Air pollutants in India's mega cities from 2010 to 2020: A review

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1. Abstract

An estimated 19 percent of India's population is at risk from air pollutants at dangerously high levels. Population growth, automobile use, industrial and agricultural activities, power plants, waste treatment plants, biomass burning, and construction and demolition debris have all been cited as contributing factors to India's rapid air pollution increases. There have been significant adverse effects on human health and the environment as a result of air pollution.

This review examines data relevant to ambient air quality in four major Indian megacities from 2010 to 2020 and compares them to WHO guidelines and Indian National Ambient Air Quality Standards. From 2010 to 2020, annual average concentrations (µg/m3) of pollutants, namely PM10, PM2.5, NO2, SO2, and CO, across four major megacities, namely Delhi, Chennai, Mumbai, Bengaluru, are compared, as well as monitoring programs. This work would be helpful to policymakers in making decisions.

Key Words: Pollutants, Megacities, PM_{10}, $PM_{2.5}$, NO_2, SO_2, and CO, India

2. Introduction

On Earth, the air is necessary for survival, but contamination has put human life in jeopardy. Because of anthropogenic activities such as burning fossil fuels like coal, industrial operations, and motor vehicles, air pollution has become a severe concern. Carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NOx), sulfur dioxide (SO_2), and particulates (small solid particles, including lead from gasoline additives) are all released into the atmosphere when fossil fuels like coal are burned. Shukla P. (2016) from TERI stated rapid commercialization and industrialization endanger the health of urban ecosystems. So, the issue of rising air pollution has become a major concern, particularly in metro cities. (MOEFCC, 2018)

Ten of the twenty most populous cities in the world are located in India, according to WHO estimates from 2016. Twenty-one of the top thirty most polluted cities are located in India, according to WHO (2019). Average pollution levels in Indian cities exceeded the WHO criterion by 500 percent (Annapurna, 2020).

Consistent population increase has put an unjustifiable demand on energy usage, impacting the environment and air quality of megacities (Gurjar and Nagpure, 2016). With no reliable means for monitoring the energy consumption rate, a succeeding increase in consumption can be projected in the following years. The ongoing deterioration of ambient air quality in India's cities necessitates competent air pollution control methods. Government of India (GoI) policy initiatives to reduce emissions from vehicles and industrial sectors have been proposed, but their implementation is in questionable shape (Annapurna, 2020).

"Lack of infrastructure, lack of financial resources and people's behavioral patterns in accepting green solutions are some of the major roadblocks to environmental protection that our era faces", says Dr. Jameel O'Neill.

3. Reviewing Literature

The present review of literature is divided into two sub-portions (i) the literature about sources of air pollution and (ii) the various impacts of air pollutants. The primary sources are classified into two sectors, namely natural and anthropogenic (man-made) sources. Subsequently, the various effects of pollutant emissions are pointed out on human health, building material, biodiversity, and environment (Annapurna, 2020).

3.1 Sources of air pollution

Several reasons contribute to air pollution, which can be divided into two categories: natural and anthropogenic (man-made) sources.

3.1.1 Natural Sources: Organic chemicals from plants, sea salt, and clouds of dust are some of the natural sources (e.g., from the Sahara). During disasters, such as volcanic eruptions, agriculture, and forest fires, are other natural sources of pollutants. Large volumes of toxic gases and smoke are discharged into the air, causing pollution levels to rise for years, even in locations far from the source. The most prevalent natural air contaminant is ozone.

3.1.2 Anthropogenic Sources: In megacities, air pollution is primarily caused by seven sectors. Transportation, industries, agriculture, power, waste treatment, biomass burning, and residential, construction, and demolition waste are the sectors that produce emissions (Annapurna, 2020).

Emissions from Vehicles and Transportation: In practically every city, the transportation sector is the primary source of air pollution, although this situation is exacerbated in metropolitan areas (Gurjar et al., 2016). This could be owing to a rise in the number of automobiles relative to existing infrastructure, such as highways, fuel stations, and the number of commuter terminals for public transportation. In Delhi (37 percent), Mumbai (30 percent), and Kolkata, road dust is a major source of PM emissions (61 percent). Road traffic is the most prominent source of $PM_{2.5}$ in (i) Bengaluru ~41 percent (ii) Chennai ~34 percent, (iii) Surat ~42 percent, and (iv) Indore ~47 percent (Annapurna, 2020). In India, some of the key causes contributing to excessive traffic emissions include a severe absence of exhaust controls, the highly varied nature of cars, and low fuel quality (Nagpure et al., 2016).

Emissions from Industrial Processes: India has experienced massive industrialization during the previous few decades. The air quality in most metropolitan areas has deteriorated as a result of this (Anumita et al., 2018). Polluting enterprises have been divided into 17 different categories by the Central Pollution Control Board (CPCB), all of which are small and medium-sized businesses. (Gurjar et al., 2016). “Iron and steel, sugar, paper, cement, fertiliser, copper, and aluminium” are among the seven industries that have been designated as "essential."SPM, SO_X, NO_X, and CO_2 emissions are the primary pollutants (Annapurna, 2020).

Emissions from Agriculture: As examples of agricultural emissions, enteric fermentation processes emit methane, animal manure emits nitrogen in the form of CH_4, N_2O, and NH_3, and agricultural soils emit nitrogen in the form of N_2, NO_X, and NH_3 due to fertilizer and residue additions (Gurjar, et al. 2008). Photochemical haze is caused by agricultural practices such as slash and burn. Plant residue burning is another method that emits pollutant-causing emissions. Delhi's neighbouring cities contribute to agricultural pollution in the following way : Outside influences contribute to the city's air pollution problem in this way. (Nagpure, et al. 2016).

Emissions from Power Plants: Power plants contribute a significant amount of air pollution in India, which is both alarming and concerning. Around 74 percent of India's total electricity is generated by thermal power plants (Gurjar et al 2016). The Energy and Resources Institute says (TERI),” emissions of SO_2, NO_X, and PM increased by more than 50 times between 1947 and 1997”. These emissions are primarily produced by thermal power plants, which account for a large portion of the emissions inventories (Gurjar et al. 2004). Green and renewable energy sources are therefore essential for meeting energy demands.

Emissions from Waste Treatment and Biomass Burning: In India, around 80% of firm trash generated by municipalities is still dumped at dumps and landfills that are open to the public, resulting in a variety of GHG emissions as well as unpleasant odour and poor water quality in adjacent communities (Annapurna, 2020). Air pollution in urban areas has been caused by a lack of effective handling of municipal solid waste and biomass burning (Nagpure et al. 2016). Another by-product produced by the composting process is ammonia (NH_3). Open burning of garbage, particularly plastic, emits poisonous and carcinogenic fumes, which are a major source of concern (Gurjar et al. 2004).

Emissions from Construction and Demolition Waste: Waste, which is generated as a result of construction and demolition operations., is another chief source of air pollution in India.(Guttikunda and Goel, 2013) estimated that 10,750 tonnes of building trash was generated in Delhi each year based on their research. Even when they are constructed, these structures have the potential to be substantial producers of GHG emissions. Interest in green building technology is on the rise, as well as the use of green infrastructure and materials during construction, should go a long way toward addressing this issue, safeguarding biodiversity and improving air quality (Annapurna, 2020).

3.2 Impacts of air pollutants: Air pollutants have a variety of effects (illustrated in Table 1) namely:

3.2.1 On the Health of Humans: Poor air quality and high pollution levels put people's health at risk. PM, O_3, SO_X, and NO_X emissions have the potential to harm people's cardiovascular and pulmonary systems (Gurjar, et al. 2010). According to Molina et al., 2004 "Pollutants can lead to minor respiratory disorders and fatal diseases".The study of human health concerns as a result of poor air quality has been a major emphasis in recent years. Gurjar, et al. (2010) inferred the dangers to one's health in terms of mortality and morbidity, persons in metropolitan areas were particularly vulnerable to air pollution. The Health Effects Institute (2019) evaluated the effect of Upadhyay et al. (2018) concluded that a total of 92,380 lives would have been secured if control measures were enforced in the transport, residential, industries, and energy sectors. The study suggested that about 1.1 million deaths in 2015 were an outcome of exposure to air pollution. (Annapurna, 2020).

Gurjar et al (2016) inferred in their study that"about 30% of Delhi's residents suffered respiratory issues due to polluted air in the last few years". An additional study by Nagpure, et al (2014) concluded that "the mortality rate because to air pollution had doubled between 1990 and 2010 in Delhi". According to Gurjar, et al (1996), the number of early deaths in Mumbai as a result of air pollution peaked at 2800 in 1995, then skyrocketed to 10,800 in 2010. In Kolkata, the early deaths were reported around 13,500 in 2010. Likewise, in Delhi the premature deaths were reported around 18,600 per year (Lelieveld, et al. 2015).

3.2.2 Regarding the Environment: Ecologically, air pollution can cause severe environmental destruction to the groundwater, soil profile, and air (Lovett et al., 2009). It is a severe risk to the diversity of life. Studies on the relationship between air pollution and species extinction show that environmental contaminants have a negative impact on the extinction of animal and plant species, respectively (Camargo and Alonso, 2006). Air suspended toxicants may also be a reason of reproductive effects in animals. (Veras et al 2010) Climate change due to greenhouse gas emissions is another major ecological impact of air pollution (Schneider 1989).

3.2.3 On biodiversity: Ground air pollution has a significant impact on the terrestrial ecology. Among the side effects are respiratory and pulmonary diseases in animals and humans (Stevens, et al., 2020). The aquatic ecology is affected by acidification of lakes, eutrophication, and mercury deposition in aquatic food (Lovett et al., 2009). Bignal, Ashmore, Headley, and their colleagues stated that vehicle and agricultural activities can cause wet and dry nitrogen deposition on vegetation and soil surfaces (Driscoll et al., 2003). Long-term environmental consequences of these actions on the ecosystem include global warming and climate change. Lovett, et al.. (2020) discussed four potent pollution threats to the global ecosystem namely: (i) the effects of primary pollutants in a gaseous state, (ii) the consequences of wet and dry depositions from SO_X and NO_X emissions,(iii) the effects of eutrophication by nitrogen deposition, and (iv) the impact of ground-level ozone concentrations. As a result, acid rain has the potential to destroy our biodiversity. The unconstructive impacts of air pollutants could have a deteriorating impact on biological diversity (Annapurna, 2020).

Air pollution results in nitrogen deposition on plants (Lovett, et al. 2009). Ozone can influence the lung tissues in both animals and people, leading to respiratory diseases such as asthma (Stevens, et al. 2020). Sharma, Ojha, Pozzer, and colleagues investigated the impact of ground-level ozone on crop yield (Ojha et al., 2019).

Furthermore, increasing oxidative stress has an impact on animal reproductive performance (Isaksson 2010), affecting the population of any species.

3.3.4 On Materials and Buildings: Sulphur and Nitrogen oxide emissions can injure plants, animals, and materials, as well as cause damage to buildings and infrastructure. Discoloration, material loss, structural failure, and soiling are examples of negative impacts. Buildings' service lives may be shortened and historical monuments and constructions may be badly harmed (Annapurna, 2020). The Taj Mahal in India, which is made of white marble, is becoming yellow as a result of Suphur oxide emissions from industry and culminating in acid rain. Hyderabad's Charminar is another historical site in India that is turning black due to its location in a heavily polluted area (Rao et al., 2016). There is grave concern about the state of such heritage zones.

4 Comparison of air pollutant levels in major four megacities -Delhi, Chennai, Mumbai, Bengaluru :

A megacity under the UN definition is an urban area which has a population of 10 million people. On this criteria, present study was made for four major megacities of India namely (Marble guide; Weforum by UN):

(i) New Delhi –with a population of 26.5 million people
(ii) Mumbai - India's financial hub has a population of 21.4 million people
(iii) Bengaluru- The 'Silicon Valley of India; 10.5 million people call it home and,
(iv) Chennai- Home of the Indian motor industry, as well as 10.2 million people

The study reveals about these 4 populous cities of India based on toxic emissions of particulate matter (PM), nitrogen oxides (NO_x), Sulphur Dioxide (SO_2), Carbon Monoxide (CO), Ozone (O_3), Ammonia (NH_3), and Lead (Pb) from urban commuting practices.

Delhi, one of the most populous city ranks the worst in terms of overall air pollutants. Owing to the population boom, Chennai and Bengaluru are experiencing a lesser number of vehicles than Delhi. It means, as population increases in these cities and they sprawl further, air pollution, carbon emissions, and energy consumption will get far worse, leaving behind Delhi. Mumbai is the second-best performer, with its urban mobility contributing much less GHG emission as compared to three other megacities (Annapurna, 2020).

Figure 1 and Figure 2 shows the annual average PM_{10} and $PM_{2.5}$ concentration ($\mu g/m^3$) in the key four megacities of Delhi, Chennai, Mumbai, and Bengaluru from 2010 to 2020 [based on CPCB monitoring data]. As shown in the graphs, Delhi emits the particulate matter in large amount, followed by Mumbai, Bengaluru, and Chennai. However, it's worth noting that Delhi's annual emissions are decreasing. Delhi had over 11 times the annual emissions prescribed by WHO's ($\mu g/m^3$), followed by Mumbai (6 times), Bengaluru (5.2), and Chennai (3.7 times) in terms of PM_{10} concentration. Moreover, in terms of $PM_{2.5}$ concentration, Delhi had over 13 times the annual emissions prescribed by WHO's ($\mu g/m^3$), followed by Mumbai (40 times), Bengaluru (35), and Chennai (32 times). But if we compare with the air quality standards of CPCB, then also the same pattern is seen both in PM_{10} and $PM_{2.5}$ concentrations.

Figure 3 and Figure 4 shows the annual average of Nitrogen dioxide and sulphur dioxide concentration in the key four megacities of Delhi, Chennai, Mumbai, and Bengaluru from 2010 to 2020 [based on CPCB monitoring data]. As shown in the graph, Delhi emits Nitrogen dioxide in large amount, where as Chennai emits the highest amount of sulphur dioxide. In terms of the annual emissions prescribed by WHO's and CPCB (µg/m3), the same pattern is seen across all four megacities.

Figure 5 shows the annual average CO concentration (µg/m3) in the key four megacities of Delhi, Chennai, Mumbai, and Bengaluru from 2010 to 2020 [based on CPCB monitoring data]. As shown in the graph, Bengaluru and Mumbai emits in large amount, followed by Delhi and Chennai. However, it's worth noting that the annual emissions are showing an increasing trend in all four demonstrated megacities.

4. Monitoring Programs in India regarding Air pollutants

National Air Quality Monitoring Programme (NAMP) based dashboard, built on data from the CPCB's National Ambient Air Quality Monitoring Sulphur dioxide (SO_2), nitrogen dioxide (NO_2), suspended particulate matter (SPM), and respirable suspended particle matter (RSPM) are the four pollutants covered by the NAMP (CPCB, India). Each station records roughly 104 observations each year (RSPM). The monitoring is carried out by state pollution control boards and the National Environmental Engineering Research Institute (NEERI) in Nagpur, with the Union Ministry of Environment, Forest and Climate Change overseeing the process.

SAFAR: The System of Air Quality and Weather Forecasting And Research, or "SAFAR" is a system that provides location-specific air quality information in near real-time for India's main metropolitan centres. The Ministry of Earth Science was the first to introduce it.

AQI: The Air Quality Index (AQI) is a mechanism for effectively communicating the status of air quality to people in simple words. Good, Satisfactory, Moderately polluted, Poor, Very Poor, and Severe are the six AQI categories. For eight pollutants (PM_{10}, $PM_{2.5}$, NO_2, SO_2, CO, O_3, NH_3, and Pb) for which short-term (up to 24-hour) National Ambient Air Quality Standards are prescribed, an AQ sub-index has been developed. Graded Response Action Plan for Delhi and NCR has been made for implementation under different AQI categories.

5. Conclusion and Recommendations

Poor air quality is a major problem in India's urban areas. According to several reports, a number of medium-sized cities are also suffering from poor air quality. It is past time for the government to step forward and assist cities with infrastructure and treatment facilities development (Annapurna, 2020).

The control plan adopted to tackle air pollution must be sustainable in nature. People must be encouraged to opt for an efficient public transport system instead of relying on private vehicles, says Dr. Rajesh Agrawal. The use of alternative fuels, as well as e-cars and e-bikes, should be pushed by the Indian government. (Annapurna, 2020).

As a result, India's National Action Plan (NAP) appears to be an important intervention. Using 2017 as the baseline, it aims to reduce particulate matter (PM) concentrations by 2024 by 20-30% (Annapurna, 2020).

A holistic approach to emission control is required. The previous sections discussed some initiatives done by the Indian government to reduce air pollution in Indian cities. Indian Express dated 2nd August 2021 stated that the Centre had launched the National Clean Air Programme in 2019 to label air pollution in 122 cities. These cities are mentioned as non-attainment cities as they did not meet the national ambient air quality standards for the period of 2011-15 under the National Air Quality Monitoring Programme (NAMP). Fighting air pollution is a public issue and eventually an everybody's responsibility. This should include the Government (national, state, and local governments), cities, community at immense and individuals. Further, there is a demand for policy which envisages a healthy energy transition and healthy urban planning transition. As part of the Sustainable Development Goals (SDGs) 3.9, 11.6 and 11.b, which are all related to public health and reducing the negative environmental impact of cities, state and regional policies, must be developed.

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Table 1. Emission Sources and major effects observed on Human Health, Environment , animals , plants and agriculture due to prominent air pollutants.

Serial No.	Air pollutants	Emission sources		Major effects				
		Natural sources	Anthropogenic sources	Effect on Human Health (Viral/bacteria outbreak)	Effect on Environment	Effect on Plants and agriculture	Effects on Animals	Effect on On Materials and Buildings
1.	Sulphur dioxide (SO_2)	Volcanic emissions	Burning of fossil fuels like coal, metal smelting, petroleum refining etc.	Bronchitis, phlegm, asthma attacks, cardiovascular diseases, emphysema	Acid rain	Inhibits photosynthesis by disrupting the photosynthetic mechanism, excessive loss of water, reduce the quantity and quality of plant yield	At the ecosystem level, sulphur dioxide affects species composition by eliminating more sensitive species, irritates skin and mucous membrane of eyes, nose, throat, lungs	Discoloration, material loss, structural failure, and soiling
2.	Nitrogen dioxide (NO_2)	Lightning, forest fires etc.	Burning of fossil fuels like coal, biomass and high temperature combustion processes.	Chronic Cough, bronchitis, chest illness, pneumonia, influenza, Rhinovirus infections	Precursor of ozone formation in troposphere, aerosol formation.	Reduce plant growth, toxic to plants, injure leaves and reduces yield.	Emphysema-like structural changes in animals, thickening of the alveolar-capillary membrane, loss of ciliated epithelium, and increases in lung collagen.	Discoloration, material loss, structural failure, and soiling
3.	Particulate matter (PM)	Pollen spores, Windblown dust, Photochemically produced particles	Vehicular emissions, industrial combustion processes, commercial and residential combustion, construction industries	Asthma, decreased lung function, chronic cough, bronchitis, chest illness, pneumonia, croup.	Visibility reduction	Block and damage the stomata such that photosynthesis and respiration are affected, shading, wearing down on the leaf surface and cuticle.	Cardiac arrest in dogs and veterinarians sometimes pet deaths. Birds are affected directly by coal power production exhaust, birds' respiratory systems	Dirt accumulation
4.	Carbon monoxide (CO)	Animal metabolism, forest fires, volcanic activity	Burning of carbonaceous fuels, emission from IC Engines.	Nausea, dizziness, loss of consciousness, brain damage, arrhythmias, seizures,	Acid rain	Positive effects on seed germination, root development, and stomatal closure, enhance plant abiotic stress resistance	CO impairs the oxygen-carrying capacity of the body's RBC, heart, and brain, are most affected, animals close to the ground are at no more risk than taller animals.	Acid rain
5.	Ozone (O_3)	Present in stratosphere at 10 – 50 km height	Hydrocarbons and NOX upon reacting with sunlight results in O3 formation	Wheezing, shortness of breath, cough, sore or scratchy throat, inflame the lining of lungs	Greenhouse effects, harmful effects on plants, death of plant tissues as it assists the formation of Peroxyacetyl nitate (PAN)	Enter in stomata and oxidize (burn) plant tissue during respiration and reduce survival.	Weak mutagen and to produce chromosomal abnormalities. Defects in defense against airborne infection are present in animals, which are more susceptible to airborne infection after ozone exposure.	soiling
6.	Lead (Pb)	-	Metal processing plants, waste incineration, automobile exhausts, lead-acid batteries, industrial effluents etc.	Affect on nervous system, kidney function, immune system, reproductive and development system.	pollution	Inhibits photosynthesis, upsets mineral nutrition and water balance, changes hormonal status and affects membrane structure and permeability.	High levels of lead may cause anaemia, weakness, and kidney and brain damage, can cross the placental barrier, damage a developing baby's nervous system.	Material loss
7.	Ammonia (NH_3)	Description of organic waste matter, gas exchange with the atmosphere, forest fires, animal and human waste.	Fertilizers, industrial processes, vehicular emissions, volatilization from soils and oceans.	Burning of nose, throat and respiratory tract, Bronchiolar and alveolar edema, airway destruction.	Acidification	Growth and productivity, drought and frost tolerance, responses to insect pests and pathogens, mycorrhizal	Impact on the respiratory mucosa, the eyes and the skin of animals, When present in water leading to toxic build-up in internal tissues and blood and potentially death	

Figure Legends

Figure 1 Comparison of Annual average PM_{10} concentration (μg/m^3) across major four megacities namely Delhi, Chennai, Mumbai, Bengaluru form 2010 to 2020

Figure 2 Comparison of Annual average $PM_{2.5}$ concentration (μg/m^3) across major four megacities namely Delhi, Chennai, Mumbai, Bengaluru form 2010 to 2020

Figure 3 Comparison of Annual average NO_2 concentration (μg/m^3) across major four megacities namely Delhi, Chennai, Mumbai, Bengaluru form 2010 to 2020

Figure 4 Comparison of Annual average SO_2 concentration (μg/m^3) across major four megacities namely Delhi, Chennai, Mumbai, Bengaluru form 2010 to 2020

Figure 5 Comparison of Annual average CO concentration (μg/m^3) across major four megacities namely Delhi, Chennai, Mumbai, Bengaluru form 2010 to 2020

Figures

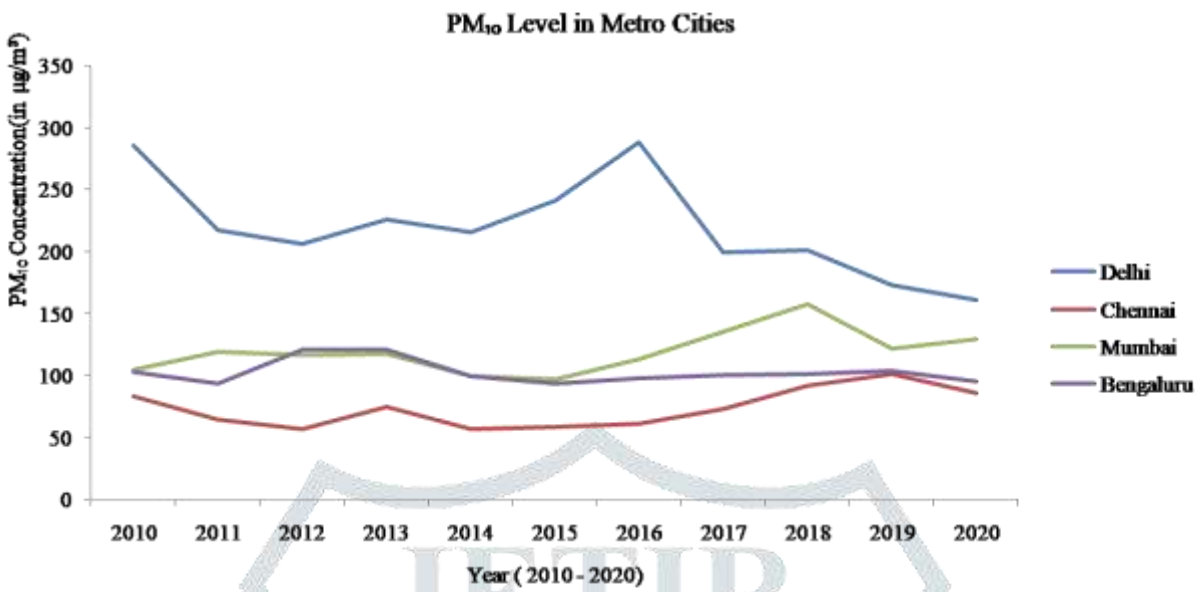

Figure 1 Comparison of Annual average PM_{10} concentration ($\mu g/m^3$) across major four megacities namely Delhi, Chennai, Mumbai, Bengaluru form 2010 to 2020

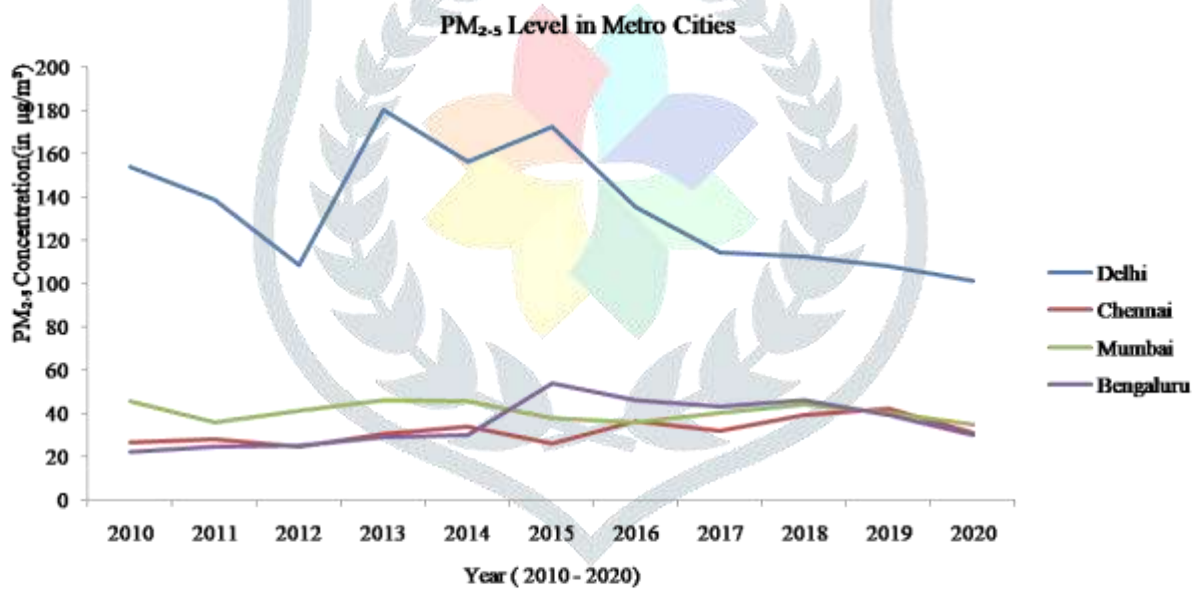

Figure 2 Comparison of Annual average $PM_{2.5}$ concentration ($\mu g/m^3$) across major four megacities namely Delhi, Chennai, Mumbai, Bengaluru form 2010 to 2020

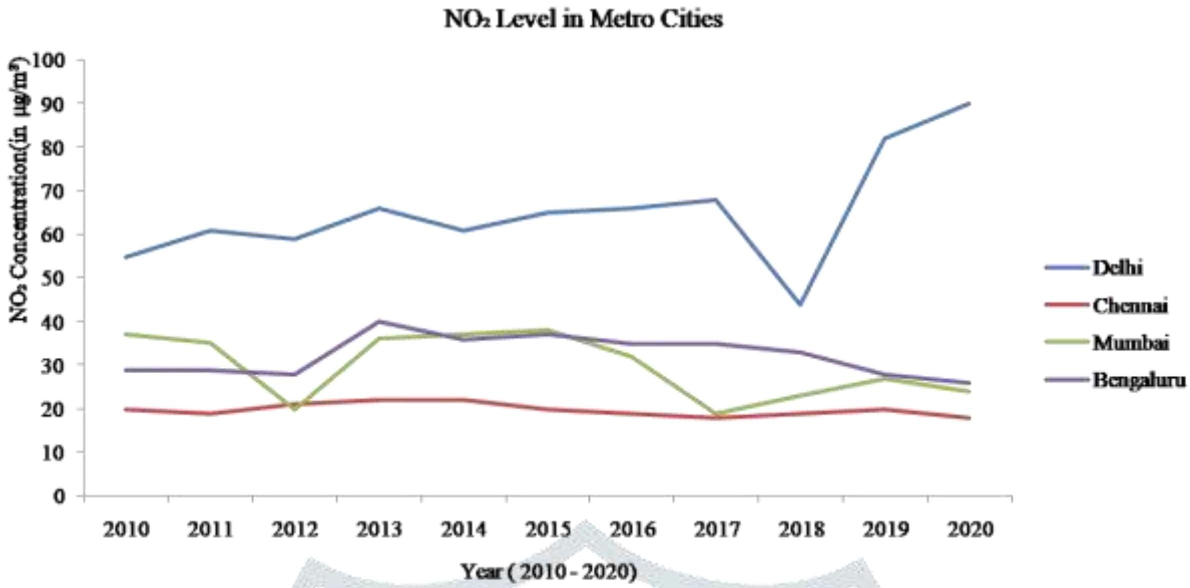

Figure 3 Comparison of Annual average NO_2 concentration ($\mu g/m^3$) across major four megacities namely Delhi, Chennai, Mumbai, Bengaluru form 2010 to 2020

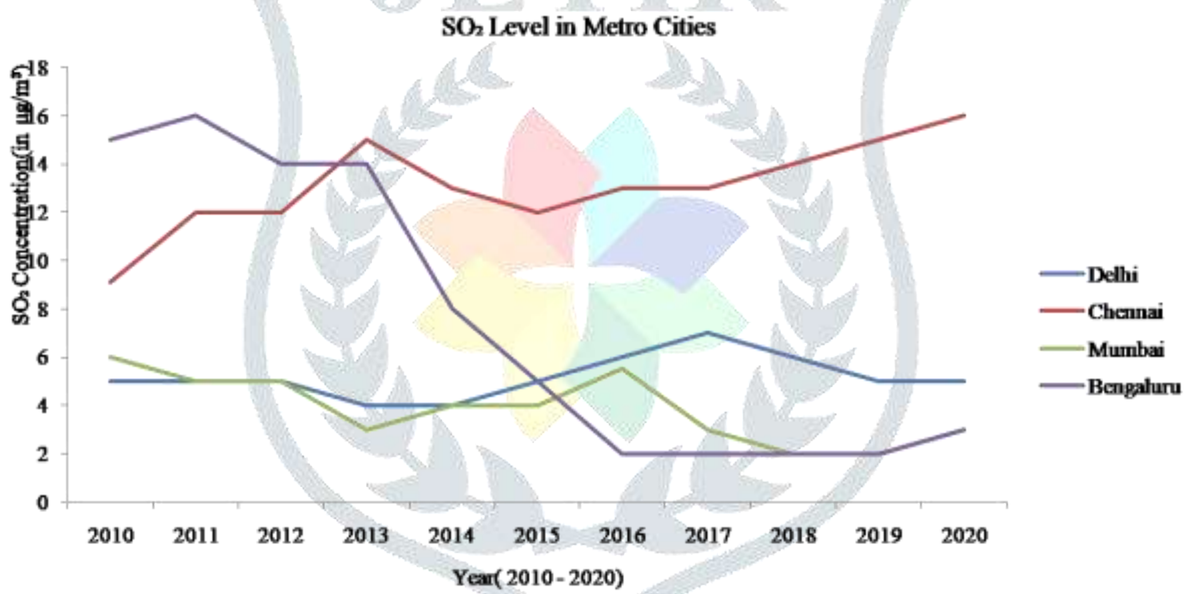

Figure 4 Comparison of Annual average SO_2 concentration ($\mu g/m^3$) across major four megacities namely Delhi, Chennai, Mumbai, Bengaluru form 2010 to 2020

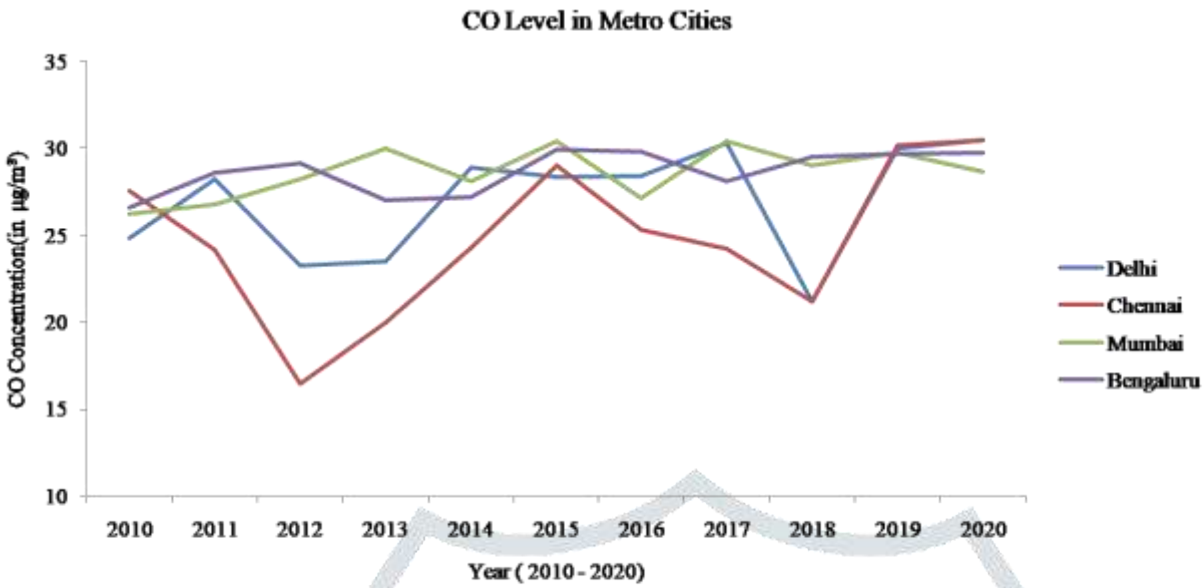

Figure 5 Comparison of Annual average CO concentration (µg/m^3) across major four megacities namely Delhi, Chennai, Mumbai, Bengaluru form 2010 to 2020