauluna. There are 4 Nagar Palikas and one Nagar Panchayat. There is very famous Sugar Mill in block Simbhauli and one Sugar Mill in Baijnathpur, Hapur. A unit of Century Ply Wood, along with many other private plywood factories, is situated in the District. Hapur is also known as a manufacturing centre for stainless steel pipes, sewing machines, and wood and paper products. The district headquarter-Hapur is well connected by road and railways to major cities of Uttar Pradesh and India. It has a lot of potential because of its proximity to New Delhi and Ghaziabad.

Details of site and collection of data

The CMAAQ station is located at Anand Vihar, HDPA office in Hapur city (**Map-1**). This site is close to the main roads coming from railway station directly leading to the highway hence receives high traffic volume. There are also industries, specifically paper manufacturing plant and plywood industry, near the site. For analysis of concentration data of $PM_{2.5}$, PM_{10}, SO_2, NO_2 and CO (all in $\mu g/m^3$) has been collected from CPCB website.

Map -1 location of monitoring station in Hapur

The numerical data for the analysis of concentration ($\mu g/m^3$) of pollutants $PM_{2.5}$, PM_{10}, SO_2, NO_2, and CO were taken from CPCB website during

i.) Before Lockdown: 1 March 2020 - 21 March 2020 (21days)

ii.) Lockdown 1: 25 March 2020 - 14 April 2020 (21 days) iii.) Lockdown 2: 15 April 2020 - 3 May 2020 (19 days)

iv.) Lockdown 3: 4 May, 2020 - 17 May 2020 (14 days)

v.) Lockdown 4: 18 May 2020 - 31 May 2020 (14 days)

The data has been taken from the Central Pollution Control Board (CPCB) website. The concentrations for all the studied pollutants are analyzed for the basic air quality statistics and Air Quality Index (AQI). Based upon the ambient concentration of pollutant, sub-index is calculated, which is a linear function of concentration. The worst sub-index determines the overall AQI. AQI categories and health breakpoints for the six pollutants are as follows (Dhere et al, 2008; Gurjar, et. al., 2016)**, Table 1.**

CPCB (Central Pollution Control Board) has well established the methods to calculate the sub-index value, AQI value, and it is necessary simply to establish the results in our study (National Air Quality Index, CPCB, October 2014**).** In IND-AQI method the sub-index of a particular pollutant is has been measured as per the following formula

$$I_P = \left\{ \frac{(I_{HI} - I_{LO})}{(B_{HI} - B_{LO})} \right\} \times (C_P - C_{LO}) + I_{LO}$$

B_{HI}= Breakpoint concentration greater or equal to given concentration.

B_{LO}= Breakpoint concentration smaller or equal to given concentration.

I_{HI} = AQI value corresponding to B_{HI}

I_{LO} = AQI value corresponding to B_{LO}

Finally;

AQI = Max (I_P) (where; p= 1,2,.,n; denotes n pollutants; provided that at least 3 parameters are required)

Table 1: AQI category of different pollutants

AQI Category	AQI	Pollutants					
		PM 10	PM 2.5	NO_2	SO_2	CO	Ozone
Good	0-50	0-50	0-30	0-40	0-40	0-1.0	0-50
Satisfactory	51-100	51-100	31-60	41-80	41-80	1.1-2.0	51-100
Moderately Polluted	101-200	101-250	61-90	81-180	81-380	2.1-10	101-16
Poor	201-300	251-350	91-120	181-280	381-800	10-17	169-20
Very Poor	301-400	351-430	121-250	281-400	801-1600	17-34	209-74
Severe	401-500	430+	250+	400+	1600+	34+	748+

Results and Discussion

The hourly data of concentration (in µg/m^3) of pollutants i.e. $PM_{2.5}$, PM_{10}, SO_2, NO_2, and CO were taken from CPCB website for pre-Covid 19 & during four lockdown periods, then computed for 24 hourly except for CO which were computed on 8 hourly basis. The data was further subjected to statistical analysis using Microsoft Excel. The summary statistics and AQI are given in Tables 2 to 7.

Trend and Statistical analysis of PM_{10}before lockdown and during lockdown 1-4

Comparative trend statistical analysis of PM_{10} concentration before lockdown and during lockdown 1 to 4 is shown in **Table 2 and Figure 1**. The 24 hour PM_{10} average concentrations was 114 µg/m^3, 114 µg/m^3, 162 µg/m^3, 138 µg/m^3, 143 µg/m^3 respectively for before lockdown, lockdown 1, 2, 3 and 4. The minimum concentration of PM_{10} was 22 µg/m^3, 36 µg/m^3, 62 µg/m^3, 73 µg/m^3 and 18 µg/m^3 respectively for before lockdown, lockdown 1, 2, 3 and 4. The maximum concentration of PM_{10} was 211 µg/m^3, 222 µg/m^3, 310 µg/m^3, 220 µg/m^3 and 233 µg/m^3 respectively for before lockdown, lockdown 1, 2, 3 and 4.The standard deviation was estimated to be 56 µg/m^3, 45 µg/m^3, 63µg/m^3, 47µg/m^3, 78 µg/$m^3$for before lockdown, lockdown 1, 2,3 and 4 respectively. The drop in coarse particles may be attributed to restriction on industries, transport, road dust (demolition and construction activities) and vehicular movement. Number of days on which the measured value crossed the standard limit during lockdown-1, 2, 3, 4 were observed as 11 (out of 21 days), 16 (out of 19 days), 11 (out of 14 days) and 9 (out of 14 days) respectively. This comparison of average concentration shows a clear declining trend in the level of PM_{10} was significant only in lockdown 1. Maximum concentration was 310 µg/m^3, during lockdown 2, which again attributed due to sudden increase traffic on the road. It was may be due to two special occasions in the month of April.

Table-2: Statistical analysis of PM_{10}

PM_{10} ($\mu g/m^3$)					
	Pre Lockdown	Lockdown 1	Lockdown 2	Lockdown 3	Lockdown 4
Minimum	22	36	62	73	18
Maximum	211	222	310	220	233
Average	114	114	162	138	143
SD	56	45	63	47	78
Number of days (out of total no of days) on which the measured value crossed the standard limit (100 $\mu g/m^3$)	14 (21)	11(21)	16(19)	11(14)	9(14)
% of days Exceeding the standard limit	66.67%	52.38%	84.21%	78.57%	64.29%

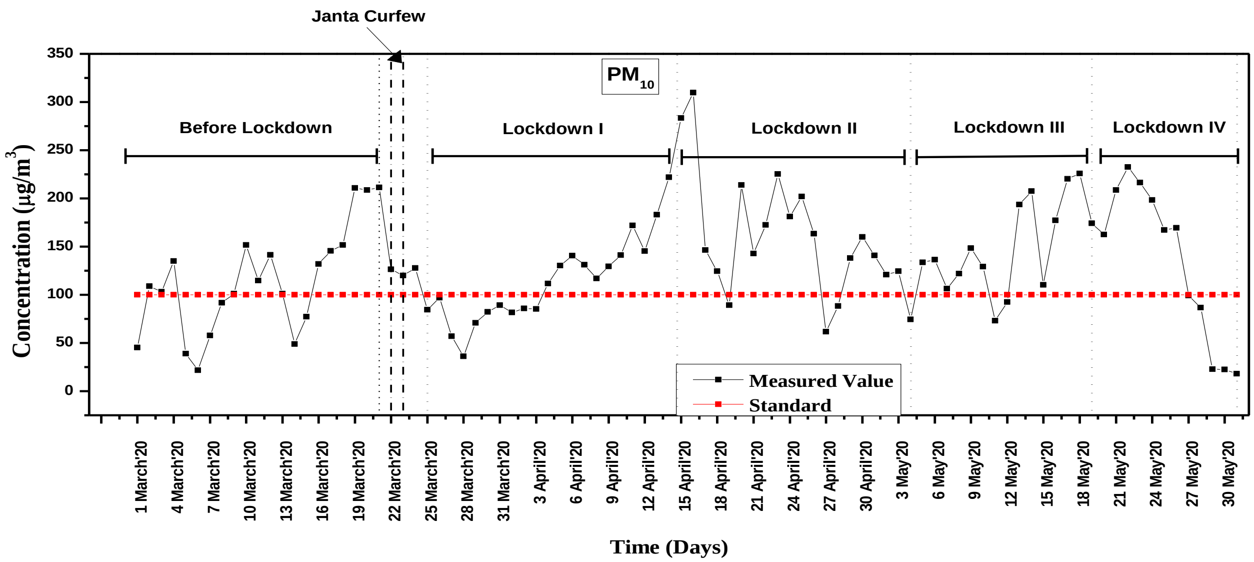

Figure-1: 24 Hourly average PM_{10} comparisons

Trend and statistical analysis of $PM_{2.5}$ before lockdown and during lockdown 1-4

Comparative trend statistical analysis of $PM_{2.5}$ concentration before lockdown and during lockdown 1 to 4 is shown inTable-3and Figure 2. The 24 hour $PM_{2.5}$ average concentrations was 46 $\mu g/m^3$, 35$\mu g/m^3$, 40$\mu g/m^3$, 41 $\mu g/m^3$, 47 $\mu g/m^3$ respectively for before lockdown, lockdown 1, 2,3 and 4. The minimum concentration of PM_{10} was 14$\mu g/m^3$, 19 $\mu g/m^3$, 18 $\mu g/m^3$, 22 $\mu g/m^3$and 13 $\mu g/m^3$respectively for before lockdown, lockdown 1, 2, 3 and 4. The maximum concentration of $PM_{2.5}$ was 98 $\mu g/m^3$, 60 $\mu g/m^3$, 74 $\mu g/m^3$, 65 $\mu g/m^3$ and 73 $\mu g/m^3$respectively for before lockdown, lockdown 1, 2, 3 and 4. The standard deviation was estimated to be 21 μg/m^3, 10 μg/m^3, 15 μg/m^3, 14 μg/m^3, 21 μg/m^3 respectively for before lockdown, lockdown 1, 2, 3 and 4. In lockdown 4 the $PM_{2.5}$ concentration fell below standard value 60 μg/m^3 for 4 number of days in total of 21 days i.e. 28.57% of total days exceeding the standard value. This is attributed due to traffic on the road.

Table-3: Statistical analysis of $PM_{2.5}$

$PM_{2.5}$ (μg/m^3)					
	Pre Lockdown	Lockdown 1	Lockdown 2	Lockdown 3	Lockdown 4
Minimum	14	19	18	22	13
Maximum	98	60	74	65	73
Average	46	35	40	41	47
SD	21	10	15	14	21
Number of days (out of total no of days) on which the measured value crossed the standard limit (60 μg/m^3)	4(21)	1(21)	2(19)	1(14)	4(14)
% of days exceeding the standard limit	19.05%	4.76%	10.53%	6.67%	28.57%

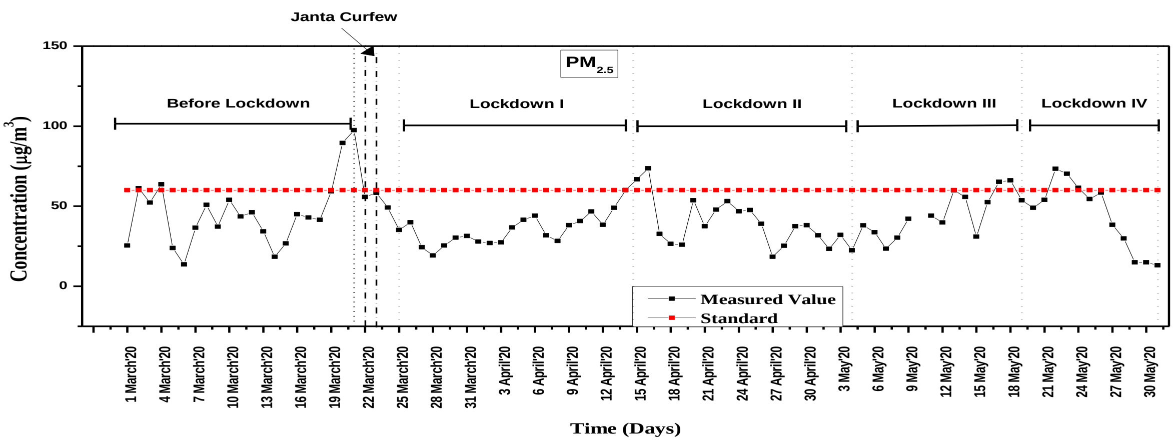

Figure-2: 24 Hourly average $PM_{2.5}$ comparisons

Trend and statistical analysis of SO_2 before lockdown and during lockdown 1-4

Comparative trend statistical analysis of SO_2 concentration before lockdown and during lockdown 1 to 4 is shown in **Table 4 and Figure 3**. The graph and the statistical analysis below depict the 24 hourly concentration trends for SO_2 for pre-lockdown and lockdown periods. The concentration value is below the standard value on all days. This may be attributed due to all the meteorological conditions.

Table-4: Statistical analysis of SO_2

SO_2 (µg/m^3)					
	Pre Lockdown	Lockdown 1	Lockdown 2	Lockdown 3	Lockdown 4
Minimum	1	6	4	3	2
Maximum	16	11	13	1	7
Average	5	9	8	5	5
SD	3	1	2	2	1
Number of days (out of total no of days) on which the measured value crossed the standard limit (80µg/m^3)	0(21)	0(21)	0(19)	0(14)	0(14)
% of days Exceeding the standard limit	0.00%	0.00%	0.00%	0.00%	0.00%

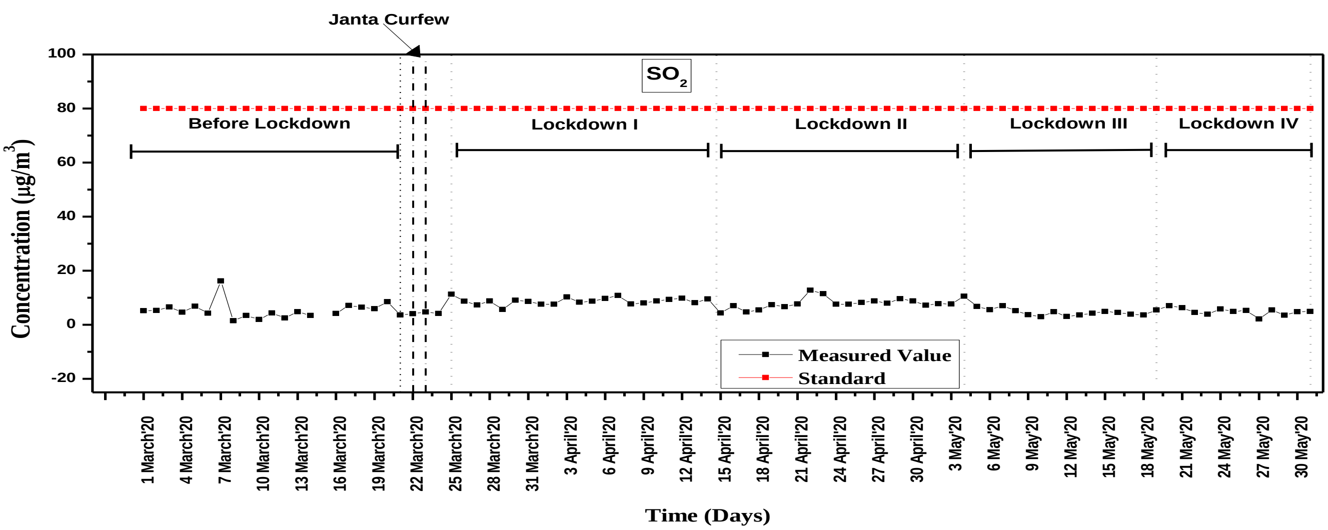

Figure-3: 24 Hourly average SO_2 comparisons

Trend and statistical analysis of NO_2 before lockdown and during lockdown 1-4

Comparative trend statistical analysis of NO_2concentration before lockdown and during lockdown 1 to 4 is shown in **Table-5 and Figure 4**. The graph and the statistical analysis below depict the 24 hourly concentration trend of NO_2 for pre-lockdown and lockdown periods. The concentration value remained below the standard value of 80µg/m^3 on all days.

Table-5: Statistical analysis of NO_2

	NO_2 (µg/m^3)				
	Pre Lockdown	Lockdown 1	Lockdown 2	Lockdown 3	Lockdown 4
Minimum	35	42	42	45	48
Maximum	72	69	67	63	69
Average	54	57	54	53	55
SD	11	8	8	5	6
Number of days (out of total no of days) on which the measured value crossed the standard limit (80 µg/m^3)	0(21)	0(21)	0(19)	0(14)	0(14)
% of days exceeding the standard limit	0.00%	0.00%	0.00%	0.00%	0.00%

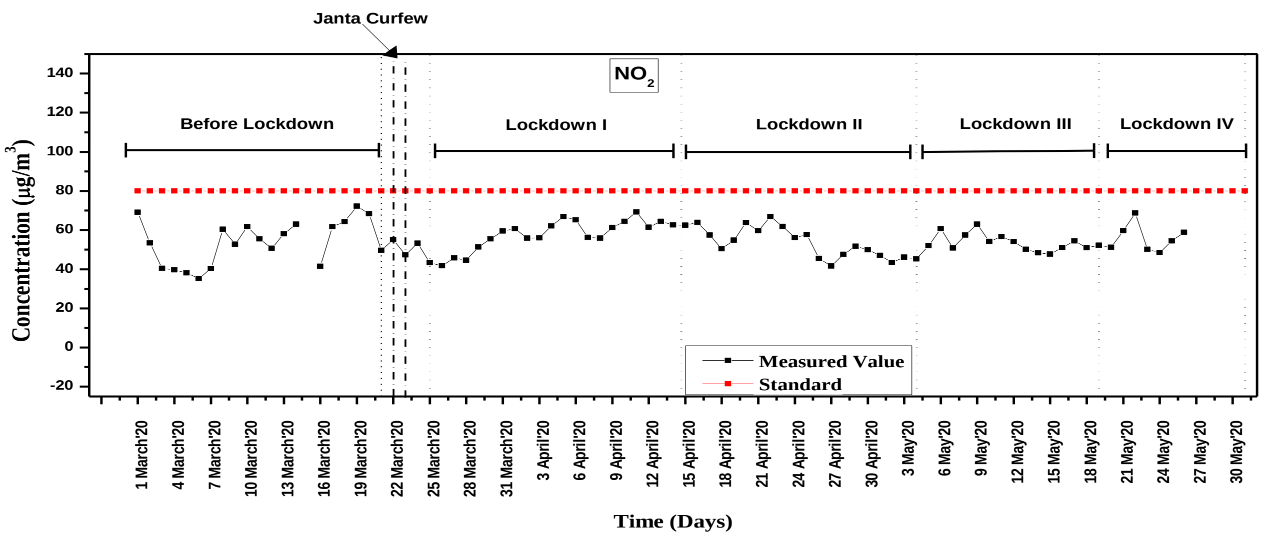

Figure-4: 24 Hourly average NO_2 comparisons

Trend and statistical analysis of CO before lockdown and during lockdown 1-4

Comparative trend statistical analysis of CO concentration before lockdown and during lockdown 1 to 4 is shown in **Tables-6(a), 6(b) and 6(c) and Figure 5**. For the first 8 hours' time interval 00.00 to 08.00 hrs average concentrations and standard deviation for CO were 1095 ±509 µg/m^3, 1949 ±514 µg/m^3, 1953 ±544 µg/m^3, 2052± 911 µg/m^3 and 1204 ±764 µg/m^3 for before lockdown, lockdown 1 , 2 , 3 and 4 respectively. For the next 8 hours' i.e. for time interval 08.00 to 16.00 hrs average concentrations for CO were 1190 ± 643 µg/m^3 , 1688 ± 517 µg/m^3, 1812 ± 947 µg/m^3, 1160 ± 640 µg/m^3 and 1212 ± 659µg/m^3 for before lockdown, lockdown 1, 2, 3 and 4 respectively. For the last 8 hours i.e. for the time interval 16.00 to 24.00 hour average CO concentrations were 1396 ± 731 µg/m^3, 1807 ± 787 µg/m^3, 1973 ± 598 µg/m^{3,}

1645 ± 538μg/m^{3}and 1019 ± 424 μg/m^3 for before lockdown, lockdown 1, 2, 3 and 4 respectively. The minimum concentrations for CO during 8 hours interval 00.00 to 08.00hour were 550 μg/m^3, 1140 μg/m^3, 1080 μg/m^3, 740 μg/m^3 and 160 μg/m^3 respectively for before lockdown, lockdown 1, 2, 3 and 4. The next 8 hours i.e. for time interval 08.00 to 16.00 hour minimum concentrations for CO were 550 μg/m^3 , 1020 μg/m^3, 150 μg/m^3, 370 μg/m^3 and 610 μg/m^3 respectively for before lockdown , lockdown 1 ,2 ,3 and 4. For the last 8 hours i.e. for time interval 16.00 to 24.00 hrs minimum concentrations for CO were 430 μg/m^3 , 820 μg/m^3, 1060 μg/m^3,770 μg/m^3 and 430 μg/m^3 respectively for before lockdown , lockdown 1, 2, 3 and 4. The maximum concentrations for CO during the 8 hours interval 00.00 to 08.00 hours were 2370 μg/m^3, 3260 μg/m^3, 2790 μg/m^3, 3420 μg/m^3 and 2460 μg/m^3 respectively for before lockdown, lockdown 1, 2, 3 and 4. For the next 8 hours i.e. for time interval 08.00 to 16.00 hour maximum concentrations for CO were 2800 μg/m^3 , 3100 μg/m^3, 3790 μg/m^3, 2030 μg/m^3 and 2470 μg/m^3 respectively for before lockdown, lockdown 1, 2, 3 and 4. For the last 8 hours i.e. for time interval 16.00 to 24.00 hour maximum concentrations for CO were 2900 μg/m^3, 4400 μg/m^3, 2950 μg/m^3, 2420 μg/m^3 and 1840 μg/m^3 respectively for before lockdown, lockdown 1, 2, 3 and 4.

In the first 8 hours period i.e. 00:00 to 08:00 hour, the concentration of CO exceeded the standard value one, ten, four, four and 3 days for pre-lockdown, first lockdown, second lockdown, third lockdown and fourth lockdown respectively. In the next 8 hour interval i.e. 08:00 to 16:00 hour the concentration of CO exceeded the standard value two, five, three, one and two days for pre-lockdown, first lockdown, second lockdown, third lockdown and fourth lockdown respectively. For the last 8 hours' time interval i.e. 16:00 to 24:00 hour CO concentration exceeded the standard value five, five, four, one and zero days for pre-lockdown, first lockdown, second lockdown, third lockdown and fourth lockdown respectively. Overall, the exceedance of CO level during time interval 00.00 to 8.00 hours varied between 4.76 % (pre lock down) to 47.62 % (lock down- 1), during the time interval 08:00 to 16:00 hour varied between 9.5% (pre-lockdown and fourth lockdown) to 23.81% (first lockdown). Finally during the last 8 hrs i.e. during 16:00 to 24:00 hrs the exceedance reduced from 23.81% (pre-lockdown) to 0% (fourth lockdown). Here, it is worth mentioning that analysis revealed that during lockdown 4 for none of the days CO crossed the standard limit as the burning of fossil fuel and residual mass completely minimized and the emission of CO also decreased as clearly evident from tables **6(c).**

Table-6 (a): Statistical analysis of CO for time interval 00:00 to 08:00hour

CO (μg/m^3) for time interval 00:00 to 08:00					
	Pre Lockdown	Lockdown 1	Lockdown 2	Lockdown 3	Lockdown 4
Minimum	550	1140	1080	740	160
Maximum	2370	3260	2790	3420	2460
Average	1095	1949	1953	2052	1204
SD	509	514	544	911	765
Number of days (out of total no of days)on which the measured value crossed the standard limit (2000 μg/m^3)	1(21)	10(21)	4(19)	4(14)	3(14)
% of days exceeding the standard limit	4.76%	47.62%	19.05%	19.05%	14.29%

Table-6 (b): Statistical analysis of CO for time interval 08:00 to 16:00hour

CO ($\mu g/m^3$) for time interval 08:00 to 16:00					
	Pre Lockdown	Lockdown 1	Lockdown 2	Lockdown 3	Lockdown 4
Minimum	550	1020	150	370	610
Maximum	2800	3100	3790	2030	2470
Average	1190	1688	1812	1160	1212
SD	643	517	947	640	659
Number of days (out of total no of days) on which the measured value crossed the standard limit (2000 $\mu g/m^3$)	2(21)	5(21)	3(19)	1(14)	2(14)
% of days exceeding the standard limit	9.52%	23.81%	14.29%	4.76%	9.52%

Table-6 (c): Statistical analysis of CO for time interval 16:00 to 24:00 hour

CO ($\mu g/m^3$) for time interval 16:00 to 24:00					
	Pre Lockdown	Lockdown 1	Lockdown 2	Lockdown 3	Lockdown 4
Minimum	430	820	1060	770	430
Maximum	2900	4400	2950	2420	1840
Average	1396	1807	1973	1645	1019
SD	731	787	598	538	424
Number of days (out of total no of days) on which the measured value crossed the standard limit (2000 $\mu g/m^3$)	5(21)	5(21)	4(19)	1(14)	0(14)
% of days exceeding the standard limit	23.81%	23.81%	19.05%	4.76%	0.00

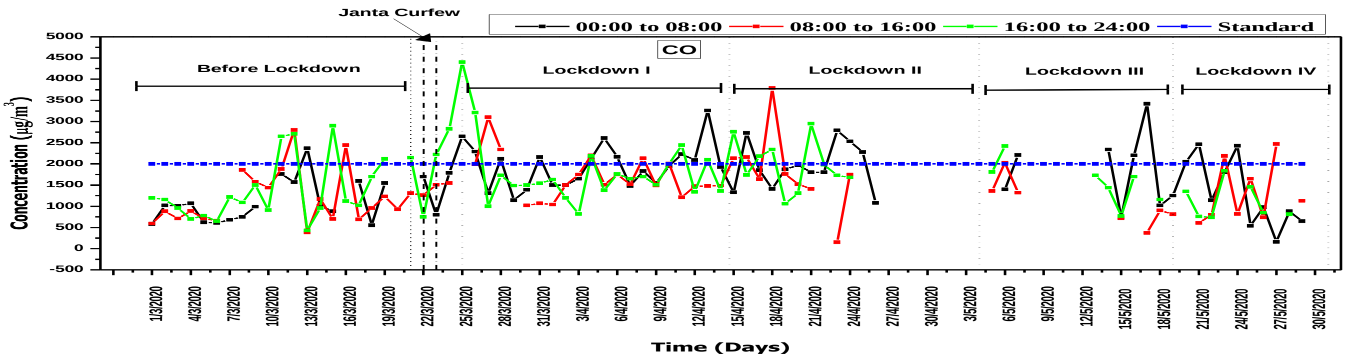

Figure-5: 8 Hourly average CO comparisons for three different time intervals

Trend of $PM_{2.5}/PM_{10}$ ratio graph before lockdown and during lockdown 1-4

$PM_{2.5}/PM_{10}$ ratio graph depicted in **Figure-6** shows that ratio started decreasing after 28th March and has been largely below 0.6 thereafter during the lockdown. This indicates that the fine particle decreased during lockdown which has a main role in air quality. The ratio fell drastically after 11th May and almost reached 0.3 on 21st May. As evident from the ratio of $PM_{2.5}$ and PM_{10} coupled with the above graphs, emissions of both parameters were reduced.

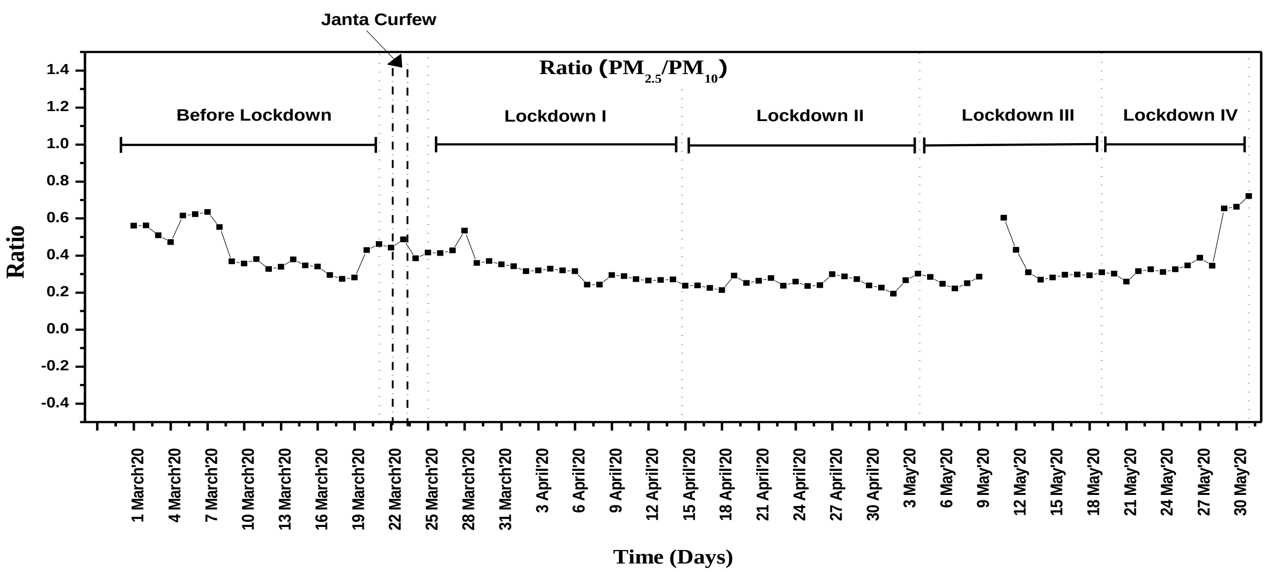

Figure-6: 24 hourly average Ratio of $PM_{2.5}/PM_{10}$

Effect of Lockdown in Hapur

Air Quality Indices were calculated according to the CPCB bulletin for pre-lockdown and lockdown 1,2,3,4 periods are shown in Table-7and Figure -7.The AQI values in Table-7 shows that Out of all 21 days of pre-lockdown 14 days had a moderate polluted category with AQI 100-200, 5 days with satisfactory category have AQI in the range of 50-100 and only 2 days of 5th and 6th march had good category with AQI 0-50. In 21 days of pre – lockdown, PM_{10} dominated 66.67 %, NO_2 19.04 % and CO with 14.28 % of time. For Pre lockdown, PM_{10} was found as dominating parameter. AQI category for dominating parameter PM_{10} ranged 100-250 and attributed to moderately polluted air. Out of all 21 days of Pre lockdown, 7 days were with satisfactory AQI i.e. ranges 67-89 and 14 days with moderate category of AQI values in the range of 100 to 181. In 21 days of lockdown-1, PM_{10} dominated 80.95%, and CO with 19.05% of time. For lockdown-1, PM_{10} was dominating parameter. AQI for dominating parameter PM_{10} ranged 100 - 250 and attributed to moderate category of polluted air. During the lockdown- 2, out of total of 19 days, there were 3 days with satisfactory AQI in range of 61 to 89 and 14 days with moderate AQI in the range of 116-183 and 2 days poor AQI in the range of 233-259. For lockdown-2, PM_{10} was dominating parameter. AQI for dominating parameter PM_{10} ranged between 61- 260 and attributed to poor category. In lockdown-3 out of total of 14 days, there were 3 days having satisfactory AQI in range of 73-92 and 11 days with moderate AQI in the range of 104-180. For lockdown-3, PM_{10} was the dominating parameter. AQI for dominating parameter PM_{10} ranges between 73 -180 and attributed to moderate polluted air. During lockdown- 4 out of total of 14 days, there were 3 days with good AQI in range of 24 to 44 and 2 days with satisfactory AQI in the range of 86 to 99 and 9 days with moderate AQI in the range of 141-183. In 14 days of lockdown-4, PM_{10} dominated 78.57%, $PM_{2.5,}$7.14% and CO with 14.29% of time. For lockdown-4 PM_{10} is dominating parameter.AQI for dominating parameter PM_{10} ranged between 86 -188 and attributed to moderated polluted category of air. The good category air quality with AQI 0-50 prevailed for 2 days in pre lockdown and for 0, 0, 0 and 3 days in lockdown 1, 2, 3 & 4 respectively. The satisfactory category air quality with AQI 51-100 prevailed for 5 days in pre lockdown and for 7, 3, 3 and 2 days in lockdown 1, 2, 3 & 4 respectively. However, the exceedance of the satisfactory AQI (100) was observed between 61.90% during pre-lockdown & lockdown-1 and 84.21% during Lockdown 2.The following table 7 summarizes the trends of the AQI variation during the different stages of the lockdowns.

Table 7: Analysis of AQI and Category during Pre-lockdown and different stages of lockdowns

AQI and category during Pre- and different stages of lockdowns					
	Pre Lockdown	Lockdown 1	Lockdown 2	Lockdown 3	Lockdown 4
Minimum	77 (satisfactory)	82 (Satisfactory)	114 (Mod. Poor)	104 (Mod. Poor)	87 (satisfactory
Maximum	225 (Poor)	181 (Mod. Poor)	260 (Poor)	180 (Mod. Poor)	188 (Mod. Poor)
Average	123 (Mod. Poor)	118 (Mod Poor)	154 (Mod. Poor)	135 (Mod. Poor)	150 (Mod. Poor)
SD	39(Good)	24(Good)	42(Good)	25(Good)	18(Good)
Number of days (out of total no of days) on which the measured value crossed the average AQI	7(21)	9(21)	6(19)	4(14)	5(14)
% of days exceeding the average AQI	33	43	31	28	36
Number of days (out of total no of days) on which AQI crossed the satisfactory AQI (100)	13(21)	13(21)	16(19)	11(14)	9(14)
% of days exceeding the satisfactory AQI (100)	61.90	61.90	84.21	78.57	64.29
Dominating Parameter	PM_{10}	PM_{10}	PM_{10}	PM_{10}	PM_{10}

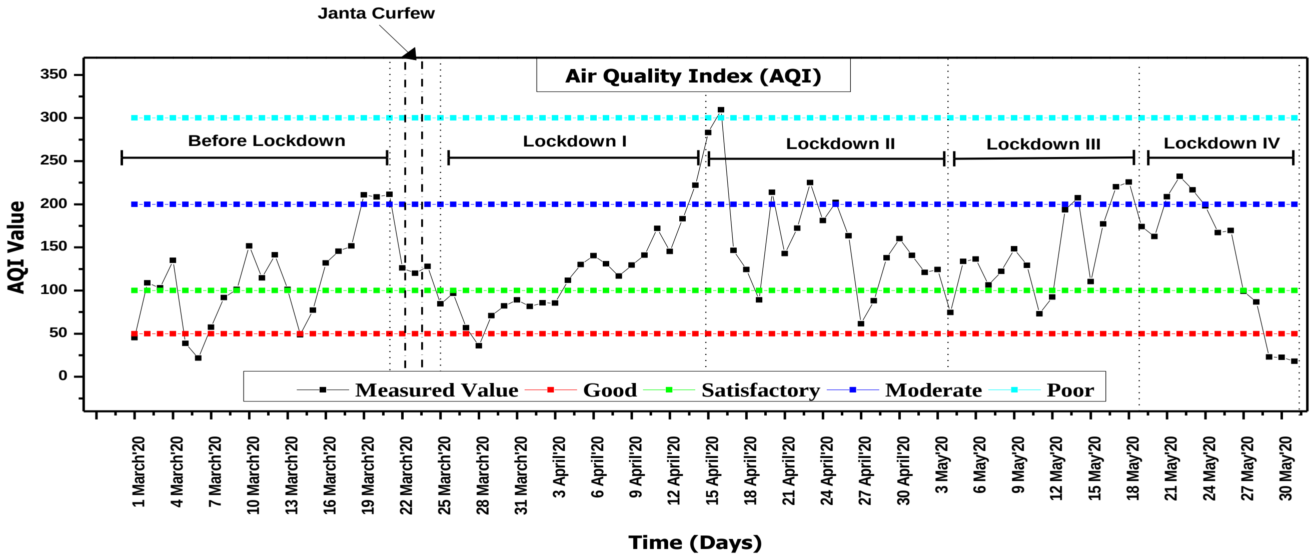

Figure-7: 24 Hourly average comparison of AQI

Conclusions

During the nation-wide lockdown period, no city entered the hazardous or severe category of AQI. The major findings of study are that as compared to pre-lockdown period air quality index has shown category of satisfactory and moderate during all stages of lockdown period. In comparison to the periods of lockdown 1,2,3,4 air quality has become worsened during the period of modified lockdown period. In all the lock down periods, PM_{10} levels were higher and the AQI decided it dominated parameter .The 24 Hour PM_{10}average and SD for Pre lock down, lock down -1,2,3,4 was estimated as 114 ± 55 µg/m^3, 114 ± 45 µg/m^3 , 162 ± 63 µg/m^3 , 138 ± 47 µg/m^3 and 143 ± 78 µg/m^{3}respectively. The 24 Hour $PM_{2.5}$average and SD for Pre lock down, lock down -1, 2, 3, 4 was estimated as 46 ± 21 µg/m^3, 35 ± 10 µg/m^3, 40 ± 15 µg/m^3, 41 ± 14 µg/m^3 and 46 ± 21 µg/m^3 respectively. The 24 Hour SO_2. average and SD for Pre lock down, lock down -1,2,3,4 was estimated as 5 ± 3µg/m^3, 9 ± 1 µg/m^3 , 8 ± 2 µg/m^3 , 5 ± 2 µg/m^3 and 5 ± 1 µg/m^3 respectively. The 24 Hour NO2. average and SD for Pre lock down, lock down -1,2,3,4 was estimated as 54 ± 11µg/m^3, 57 ± 8 µg/m^3, 54 ± 8 µg/m^3, 53 ± 5 µg/m^3 and 55 ± 6 µg/m^3 respectively.

The SO_2 and NO_2 levels remained below the standard value during the lockdown 1, 2, 3,and 4.Whereas, PM_{10} levels were exceeding the standard value by 66.67%,52.38%,84.21%,78.57% and 64.29% of total days during pre-lockdown, lockdown 1, 2, 3 and 4 (a decrease in levels of PM_{10} was observed in lockdown 1 & 4 only). The$PM_{2.5}$ levels were exceeding the standard value by 19.05%, 4.76%, 10.53%, 6.67% and 28.57% of total days during pre-lockdown, lockdown 1, 2, 3 and 4 (a decrease in levels of $PM_{2.5}$was observed in lockdown 1,2 & 3).The reduced NO_2 values were observed, largely due to the reduced presence of vehicles on the road and locked industrial activity. Overall, the exceedance of CO level during time interval 00.00 to 8.00hour varied between 4.76 % (pre lock down) to 47.62 % (lock down- 1), during the time interval 08:00 to 16:00 hour varied between 9.5% (pre-lockdown and fourth lockdown) to 23.81% (first lockdown). Finally during the last 8hours i.e. during 16:00 to 24:00 hour the exceedance reduced from 23.81% (pre-lockdown) to 0 % (fourth lockdown). Here, it is worth mentioning that analysis revealed that during lockdown -4 for CO none of the days it crossed the standard limit as the burning of fossil fuel and residual mass completely minimized and the emission of CO also decreased as clearly evident from tables6(c)**,** which may be attributed to maximum reduction of emission of CO during this period. The statistical analysis and comparative trend of different stages of LDs with Pre lockdown suggests that concentration of SO_2 & NO_2 remained below the standard limit.

In brief, there was little improvement in air quality during lockdown first (wrt AQI, PM10 & PM2.5) and fourth (wrt CO during 16-24 hour) as compared to 21 days of the pre-lockdown period. On March 22, 2020; the day of Janata curfew, AQI was moderate in Hapur, which remained moderate and little improved in lockdown first but again increased in consecutive lockdowns. The range of $PM_{2.5}$ concentration in pre-lockdown and lockdown 1, 2, 3, 4 was reported as 14–98µg/m^3, 19–60 µg/m^3, 18-74 µg/m^3, 22–65 µg/m^3, and 13–73 µg/m^3 respectively with exceedance of standard limit between 4.7% to 28.5% of days . The range of PM_{10} concentration in pre-lockdown, and lockdown 1, 2, 3, 4 was reported as 22- 211 µg/m^3, 36-222 µg/m^3, 62 -310 µg/m^3,73-220 µg/m^3, and 18 -233 µg/m^3 respectively with exceedance of standard limit between 52.38% to 84.21% of days . The range of SO_2 concentration in pre-lockdown, and lockdown 1, 2, 3, 4 was reported as 1-16 µg/m^3, 6-11 µg/m^3, 4-13µg/m^3, 3-11 µg/m^3, and 2-7 µg/m^3 respectively. The range of NO2 concentration in pre-lockdown, and lockdown 1, 2, 3, 4 was reported as 35-72 µg/m^3, 42 -69 µg/m^3,42 -67 µg/m^3,45-63 µg/m^3, and 48-69 µg/m^3 respectively. No significant effect of lockdown was observed in SO_2 & NO_2 and no violation of standard limit observed throughout the study. The 8 hourly CO concentration was analyzed and it was found exceeding the standard limit ranging from nil % (4th lock down in time interval 16:00 to 24.00hrs) to 47.62% % (1st lock down in time interval 00.00 to 08.00 hrs). The ratio of $PM_{2.5}$ and PM_{10} was also calculated to analyze the impact of fine particles in the composition of particulate matter due to lockdowns, which is observed ranging between 0.3 and 0.6. The results displayed reduced levels during lockdown-1, in comparison to others during the study period, which can be seen from the percentage of days they exceeding the standard limits for different pollutants. However, CO in the air have very fluctuating data during lock down periods. This case study disclosed no much impact of lockdown 2,3& 4 probably due to pollution generated from transport, vehicular movement, industries, construction and demolition activities, biomass and excessive burning, road dust which was curbed down due to the lockdown 1 restrictions and as result air quality was improved.

It was also observed during the lockdown period the transport activities to carry the essential goods were allowed and sometimes the traffic was also increased due to the mass movement during 13, 14 April specially the occasion of Baisakhi and Sir Ambedkar Jayanti. After LD 1, many labours were also travelling by different type of modes of transport and major halt on Tehsil crossing in Hapur. It is Delhi -Hapur-Garh road connecting the highway, so the movement of Trucks was frequent on Hapur–Delhi Road. Govt. Scheme to distribute Rashan to everybody was also implemented at that time, in Hapur warehouse storage of wheat is present, so many trucks and tractors were on the road to carry wheat from store to Govt. distribution points. These were factors which might be responsible for not showing appreciable reduction in overall pollution in Hapur. The findings reveal attention to the scope to reduce the air pollution by adopting some new polices and review of national standard limits & AQI basis in this perspective. We found that in LD -1, reduced pollution was recorded in those area also which were more polluted. AQI also reveal that in all PM_{10} was dominating pollutant, which impact health to great extent. It should be minimized to breath in fresh air. Although Hapur is a district headquarter now, but still some facilities are on the way to be generated. In this direction, it is pertinent to say that a single monitoring centre by CPCB is not enough to provide the clear picture of the state of the air pollution and at least one more air quality monitoring station preferably at Tehsil crossing, on Atarpura (a busy traffic intersection of Delhi –Garh and Meerut Bulandshar roads) is must to provide the better picture of the pollution levels in Hapur city so that more lucid effects may be recorded. Then, more vivacious scientific contributions towards the solution to menace of air pollution by carrying out more extensive studies in Hapur would be possible. Under the nationwide lockdown, the good air quality index was observed globally.

The government may think over the prevailing healthy air post covid-19 and may formulate a good policy to mitigate the problem of pollution including revisiting criteria of fixing NAAQS for PM10, PM2.5 &

AQI, which violate safe levels even during lockdown period even in a smaller town then how we can expect these may be controlled during normal period in bigger cities. Further, at least one-day heavy vehicle-free, one-day car-free, odd and even day type of consideration twice a month and up to week long complete lockdowns during peak pollution periods in winter season may be needed to reduce or combat the pollution besides augmenting public transport rather than private vehicles, promoting non-motorized & e- mobility, vacuum cleaning of roads, preventing dust from construction/demolition activities and total ban on burning of waste refuge & plant leaves etc It reflects that their control within laid down national standard limits is a challenge even in a smaller town. The study findings are unique in air pollution trend for a NCR town different from a metropolitan city like Delhi.

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References

1. Ambasht, R.S; and Ambasht, P.K; (2006), Environment & Pollution, 4th edition, New Delhi, CBS Publishers & Distributors, page 162,
2. Central Pollution Control Board (Ministry of Environment, Forest and Climate Change), CPCB. (2009).Comprehensive Environmental Assessment of Industrial Clusters. Ecological Impact Assessment Series: EIAS/5/2009– 2010. Central Pollution Control Board, Ministry of Environment and Forests, Govt. of India, New Delhi.
3. CPCB (2010). Status of the Vehicular Pollution Control Program in India Program Objective Series. PROBES/136/
4. CPCB Website (http://www.cpcb.gov.in)
5. Dhere, A.M., Pawar, B.B., Pardeshi, P.B., andPatil, D.A. (2008). Municipal solid wastedisposal in Pune City – An Analysis of Air and Ground Water Pollution. Current Science, 95,773–777.
6. Gupta Usha; (2008).Valuation Of Urban Air Pollution-A case study of Kanpur City in India, Environ resource. Economics, Vol.41 Issue 3, PP. 315-326.
7. Gurjar, B.R., Khaiwal, R., and Nagpure, A.S.(2016). Air Pollution Trends Over Indian Megacities and their Local to Global Implications. Atmospheric Environment, 142, 475–495.
8. Jain R., Palwa K.. (2016). Air Pollution and health *The Energy and Resources Institute*
9. Jamwal, P.,Mittal,(2006). International POPs Elimination Project (IPEP), Country Situation on Persistent Organic Pollutants (POPs) in India. PP.57.http://ipen.org/sites/default/files/
10. Khandar, C. and Kosankar, S. (2014). A Review of Vehicular Pollution in Urban India and its Effects on Human Health. Journal of Advanced Laboratory Research in Biology, V, 54–61.
11. Lawrence, A. and Fatima, N. (2014) Urban air pollution and its assessment in Lucknow City – the second largest city of North India.Science of the Total Environment, 488–489, 447–455.
12. Miller, M.R., Oxidative stress and the cardiovascular effects of air pollution. Free Radical Biology and Medicine, 2020. 151: p. 69-87.
13. Sharma, S.K., Mandal, T.K., Saxena, M.,Rashmi, Rohtash, Sharma, A., and Gautam,R. (2014). Source Apportionment of PM10 byusing Positive Matrix Factorization at an Urban Site of Delhi, India. *Urban Climate*,10, 656–670.

14. Singh, R.B. and Grover, A. (2015). Spatial Correlations of Changing Land Use, Surface Temperature (UHI) and NDVI in Delhi using Landsat Satellite Images. In: Singh, R.B.(ed.), *Urban Development Challenges, Risks and Resilience in Asian Mega Cities.* Advances in Geographical and Environmental Sciences; Springer, Japan,pp. 83–97
15. Shrivastav, R.K., Saxena, N., and Gautam, G.(2013). Air Pollution due to Road Transportation in India: A Review on Assessment and Reduction Strategies. Journal of Environmental Research and Development, 8, 69–77.
16. Shrivastava M., Ghosh A., Bhattacharyya R., Singh S.D.(2018).Urban Pollution in India. Centre for Environment Science and Climate Resilient Agriculture, Indian Agricultural Research Institute
17. Tyagi, S.K.; Upadhyay, V.K.; Kulshreshtha, D.; Kumar, S.; Krishnamurthy, P. and Sen, A.K. (2016). Study of Background Ambient Air Quality in Northern Himalayan Regions: Uttrakhand and Himachal Pradesh, India, Indian Journal of Air Pollution Control, Vol XVI, No. 1:1-9
18. .WHO/UNEP Report; (1992), Urban Air Pollution in Mega-Cities of the World. World Health Organisation and United Nations Environment Programme. Blackwell Publishers, 108 Cowley Road, Oxford OX4' 1JF Cambridge, UK..
19. Wong, M.S., Nichol, J.E., To, P.H., and Wang, J.,(2010). A simple method for designation of urban ventilation corridors and itsapplication to urban heat island analysis.Building and Environment, 45, 1880–1889.
20. Xiangdong Li, Ling Jin & Haidong Kan, Air pollution: a global problem needs local fixes; Nature 570, 437-439 (2019)

Comparative Assessment of Ambient Air Quality Standards

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Abstract

The first NAAQS of India was formulated in 1982. It was revised twice, in 1994 and 2009. The Ambient Air Quality guidelines issued by the World Health Organization (WHO) in 2005 for four main criteria pollutants are currently under revision (expected to be published in 2020). The revised AAQ guidelines are based on accumulated scientific evidences on impact of air quality on human health collected from all over the world. The main problem in ambient air quality of India is high concentrations of Particulate Matter (PM_{10} and $PM_{2.5}$) generated from the Gangetic plains, Thar desert (natural origin), urban centres and industrial areas (anthropogenic origin; mostly laded with As, Ni and Pb). Otherwise, the PM_{10} and $PM_{2.5}$ concentration in the outdoor air of many areas of rural India is below the Indian NAAQS. At some pristine locations like the Himalayas, North East India, Eastern Ghat, Western Ghats and the Nilgiris, India even achieves the WHO guidelines for both PM_{10} and $PM_{2.5}$ concentration. Air quality of such pristine areas should be preserved by prescribing stringent standard. Indian NAAQS of SO_2 is achieved throughout the country, even the WHO guidelines of SO_2 is achievable. India requires to revisit the NAAQS of NO_2 because the world has moved to 1-hour standard for NO_2. The Indian NAAQS of ozone meets the WHO guidelines. The Indian NAAQS for CO is most stringent in the world. It is advisable to revisit the NAAQS and frame attainable and more than reasonable concentrations for different geo-climatic regions of India.

Key words: National Ambient Air Quality Standards (NAAQS)

Introduction

Ambient air quality standards, are maximum acceptable concentration of pollutants in the outdoor air, measured for a certain period of time, over which the concentrations are averaged. The standards are specified for a variety of reasons including for the protection of human health, buildings, crops, vegetation, ecosystems, as well as for planning and other purposes. There is no internationally accepted definition but usually "standards" have some legal or enforcement aspect, whereas "guidelines" may not be backed by laws. Criteria can be used as a generic term to cover standards and guidelines (WHO 2018).

National Ambient Air Quality Standards (NAAQS) are set on the basis of scientific studies on air quality and human health by organizations like the World Health Organization. These AAQS are often similar - but not always, even if they are proposed for the same purpose (protection of human health). The standards / guidelines varied greatly between countries, despite universally generalizable scientific evidence of the substantial and serious health effects of air pollution. The discrepancy in dealing with scientific evidence reflects the diversity in abilities and priorities of policy makers to regulate air quality and to implement policies that aim at reducing air pollution and protecting health (WHO 2018).

WHO has documented the revised / proposed Ambient Air Quality Guidelines for four major pollutants, namely, Particulate Matter (separate for PM_{10} fraction and $PM_{2.5}$ fraction), Ozone, Nitrogen Dioxide and Sulphur Dioxide (WHO 2018). The guidelines are based on the outcome of extensive health studies conducted all over the world over the past few decades. According to the WHO, its Ambient Air Quality Guideline aim at air quality that have little or no effects on human health. Despite strong evidence of the serious health effects of ambient air pollution, air quality standards vary greatly among regions and countries.

Materials and Methods

Data collected from various sources indicates that the only problem in outdoor air quality of India is high concentrations of fine dust particles (referred as Particulate Matter fractions; PM_{10} and $PM_{2.5}$) generated from the Gangetic plains, Thar desert (natural origin), all urban centres and all industrial areas (anthropogenic origin) (CPCB 2017, 2018). Otherwise, the PM_{10} and $PM_{2.5}$ concentration in the outdoor air of rural India is below the Indian NAAQS (EIA Reports 2010-2020). At some pristine locations, like the North-Eastern part of India and the Himalayas, the WHO guidelines for both PM_{10} and $PM_{2.5}$ concentration are complying (EIA Reports 2010-2020).

The National AAQS of some developed countries, obtained from published literature, are compared with applicable WHO guidelines, and are presented in Table 1 to Table 8.

Table 1: Comparison of AAQS for $PM_{2.5}$

	Country/Organization	**Unit**	24-hour mean	Annual mean	Other
1	**WHO**	µg/m³	25	10	-
2	**India**	µg/m³	60	40	
3	**USA**	µg/m³	**35**	**12**	
4	**Australia**	µg/m³	**25 (Advisory)**	**-**	**-**
5	**Canada**	µg/m³	**28**	**10**	**-**
6	**European Union**	µg/m³	**-**	**25**	**-**
7	**China**	µg/m³	**35 (Cat 1 area)** 75 (Cat 2 area)	**15 (Cat 1 area)** 35 (Cat 2 area)	
8	**New Zealand**	**-**	**Not prescribed**		
9	**Qatar**	-	**Not prescribed**		

Note: In China, National Park is Category 1 area all other areas are Category 2 area

Table 2: Comparison of AAQS for PM_{10}

	Country/Organization	**Unit**	24-hour mean	Annual mean	Other
1	**WHO**	µg/m³	**50**	20	-
2	**India**	µg/m³	**100**	60	-
3	**USA**	µg/m³	**150**	**-**	**-**
4	**Australia**	µg/m³	**50**	**-**	-
5	**Canada**	-	**No standard**	**-**	-
6	**European Union**	µg/m³	**50**	**40**	-
7	**China**	µg/m³	**50** (Cat 1 area) 150 (Cat 2 area)	**40 (Cat 1 area)** 70 (Cat 2 area)	**-**
8	**New Zealand**	µg/m³	**50**		**-**
9	**Qatar**	µg/m³	**150**	**50**	**-**

Table 3: Comparison of AAQS for Ozone (O_3)

	Country/Organization	**Unit**	8-hour mean	1-hour mean	4-hour mean
1	**WHO**	μg/m³	100	-	
2	**India**	μg/m³	**100**	**180**	
3	**USA**	μg/m³	137.4 (0.07 ppm)	-	
4	**Australia**	μg/m³	-	**196.3 (0.1 ppm)**	**157 (0.08 ppm)**
5	**Canada**	μg/m³	**123.6 (0.063 ppm)**	**-**	**-**
6	**European Union**	μg/m³	**120**	**-**	**-**
7	**China**	μg/m³	100 (Cat 1 area) 160 (Cat 2 area)	160 (Cat 1 area) 200 (Cat 2 area)	
8	**New Zealand**	μg/m³	**No Standard**	**-**	
9	**Qatar**	μg/m³	**120**	**235**	**-**

Table 4: Comparison of AAQS for SO_2

	Country/Organization	**Unit**	24-h mean	Annual mean	Other averaging time
1	**WHO**	μg/m³	**20**	**-**	500 (10-min mean)
2	**India**	μg/m³	**80**	50 20 (Sensitive area)	-
3	**USA**	μg/m³			196 (1-h mean) (0.075 ppm) 13 (24-h mean) (0.005 ppm)
4	**Australia**	μg/m³	**209 (0.08 ppm)**	**52 (0.02 ppm)**	523(1-h mean) (0.2 ppm)
5	**Canada**	μg/m³	**183 (0.070 ppm)**	**13 (0.005 ppm)**	**-**
6	**European Union**	μg/m³	**125**	**-**	350 (1-h mean)
7	**China**	μg/m³	**150**	**20**	
8	**New Zealand**	μg/m³	**120**	**-**	**350 (1-h)**
9	**Qatar**	μg/m³	**365**	**80**	**-**

Table 5: Comparison of AAQS for NO_2

	Country/Organization	**Unit**	1-hour mean	24-hour mean	Annual mean
1	**WHO**	µg/m³	200	**-**	**40**
2	**India**	µg/m³	**-**	**80**	**40** 30 (sensitive area)
3	**USA**	µg/m³	**188 (100 ppb)**	**-**	**99.7 (53 ppb)**
4	**Australia**	µg/m³	**225.7 (0.12 ppm)**		56.4 (0.03 ppm)
5	**Canada**	µg/m³	**113 (60 ppb)**	**32 (17 ppb)**	-
6	**European Union**	µg/m³	**200**		40
7	**China**	µg/m³	200	**80**	**40**
8	**New Zealand**	µg/m³	**200**	**100**	**-**
9	**Qatar**	µg/m³	**400**	**150**	**100**

Table 6: Comparison of AAQS for Carbon Monoxide

	Country/Organization	**Unit**	1-hour mean	**8-hour mean**	24-hour mean
1	**WHO**	mg/m³	**Not prescribed**	**-**	-
2	**India**	mg/m³	**4**	**2**	-
3	**USA**	mg/m³	**40 (35 ppm)**	**10 (9 ppm)**	-
4	**Australia**	mg/m³	**-**	**10 (9 ppm)**	-
5	**Canada**	-	**Not prescribed**	**-**	-
6	**European Union**	mg/m³	**-**	**10**	**-**
7	**China**	mg/m³	**10**	**-**	4
8	**New Zealand**	mg/m³	**30**	**10**	**-**
9	**Qatar**	mg/m³	**40**	**10**	**-**

Table 7: Comparison of AAQS for Lead

	Country/Organization	**Unit**	24-hour mean	Annual mean	3 months mean
1	**WHO**		**Not prescribed**	**-**	-
2	**India**	µg/m³	**1**	**0.5**	
3	**USA**	µg/m³	**-**	**-**	0.15
4	**Australia**	µg/m³	**-**	**0.5**	-
5	**Canada**		**No standard**	**-**	-
6	**European Union**	µg/m³	**-**	**0.5**	-
7	**China**	µg/m³		**0.5**	1
8	**New Zealand**		**Not prescribed**	**-**	**-**
9	**Qatar**	µg/m³			**1.5**

Table 8: AAQS for other Parameters

	Name of Air Pollutants	Unit	WHO	India (Annual average)	European Union (Annual average)
1	**Benzene**	$\mu g/m^3$	**Not prescribed**	**5**	5
2	**PAH as Benzo(a)pyrene**	ng/m^3		**-**	1
3	**Benzo(a)pyrene** Particulate phase only	ng/m^3		**1**	-
4	**Ammonia**	$\mu g/m^3$		**100 (annual avg)** 400 (24-h avg)	-
5	**Arsenic**	ng/m^3		**6**	6
6	**Nickel**	ng/m^3		**20**	20
7	**Cadmium**	ng/m^3		**Not prescribed**	5

Note: WHO or any other country has not issued any guidelines or standards for above 7 parameters

Results and Discussion

PM_{10}: The proposed WHO guideline for 24-hour average PM_{10} is 50 $\mu g/m^3$. Australia, New Zealand and EU has accepted the WHO guideline. Indian standard for 24-hour average PM_{10} is 100 $\mu g/m^3$ whereas China and USA have fixed it at 150 $\mu g/m^3$. Canada did not prescribe any national standard for PM_{10} concentration. Concentrations of 50 $\mu g/m^3$ and less is found in India only at some pristine areas of Himalayas, Eastern Ghats, Western Ghats, Nilgiris and the North East. In urban centres of India, it mostly exceeds the national limit of 100 $\mu g/m^3$. In rural India, the outdoor concentration varies between 50 to 80 $\mu g/m^3$. The PM_{10} standard requires reconsideration based on geo-climate regions of India.

$PM_{2.5}$: The guideline proposed by WHO for 24-hour average $PM_{2.5}$ concentration is 25 $\mu g/m^3$. Australia has issued advisory but New Zealand and Qatar has not prescribed any standard for $PM_{2.5}$. Indian 24-hour average $PM_{2.5}$ standard is 60 $\mu g/m^3$ whereas China has fixed it at 75 $\mu g/m^3$. Concentrations of 25 $\mu g/m^3$ and less is found in India only at some pristine / virgin areas of Himalayas, Eastern Ghats and North East. In urban centres of India, it mostly exceeds the national limit of 60 $\mu g/m^3$. In rural India, the concentration varies between 35 to 60 $\mu g/m^3$. The $PM_{2.5}$ standard requires reconsideration on similar line because $PM_{2.5}$ is part of PM_{10}.

O_3: The WHO guideline for 8-hour average is 100 $\mu g/m^3$ and India has also fixed the limit at 100 $\mu g/m^3$. WHO did not prescribe any 1-hour average guidelines for O_s. All other countries have fixed the limit for 8-hour average higher than the WHO guidelines. Concentrations of 100 $\mu g/m^3$ and less is generally found all over India.

SO_2: The WHO guideline for 24-hour average is 20 $\mu g/m^3$. India has fixed the limit for 24-hour average at 80 $\mu g/m^3$ whereas China has fixed it at 150 $\mu g/m^3$. EU Australia, Canada has fixed the SO_2 limit much higher than the WHO guidelines. Concentrations around 20 $\mu g/m^3$ is generally found all over India.

NO_2: The WHO guideline for 1-hour average is 200 $\mu g/m^3$. WHO, USA and EU did not prescribe any 24-hour average guidelines for NO_2. India and China have fixed the limit for 24-hour average at 80 $\mu g/m^3$. Concentrations of 10 to 60 $\mu g/m^3$ is generally found all over India. Since NO_2 is a criteria pollutant prescribed by WHO and USEPA, its averaging period should be harmonised.

Pb: The WHO did not prescribe any guideline for lead. USA, EU, China and India prescribed annual mean limit of 0.5 $\mu g/m^3$ for Pb. Canada has not fixed any limit for Pb. Only India has fixed the 24-hour average limit of Pb at 1 $\mu g/m^3$. Concentrations of less than 0.5 $\mu g/m^3$ is generally found all over India. Pb is an important constituent of PM from the point of industrial emissions; like the metallurgical industries.

CO: The WHO did not prescribe any guideline for CO because it is not considered as criteria pollutant. Canada has not fixed any limit for CO. USA, New Zealand China and Qatar prescribed 1-hour average limit of CO; 17, 30, 10 and 40 mg/m^3 respectively. USA, Australia, EU prescribed 8-hour average limit of 10 mg/m^3 of CO compared to Indian limit of 2 mg/m^3. The NAAQS of 1-hour average CO in India is 4 mg/m^3, which is very stringent. Concentrations of less than 0.1 mg/m^3 is generally found in outdoor air all over India. The concentration of 4 mg/m^3 and above is found only at dense traffic intersections and along the major traffic corridors. Indian standards for CO requires careful consideration during the revision of NAAQS.

Benzene, PAH, Ni, As and Cd: Only European Union has prescribed NAAQS for Benzene, PAH, Ni, As and Cd. India prescribed NAAQS for Benzene, PAH, Ni and As but excluded Cd. The NAAQS of India and EU are similar, except that EU prescribed NAAQS for Poly Aromatic Hydrocarbons in ambient air to be reported as Benzo(a)pyrene whereas India prescribed for Benzo(a)pyrene in particulate phase. The WHO did not prescribe any guidelines for Benzene, PAH, Ni, As and Cd. Ni, As and Cd are important constituents of PM from the point of industrial emissions, like the metallurgical industries. Benzene and PAH are important, particularly for the work zone air quality and vicinity of coal and oil based industrial establishments, as they are carcinogenic in nature.

NH_3: India is the only country in the world that has prescribed NAAQS for ammonia. The NAAQS is 100 $\mu g/m^3$ (annual average) and 400 $\mu g/m^3$ (24-hour average). Ammonia is an essential parameter in outdoor air around the urea manufacturing plants.

India is a signatory to the Sustainable Development Goals of United Nations (2016) and is a member country of World Health Organization (WHO). WHO is the custodial agency for three air pollution-related Sustainable Development Goals (WHO 2016): i) Mortality from air pollution, ii) Access to clean fuels and technologies and iii) Air quality in cities. WHO assists its 194 Member country in sharing information related to health impacts of air pollution (WHO 2018). Therefore, it is desirable that India may consider different category standards for PM for different geo-climatic regions and settings, keeping in mind that such standards should be practically attainable. Indian NAAQS of SO_2 is achieved throughout the country, even the WHO guidelines of SO_2 is achievable. India requires to harmonise the NAAQS of NO_2, because the world has moved to 1-hour standard for NO_2. The Indian NAAQS of ozone meets the WHO guidelines and India is achieving this standard. The Indian NAAQS for CO is most stringent and requires careful consideration for relaxation. The main criteria pollutants like PM_{10}, $PM_{2.5}$, SO_2, NO_2 and O_3 may be segregated from the source specific pollutants (CO, Benzene, PAH and NH_3). Relevant details on monitoring requirements; namely the number of stations, parameters, frequency and instrumentation may be specified separately for National Ambient Monitoring Program, Air Quality of Cities, Air Quality of Industrial Areas, Background Air Quality, Air Quality of Pristine Locations, and routine studies like the Environmental Impact Assessment Study and Regional Carrying Capacity Study. It is prudent to harmonise NAAQS with the world community and fix workable, attainable and more than reasonable concentrations and averaging times. Air quality of pristine areas in India should be carefully preserved by prescribing stringent standard.

References

1. Ambient Air Quality Data Generated by EMTRC Laboratory at 5 locations for Indian Oil Corporation Limited, Bongaigaon Refinery, PO: Dhaligaon, Dist Chirang, Assam, July 2017 to June 2020.
2. Ambient Air Quality Data Generated by EMTRC Laboratory for NTPC Limited at 4 locations, PO: Salakati, District Kokrajhar, Assam, March 2018 to June 2019.
3. Ambient Air Quality Data Generated at 20 locations by EMTRC Laboratory for the Pipeline of DNP Limited from Duliajan to Numaligarh, PO: Duliajan, District Dibrugarh, Assam, June 2017
4. CPCB Annual Report, 2017-18
5. CPCB Annual Report, 2018-19
6. European Environment Agency, Air Quality Standards, 21Nov 2019 (www.eea.europa.eu)
7. EIA report of Uttaranchal Power Sector Investment Program- Sub Project-I (Sobla Basin HEP) by Uttarakhand Vidyut Jal Nigam Limited, Tehsil Dharuchala, District Pithoragarh, Uttarakhand, January 2010
8. EIA report of Tidong HEP (100 MW) by NSL Renewable Power Limited, Tehsil Moorng, District Kinnaur, Himachal Pradesh, November 2011
9. EIA report of Rufrin HEP (45 MW) by SB Power Limited, Tehsil Dodrakwar, District Shimla, Himachal Pradesh, September 2014
10. EIA Report of Heo Hydro Electric Project, Sub-division Meehuka, District West Siang, Arunachal Pradesh, Report by University of Delhi, May 2014
11. EIA Report of Kirthai-I HEP (390 MW) by J&K State Power Corporation Limited, Tehsil Paddar, District Kishtwar, Jammu & Kashmir, January 2011
12. EIA Report of Rongnichu HEP (115 MW) by Madhya Bharat Power Corporation Limited, District East Sikkim, May 2019
13. EIA Report of Onshore Oil & Gas Exploration in AA-ONHP-2015/5 Block in Jorhat, Lakhimpur and Sibsagar District, Assam by Vedanta Limited, October 2019
14. EIA Report of Onshore Oil & Gas Development and Production, EPS and Laying of Pipeline in Duarmara Block, Margarita, District Tinsukia, Assam, November 2019
15. EIA Report of Onshore Oil & Gas Exploration in AAONHP-2017/11 Block in Jorhat and Golaghat District, Assam by Vedanta Limited, October 2019
16. EIA Report of Onshore Oil & Gas Exploration in AAONHP-2017/14 Block in Karimganj and Hailakandi District, Assam and Kolasib District of Mizoram by Vedanta Limited, October 2019
17. EIA Report of Onshore Oil & Gas Development, Drilling and Production in Jorajan Block in Tinsukia and Dibrugarh District, Assam by Vedanta Limited, October 2018
18. EIA Report of New Umrangshu Limestone Mine in Teshil Umrangshu, District Dima Hasao, North Cachar Hills Assam by Assam Mineral Development Corporation Limited, December 2014.
19. ESIA Report of Assam Inland Water Transport Project on Brahmaputra River, by Govt of Assam, May 2019
20. Joss et al, Time to Harmonise National Ambient Air Quality Standards, International Journal of Public Health, February 2017, 62 (4) pp 453-462
21. MOEFCC, National Ambient Air Quality Standards, Gazette Notification GSR 826 E, 16th November 2009.
22. Teesta State VI HEP by Lanco Energy Pvt Ltd., Report by Forest, Environment and Wildlife Management Department, Govt of Sikkim, Khanitar, District South Sikkim, 2019
23. USEPA, Criteria Air Pollutant, 2019 (www.epa.gov)
24. WHO, Air Quality Guidelines - Global Update, 2005.
25. WHO, Ambient (Outdoor) Air Pollution, 2May 2018
26. WHO, Global Air Quality Database, WHO (update 2018)

RECOMMENDATION OF IAAPC-DELHI CHAPTER BRAINSTORMING SESSION ON SHORT TERM AND LONG TERM SOLUTIONS FOR IMPROVEMENT OF AIR QUALITY IN DELHI-NCR HELD ON 30th NOVEMBER 2019.

Indian Association for Air Pollution Control (Delhi Chapter) organised one day Brainstorming Session on 30th November 2019, titled "Long Term and Short-Term Solutions for Restoring the Air Quality in Delhi-NCR" at the Constitution Club, Rafi Marg, New Delhi. The session was attended by 40 air quality experts (attendance list attached).

Dr. J.S.Sharma (President IAAPC) extended warm welcome to all the experts and reiterated the objectives of the session. Plenty of news on air pollution in Delhi – NCR is doing rounds post Diwali 2019, during the past 6 weeks. The variety of statements published in the newspapers are often confusing to the general public. IAAPC, being a body of air quality professionals, thought it prudent to conduct a brainstorming session at this stage and submit its opinion and recommendations for the benefit of civil society.

Guest of Honour Dr. J.P.Gupta (Chairman-EAC-Industry 2) delivered the inaugural address and told the attendees not to compare the problem of Delhi with other cities of the world and try to find innovative solutions with a positive attitude. He urged the experts to pick up only 2 or 3 issues ata time, work on it to find a feasible solution.

Dr. Rakesh Kumar (Director NEERI) said that there is a need to communicate with general public in a right manner, emissions from few sources are yet to be tagged in inventory, like use of cow dung, charcoal and tyres as fuel in tandoors and domestic chulhas, garbage and solid wastes burning, etc. He said that meteorological factors are mainly responsible for the smog episodes.

Dr. J.K.Moitra (VP-IAAPC) presented an overview of existing air pollution issues in Delhi-NCR. He deliberated on following four points.

a. Instruments and Quality of Data: There are 37 CAAQMS in Delhi, that are operated by three different agencies; namely Central Pollution Control Board, Delhi Pollution Control Committee and India Meteorological Department / Indian Institute of Tropical Meteorology. The instruments have different range of measurement, the CPCB and IMD stations cap maximum $PM_{2.5}$ at 999 µg/m^3, whereas DPCC stations cap the maximum $PM_{2.5}$ at 5000 µg/m^3. Therefore, the spikes during Diwali and Smog episodes are different, leading to confusion in public. There are calibration related issues. Data from some location are not representative. Therefore, the Air Quality Index (AQI) values calculated for the 37 locations suffers from uncertainty.

b. Air Quality Index: The AQI is calculated based on hourly average values, then mean of 24 values are taken as daily average. This concept is erroneous. Implementation of Graded Response Action Plan (GRAP) is based on AQI, therefore, all uncertainties in CAAQMS location, operation, calibration and AQI calculation should be removed.

c. Odd-Even scheme: The odd-even scheme implemented from November 4 to 14, 2019 (8 AM to 8 PM, only for private cars) showed visible impact on traffic flow, smooth congestion free flow of traffic was observed. Obviously, there was less exhaust emissions. But the impact of the odd-even scheme was not quantified.

d. Unidentified Sources: Many sources of air pollution inside Delhi are not factored in GRAP, namely from use of Diesel Engines in Railways (Shatabdi/ Rajdhani express & Shunting Engines), Increase in Aviation Traffic (Number of daily aircraft movement at IGI Airport is approx. 5000), use of CNG in automobiles and thermal power plants, untreated emissions from wood crematoria and partially treated emissions from CNG/wood crematoria, etc.

Dr. B.Sengupta (Former Member Secretary, CPCB) described the various mitigation measures required to control the non-seasonal pollution like pollution from transport, small and medium scale industry, Coal based Thermal Power Plans, MSW dumpsites and Plastic Wastes, DG sets and Construction dust and seasonal pollution like stubble burning. He stressed the urgent need for capacity building and suggested an action plan so that the air pollution issues of Delhi-NCR could be solved.

Dr. Sumit Sharma (TERI) presented the results of source apportionment study, highlighting the sources contributing to air pollution in Delhi during winter and possible reduction strategies. The experts advised TERI to validate the modelling results by using tracer techniques/ chemical finger printing studies.

Dr. Virendra Sethi (IIT-Bombay) presented an overview of lessons learnt from recent case studies. He stressed the need for Capacity Building for Planning and Implementation of source control (Compliance). He said that by using satellites, a relative measurement of pollution could be made across larger areas. Therefore, efforts towards developing a satellite for air quality measurment, and data retrieval should to be given importance

Dr. A.L.Agarwal, (Former Dy Director, NEERI) stressed that Air Shed of Delhi-NCR should be clearly defined by following a scientific approach, with Latitudes and Longitudes of each boundary. He said that the representative areal domain of each monitoring station should be defined. He also said that Source Contribution for Each Town of NCR should be done through comprehensive emission inventory, Source Apportionment Study & air pollution modeling for all three seasons.

Dr. Abhijit Pathak, (Senior Scientist, CPCB) pointed the gaps in Source Apportionment Studies conducted by different organizations, mainly because of poor and incomplete emission inventory, half-hearted use of CMB model and scanty data on organic aerosol. He cited two examples of IIT and TERI. IIT findings indicate - Control in Fly ash and road dust can lower $PM_{2.5}$ by 54% in Summer and TERI findings indicate - Control in road dust, construction and vehicle can lower $PM_{2.5}$ by 55% in Summer. Similarly, IIT findings indicate - Control in Biomass burning and Vehicle movement can lower $PM_{2.5}$ by 51% in Winter and TERI findings indicate - Control in Biomass burning and Vehicle movement can lower $PM_{2.5}$ by 53% in Winter.

Thereafter, the experts deliberated on the issues and options and came out with following observations:

1. Two CAAQMS stations, namely Anand Vihar and ITO are located near heavy traffic area, represents the impact of vehicular pollution. Hence, they should be excluded from calculation of AQI. (Immediate Action by CPCB and DPCC)

2. Reporting of AQI should be done by taking average concentration of previous 24 hours. Calculating hourly average and then taking average of 24 values is misleading. (Immediate Action by CPCB and DPCC)

3. Use of charcoal and coal dung in Tandoors should be banned in Delhi-NCR. (Immediate by CPCB)

4. Contribution of emission sources (like stubble burning, vehicular exhaust, small and medium scale industry, coal and CNG burning in power plants, etc) to 24-hour average $PM_{2.5}$ concentration of Delhi should be presented only if derived emission factors are used and chemical transformations of SO_2 and NOx to sulphates and nitrates (ultimately to $PM_{2.5}$) are adequately considered. Further the results obtained after modelling should be validated using actual field measurement. Uncertainty analysis should be reported along with accuracy and precision. (Immediate direction by CPCB)

5. System should be put in place to check emission compliance in DG Engines used by Indian Railways for Rajdhani/ Shatabdi express trains and Shunting Locomotives. Emission load from such locomotives should be determined and checks and balance should be put in place during severe+ AQI. (Short Term by CPCB)

7. Emission load from all Gas based power plants in Delhi-NCR region should be determined and checks and balance should be put in place during severe+ AQI. (Short Term by CPCB

8. Emission standard for in-use DG sets should be evolved and implemented urgently. (Short Term action by CPCB)

9. Implementation of comprehensive inspection and maintenance program for in-use vehicles in place of PUC system (as recommended in Auto fuel Policy – Vision 2025 by Niti Ayog) for reduction of on-road vehicle emission. Short term action by CPCB and Transport Deptt of NCT states.

10. A group of about 200 scientists / engineers (20 for CPCB, 10-15 each for Gujarat, Maharashtra, Tamil Nadu, Orissa, Karnataka, UP, MP, Bihar, Haryana, Rajasthan, Punjab, Kerala, West Bengal, Andhra Pradesh, Himachal Pradesh etc.) should be recruited and properly trained in all aspects of air pollution management. The personnel should be recruited centrally by CPCB (after written examination, group discussion and final interview). After training they may be posted in respective state for solely working in the field of air quality management. (Long Term)

11. The air pollution mitigation group (200 personnel from CPCB and SPCBs) should be trained in following areas (Long Term)

a) Emission inventory preparation of various air pollutants.

b) Source apportionment studies in CPA / Non-attainment cities

c) Development of emission factor for various air polluting industries.

d) Air quality monitoring including calibration of analysers and data processing.

e) EC / OC analysis of PM2.5 / PM10

f) Emission assessment and control due to agriculture residue burning.

g) Emission assessment and control from municipal solid waste burning

h) Emission assessment and control from industrial plastic waste and other industrial waste burning.

i) Vehicular pollution control including adoption of Bharat Stage VI standards

j) Fuel quality improvement including Bharat Stage VI fuel.

k) Retrofitting of diesel particulate filter in in-use commercial diesel vehicles.

l) Integrated approach for inspection and maintenance for in-use (on-road) vehicles.

m) Electric vehicle availability in fleet and recycling of lithium from battery

n) Air pollution control from thermal power plants including SOx / NOx control by installing FGD and DeNOx system.

o) Air pollution control from Iron and Steel plant including fugitive toxic gas emission control from coke oven batteries.

p) Air pollution control cement plants including co-processing of waste in cement plants (dioxin/furan measurement)

q) Air pollution control from oil refinery / petrochemical including VOC assessment.

r) Air pollution control from SSI units (brick kiln, induction and arc furnace, foundry, rerolling mills etc.)

s) Air pollution control from diesel generating sets.

t) Role of Micro meteorology in Air Pollution control .

After intense discussion and careful consideration, the experts are of the view that following measures should be taken up in entire Delhi NCR. The recommendations are given below in three categories: Immediate; Short time; Long term.

Immediate

1. Comprehensive inspection and maintenance system for on-road vehicles should be introduced in place of PUC system.
2. Vapour recovery system should be installed in all petrol pumps.
3. Fuel adulteration should be checked by increasing the surveillance.
4. All mobile towers in Delhi-NCR should be equipped with Solar Power or CNG fired DG.
5. All other DG sets should be operated only after installing pollution control devices to control Particulate Matter.
6. No new polluting industry should be allowed to set up in Delhi-NCR from 1-1-2020.
7. Industrial waste burning should be stopped immediately by increasing the surveillance and imposing heavy fine and imprisonment.
8. Necessary pollution prevention systems should be implemented for brick kilns, Stone crushers and hot mix plants.
9. Demonstration pilot-plants should be established for showcasing effective measures for dust control from construction sites.
10. Ensure that there is no fire in MSW dumpsites immediately by increasing the surveillance and imposing heavy fine and imprisonment.

Short term

1. System should be put in place to check emission compliance in Aircrafts (as per Guidelines of International Civil Aviation Organization). Emission load from IGI Airport should be determined and checks and balance should be put in place during severe+ AQI. Aircraft landing should be restricted post 5 PM during winter season.
2. Emission standard for wood-based Crematoria and CNG/Electric fired crematoria should be notified immediately and all crematoria in Delhi-NCR should be directed to install scrubbers /suitable air pollution control equipment.
3. Emission standards notified by Ministry of Environment, Forests & Climate Change in December 2017 for coal based Thermal Power Plants should be implemented immediately in Delhi-NCR.
4. Immediate measures should be taken for effective collection of Plastic Wastes and its recycling.
5. Public transport system needs immediate augmentation and should be made safe, clean and punctual with improvement in last mile connectivity.
6. In addition to above, tree plantation drive to be promoted and areas where plantation to be done be advertised for public support and cooperation.

Long Term

1. Policy mismatch should be rectified. A single regulatory body should be set up to deal with all matters related to prevention and control of pollution, including grant of environmental clearance to all other projects involving air pollution (except air polluting industries that should be banned).
2. Sale and Use of VOC containing paints should be banned

3. Waste to Energy plants, with internationally best available pollution control design (ensuring near zero pollution discharges) should be commissioned in Delhi-NCR.
4. Cycle track and foot path should be made user friendly and should be provided with soft carpeting with appropriate grass species. This will enormously curtail road dust.
5. From 1-4-2020 only Electric two-wheelers should be sold and registered in Delhi- NCR
6. Attractive incentives should be provided to individuals and firms who purchase and use electric vehicles
7. Clean technology should be promoted for Brick Kilns. All brick kilns should switch over to gas. demonstration plants should be installed.
8. Public awareness campaigns should be augmented with demonstration plants and / or pilot projects.

Workshops Jointly Organised by CSIR-NPL and IAAPC: Memories and Recommendations

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The association of CSIR-NPL and IAAPC was seeded way back in year 2001 when IAAPC launched its Delhi Chapter. Several scientists of CSIR-NPL have been the active members of this association. Here, we take an opportunity to highlight some of the recent activities especially workshops that were successfully planned and jointly organised by CSIR-NPL and IAAPC, Delhi Chapter on the very important issues, and the recommendations of these workshops in brief.

National Workshop on Black Carbon and $PM_{2.5}$

We take this opportunity to pay my tribute to late Swami Gyan Swaroop Sanand ji (Prof. G. D. Agrawal), who actively attended the joint workshop organised on an important topic "Black Carbon/$PM_{2.5}$: Measurement, Impact and Control", April 19, 2014 at CSIR-NPL. About 80 participants from students to academicians, regulators, and industry personnel participated in the workshop. All speakers in the program made the presentations followed by the interaction with the participants. Because of the limited space of pages in the journal, it is not possible to write about all the technical details of discussions during the workshop but we would like to quote an important point highlighted by Swami ji here. He said that "black carbon particles are really slow poison to Himalayan glaciers and thus to Himalayan rivers. A multifaceted approach for minimising the sources of BC emission is needed" [1].

Photograph 1. Memories of Swami ji during Black Carbon/$PM_{2.5}$ workshop held at CSIR-NPL on April 19, 2014

Herewith, we present few photographs in his memory of this workshop, Other points highlighted during discussions, and important to mention here in brief are that although climate implications of BC have been researched upon considerably throughout the globe, the research on health issues related to it is lacking but is equally important especially in urban cities and hence needs more emphasis. Also, it was recommended that BC should be incorporated as one of the regulatory parameters in national air quality standards and the measurement method should be standardized for its reliable measurements [2].

Indo-China workshop: Mitigation of Air Pollution

An Indo-China workshop was organized jointly by IAAPC and CSIR-NPL on January 9, 2019 at CSIR-NPL. Again, the topic was very relevant, and need of the hour, i.e. “Trends of Air Pollution and Strategies for its Mitigation in Asian Megacities". About 70 participants from CSIR-NPL, IAAPC, CPCB, industries, and other organisations attended this workshop including 8 delegates from Chinese counterpart. I am presenting a group photograph and other clips of this workshop, which revives some of the memories of this very successful and unique workshop, Photograph 2. Chinese experts presented their experiences on controlling air pollution problem in Chinese megacities. They reported that within 2-3 years they could control about 25-30% of $PM_{2.5}$ concentration as a first step by reliable study of the sources, and then accordingly controlling them using specific technology or reduce the emission at sources itself. The aim of this workshop was to learn from the experiences of Chinese experts in abatement of air pollution and ascertain the possibility and feasibility in Indian context to implement them in similar way. Experts were also in view of that the filter towers are good for cleaning the air for a defined area or volume of air, e.g. park, playground, apartment open space, etc. [3] but may not be much effective to clean the air of a whole city altogether. Major sources discussed in Indian context were road dust and local activity which includes private or public transport, construction activities and small industries (also includes emission from restaurants and open burning practices), and thus strategic planning is needed to control the emission from these sources [4].

Post-AdMet Workshop: Criteria for Air Quality Measurement Devices

In this year on January 7th, one more joint workshop as Post-AdMet workshop was organised at CSIR-NPL on “Criteria for Appropriate Devices used for the Measurement of Air Quality in India”. The workshop on this topic was necessitated by the fact that the rapid evolution of technology has made possible a wide emergence of several new measurement concepts in air quality monitoring field. For example, in these days, among the community the sensor-based measurements are getting popularity and are extensively talked about. Similarly, a great amount of attention is paid on optical technology where light absorption/emission and scattering are the key phenomena for the measurement. Although they do not realise measured quantity directly as primary methods do, but these techniques can provide continuous on-line measurement data, thus facilitates to make faster decisions, are convenient to use, and most importantly they are cost-effective so enable the user to use them in cluster in closer proximity for better identifying the hot spot of air pollution. On the other hand, they have several limitations. For example, large uncertainty in measurement, narrow range of ambient parameters under which they can be used, limited application site where they can deploy, etc. Other important gap for deploying these technologies is that they have no space in the regulatory standards and also in the compliance standards. Moreover, if these technologies are adequate, a discussion on the need to revise the standards and to form new protocol standards should be made. Also, as per the need of Indian scenario, a certification scheme for the technology approval and promotion is essentially required [2, 5]. Therefore, it is important that by looking at all these aspects and "fit for purpose" usage of these emerging and well-established technologies, a brain storming workshop should be called for the in-depth discussion on the topic. In view of all these issues, this joint workshop was organised. More than 80 participants actively took part in this workshop. A group photograph is presented in Photograph 3.

Photograph 2. The group photo and other clips taken during the Indo-China workshop held on January 9, 2019 at CSIR-NPL

In brief following conclusions were made at the end during the panel discussions and from the workshop presentations:

- Importance of maintenance of data quality in respect of air quality monitoring and the impact of it on policies and general public domain.
- All systems/methods should be calibrated to traceable standards. Calibration is needed for all parameters/systems involved taking part in calculations of results.
- India has wide range of meteorological and environmental conditions. Therefore, we need our own instrument design to meet and cover such conditions and pollution levels from very low to high. Also instrument design should withstand erratic voltage and frequency fluctuations, and instrument should be resistant to abrasive pollutants.
- Devices should undergo rugged test in Indian environment before becoming acceptable.

- Should be Indigenous – so that their operability is ensured for at least 10-15 years. Indigenous instruments/devices should be promoted which will support make in India and self-reliant India program of Government of India and also create a path of employment in the country.
- Design should be simple, easy to operate and maintain in field by the quality of manpower available in India.
- Instrument should be as versatile as possible. It should be usable in most of the field situations with the help of some accessories.
- Technology used in instruments should meet requirements laid down by Indian regulatory bodies. Also, the instrument should meet the desired objective of monitoring.
- Certification of instruments/devices used in air quality monitoring for quality measurements is necessary.
- CSIR-NPL and CPCB are working on Indian certification scheme and the process to be finalized soon in collaboration with NPL-UK.
- Acceptance of newer technologies such as low-cost sensor devices in the monitoring framework. It was suggested to keep such devices in the chain as part of indicative monitoring rather than the regulatory monitoring considering their several working limitations.
- Another important point discussed in light of maintaining data quality was the awareness and capacity building training of all the staffs, whether based in fields or laboratories who directly or indirectly handle monitoring instruments or the data which will reduce the errors in data generation and reporting substantially. Government institutes and industries should come forward to make policy of such programs and conduct them on regular basis. All monitoring stations and laboratories should be accredited for ensuring the data quality.

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References

1. Sarwar Nizam, Indra S. Sen, Velu Vinoj, Valier Galy, David Selby, Mohammad F. Azam, Satyendra K. Pandey, Robert A. Creaser, Avinash K. Agarwal, Akhilendra P. Singh, and Michael Bizimis, Baiomass-Derived Provenance Dominates Glacial Surface Organic Carbon in the Western Himalaya. Environmental Science & Technology 54 (14), 8612-8621(2020). DOI: 10.1021/acs.est.0c02710.

2. Shankar G. Aggarwal, Sudhanshu Kumar, Bighnaraj Sarangi, Khem Singh, Jyoti Pokhariyal, Sumit K. Mishra, Sukhvir Singh, Chhemendra Sharma, and Prabhat K. Gupta, Traceability Issue in PM2.5 and PM10 Measurements. MAPAN 28, 153–166 (2013). https://doi.org/10.1007/s12647-013-0073-x.
3. Qingfeng Cao, Thomas H. Kuehn, Lian Shen, Sheng-Chieh Chen, Ningning Zhang, Yu Huang, Junji Cao, and David Y.H. Pui, Urban-scale SALSCS, Part I: Experimental Evaluation and Numerical Modeling of a Demonstration Unit. Aerosol Air Qual. Res. 18, 2865-2878 (2018). https://doi.org/10.4209/aaqr.2018.06.0238.
4. Jianjun Li, Gehui Wang, Shankar G. Aggarwal, Yao Huang, Yanqin Ren, Bianhong Zhou, Khem Singh, Prabhat K. Gupta, Junji Cao, Rong Zhang, Comparison of Abundances, Compositions and Sources of Elements, Inorganic Ions and Organic Compounds in Atmospheric Aerosols from Xi'an and New Delhi, Two Megacities in China and India, Science of The Total Environment 476–477, 485-495 (2014). https://doi.org/10.1016/j.scitotenv.2014.01.011
5. Chuen J. Tsai, and Shankar G. Aggarwal, Overview of the Gas and Aerosol Metrology. MAPAN 28, 141–143 (2013). https://doi.org/10.1007/s12647-013-0075-8.

Photograph 3. The group photo and other clips taken during the Post-AdMet workshop held on January 7, 2020 at CSIR-NPL

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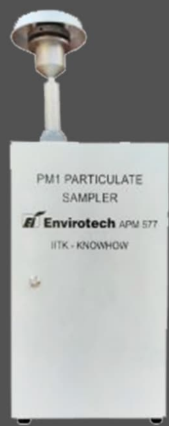

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