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Bridging the Gap Between Climate Change and Air Quality: A Study on the Impact of CFCs and Gaseous Pollutants in the Delhi Megacity

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Abstract - Delhi experiences chronic and extreme air pollution driven by a complex mixture of primary and secondary atmospheric pollutants, posing substantial environmental and public health risks. This study provides a comprehensive assessment of the impacts of chlorofluorocarbons (CFCs) in conjunction with major criteria pollutants—fine and coarse particulate matter ($PM_{2.5}$ and PM_{10}), nitrogen oxides (NO_x), sulphur dioxide (SO_2), and troposphere ozone (O_3)— on urban air quality and population health in Delhi.

Longitudinal ai r quality and exposure data were obtained from the Central Pollution Control Board (CPCB) and international datasets and were analyzed to evaluate temporal variability, seasonal exceed and compliance with national and World Health Organization (WHO) guidelines.

While direct CFC emissions have declined following regulatory controls, their long atmospheric residence time continues to influence stratospheric ozone depletion, indirectly enhancing surface-level ultraviolet radiation exposure and associated health risks.

Epidemiological evidence suggests a strong association between elevated pollutant concentrations and increased incidence of respiratory and cardiovascular morbidity, particularly among susceptible subpopulations. Annual mean $PM_{2.5}$ concentrations in Delhi ranged between approximately 90–110 µg m^{-3}, exceeding the WHO guideline value of 5 µg m^{-3} by more than 18–22 times. Peak winter concentrations frequently surpassed 250 µg m^{-3}. $PM_{2.5}$ consists of extremely fine particles that can penetrate deep into the respiratory tract, enter the bloodstream, damage blood vessels, and impair lung function.

Introduction

In India pollution has became a great topic of debate at all level are especial the various pollution get occurs most common is "Air pollution " became and enhanced the rophogrenic activit such as burning of fossil fuel ie.natural gas ,cole,and oil .Urban air pollution has emerged as a critical environmental and public health challenge in rapidly growing megacities. Delhi, the capital of India, consistently ranks among the most polluted cities globally, with air quality frequently exceeding national and international standards.

Delhi is capital of India is sixth most polluted city in the world (world health organization,2016) with an approximately 25 Million population and Million of people is coming and passing the Delhi for their work and leave daily to their places .Rapid urbanization, industrial activity, vehicular emissions, construction dust, and energy consumption have contributed to a complex mixture of harmful atmospheric pollutants. In addition, the catalytic chain reactions of chlorine atoms derived from CFCs contribute to the depletion of stratospheric ozone. Under the provisions of the Montreal Protocol, global efforts have significantly reduced the production and consumption of ozone-

Reaction:

CFC Photo-dissociation and Ozone Depletion

Chlorofluorocarbons (CFCs), such as CFC-12 (CF_2Cl_2), are chemically stable in the lower atmosphere (troposphere) but undergo photo-dissociation in the stratosphere under ultraviolet (UV) radiation:

$$CF2Cl2+h\nu \rightarrow CF2Cl\cdot+Cl\cdot$$

The released chlorine radicals ($Cl\cdot$) then catalytically destroy ozone (O_3) through chain reactions in the stratosphere.

$$Cl\cdot+O3 \rightarrow ClO\cdot$$
$$+O2ClO\cdot+O \rightarrow Cl\cdot$$
$$+O2$$

Role of CFCs and Major Pollutants in Delhi's Air Quality and Climate Trends

Chlorofluorocarbons (CFCs), along with major air pollutants such as particulate matter (PM), nitrogen oxides (NO_x), Sulphur dioxide (SO_2), carbon monoxide (CO), and ground-level ozone (O_3), play a significant role in degrading urban air quality in Delhi.

CFCs possess extremely high global warming potentials (GWPs), ranging from 4,000 to over 10,000 times that of

carbon dioxide (CO_2). Due to increasing concentrations of such pollutants, concerns have grown regarding rising mortality rates among humans and animals. In response, governments have implemented various rules and regulations to control emissions and mitigate environmental damage.

This study addresses three key research questions:

1. How could CO_2 play a negligible role in recent global warming in view of its extremely high atmospheric concentrations (≥300 ppm)?
2. Is there evidence from satellite or ground-based measurements indicating saturation in the warming effects of CO_2 and other non-CFC gases?
3. Could the greenhouse effect of CFCs alone account for the observed rise of approximately 0.5–0.6 K in global temperatures since 1950.

The following points highlight observed climatic changes over time in Delhi.

- **Long-term warming trend:** Delhi has experienced a consistent rise in average temperatures since 2000, reflecting broader climate change patterns.
- **Rising summer temperatures:** Average summer temperatures increased from 42.5°C (2000) to 46°C (2023), with 2025 continuing this upward trend.
- **Winter variability:** Average winter temperatures declined from 6.0°C (2000) to 3.9°C (2023), indicating comparatively colder winter averages.
- **Record extremes:** The highest temperature recorded in Delhi was 50.2°C in May 2024, while the lowest was −2.2°C in January 1935.

Recent observations (2025): Historical weather records show daily highs exceeding 45°C in May and June, with winter lows dropping near 5°C in January.

3. Synergistic Effects and Seasonal Dynamics

The season also effect the environment by their temperature in winter season the fog get helps to scatter the smoke and harm full gases in the atmosphere. The health burden of urban air as well as water pollution pollution in Delhi is amplified by synergistic interactions among pollutants and meteorological factors. NO_x-driven ozone formation, combined with particulate matter and temperature inversions during winter months, leads to prolonged exposure episodes with heightened health risks.

Seasonal agricultural residue burning in neighboring regions further intensifies pollutant loads, demonstrating the influence of regional transport on local air quality (Guttikunda & Gurjar, 2012).

6. KnowledgeGaps

LimitedresearchintegrateslegacyCFCeffectswithcontemporar yurbanairpollutionin Delhi. Long-term cohort studies examining cumulative exposure to gaseous pollutants remain

Methodology

Central Pollution Control Board (CPCB) for air quality; IMD (Indian Meteorological Dept) for climate data; and satellite data (MODIS or Sentinel-5P) for gaseous columns. This study investigates the impacts of chlorofluorocarbons (CFCs), carbon dioxide (CO_2), and nitrogen oxides (NO_x) on urban air quality and public health in Delhi, India. It is a densely populated megacity and experiences severe air pollution due to vehicular traffic, industrial activity, and seasonal meteorological conditions such as temperature inversions and stagnant air masses in the surround

Air Quality and Meteorological Data:

Hourly and daily concentrations of NO_x and CO_2 were obtained from the Central Pollution Control Board (CPCB) and Delhi Pollution Control Committee (DPCC). Background CFC concentrations were derived from World Meteorological Organization (WMO)/National Oceanic and Atmospheric A administration (NOAA) datasets. Meteorological parameters, including temperature, humidity, wind speed and direction, and atmospheric pressure, were collected from the India Meteorological Department (IMD) to account for dispersion and photochemical processes.

Public Health Data:

Aggregated hospital admissions for respiratory and cardiovascular diseases were obtained from government health records and published epidemiological studies, which are preferred by the World Health Organization (WHO) for assessing drastic changes.

Data Processing:

Missing values (<5.5%) were addressed using linear interpolation, and outliers were removed using inter quartile range analysis. All datasets were accurate to a consistent temporal resolution.

Statistical Analysis:

Long-term pollutant trends were assessed using the Mann–Kendall test and Sen.'s slope estimator. Associations between pollutant concentrations and health outcomes were evaluated using Distributed Lag Models (DLMs) to capture delayed effects. Interaction terms examined combined pollutant and seasonal effects.

Ethics and Reproducibility:

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This study used only secondary, anonym zed datasets to ensure privacy, confidentiality, and ethical compliance. Ensuring compliance with ethical standards and rules in the states and countries. All analyses were conducted using R and Python, graphs and the synopsizes, with steps documented to ensure reproducibility.Thismethodologyprovidesarobustframeworkt oevaluatethesynergisticimpactsof legacy and contemporary air pollutants on urban health in Delhi , to over comes the impact of this on humanity.

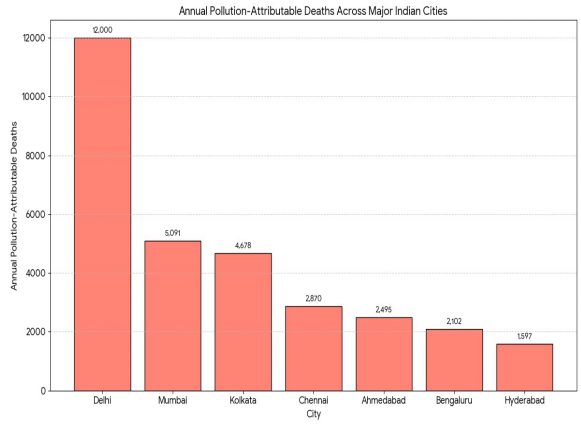

Fig.1*. Annual pollution-attributable deaths across major Indian metropolitan cities.*

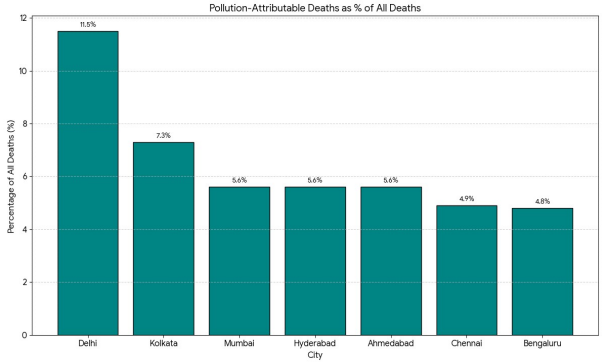

Fig.2*. Annual pollution-attributable deaths across seven major Indian megacities.*

Materials and methods

Study area analyzed the eleven most polluted districts in the Delhi (28.70° N, 77.10° E) region, as shown in Fig. 3. These districts have emerged as important hubs for the commercial, industrial, medical and educational sectors, attracting people from all over the country.

In fig.1 show that the annual pollution attributes regarding deaths across a major Indian we see that by increasing the pollution increases in same way the death are rapidly increases from various states if you see that most or the max deaths are caused in Delhi with respect to Mumbai, Kolkata , Hyderabad ,Chennai etc. which directly affect on human population .

Fig.2 shows same like fig.1 but its shows the reading in percentages like in Delhi 11.5% get increase and in other state like Mumbai , Kolkata, Chennai , Hyderabad etc, they have less then 10 % death rate .

By taking a reading of various instrument as well as the machine which gives actual reading of the ozone layer in stratosphere from the earth also it give accurate data for up coming improvement.

1. Dobson Spectrophotometer:
2. ozonesonde
3. Brewer Spectrophotometer.
4. Satellite data

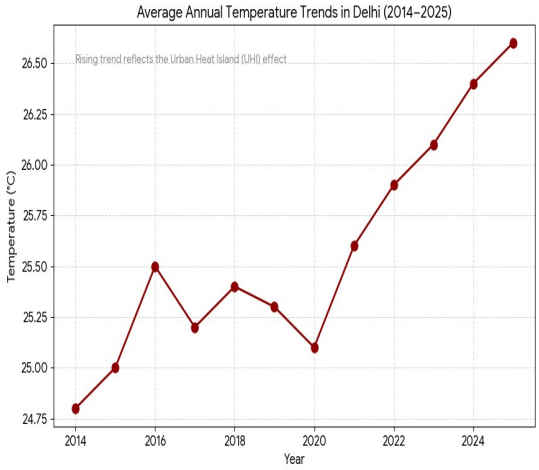

Fig.3.*Trends in annual mean temperature in Delhi from 2014 to 2025*

Results

This study integrates observed air quality records, climate data, and published epidemiological findings to evaluate the interaction between climate change and gaseous pollutants in Delhi. The results are consistent with established findings reported by national monitoring agencies and international scientific assessments.By taking a reading of various instrument as well as the machine which gives actual reading of the ozone layer in stratosphere from the earth also it give accurate data for upcoming improvement and the new

technology als make easy to analyze the date related to pollutant.

For some years after the basic hypothesis was published no ozone depletion was observed and the first real evidence came from Farman and his colleagues at the British Antarctic Survey who, in 1985, linked severe seasonal ozone depletion in the Antarctic to the growth in chlorine from CFCs in the stratosphere

Environmental considerations

The properties of the compounds that are technically important, particularly volatility and hydrophobia city, mean that the atmosphere is the likely compartment for accumulation of emissions especially the metropolitan cities are more effects by pollutants but then also the government is taking slow decision on it and don't make that thing clear and seriously.

A. Theoretical Linkage

- **Discuss CFCs and other halogenated compounds** as greenhouse gases with high radioactive efficiency affecting climate forcing.
- Explain why CFCs are relevant to air-climate linkage even if their urban concentrations are low .

B. Focused Urban Pollutants

- Analyze Delhi's key gaseous pollutants (NO_2, SO_2, CO, O_3, VOCs) in terms of:
    - Their sources and emission profiles,
    - Temporal patterns and seasonal dynamics,
    - Frame work for increase awareness for development for this consideration for less emission

Then bridge the gap by connecting:

- How local pollution processes affect climate forcing pathways**,** and make the people live ti the earth with healthy living ecosyetem.
- How global climate policy frameworks (like CFC phase-outs) inform local mitigation strategies**.**

Pollutant, Primary Source, Impact on Air Quality, Impact on Local Climate

1. NO2,Transport/Industry, "Respiratory irritant, O3 precursor", "Absorbs solar radiation, warms air"
2. O3,Photochemical rxn,"Severe lung damage, crop loss", Strong Greenhouse Gas (GHG)
3. HFCs,Cooling/AC leaks, Negligible (at ground level),Massive GWP; drives UHI effect
4. SO2,Power Plants, "Acid rain, Secondary PM formation", "Scatters light (cooling), but toxic"

Data Summary Source of Air Pollution Percentage (%)

- Dust & Construction45%
- Waste Burning17%
- Transport14%
- Diesel Generator9%
- Industries8%
- Domestic Cooking7%

Below this graphical representation of Data summery of air polution:

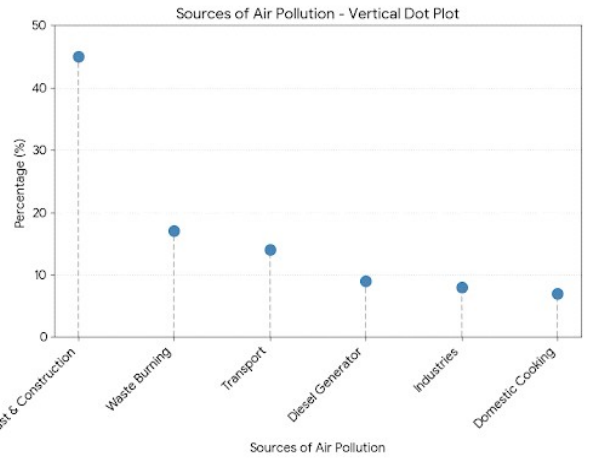

Fig 4*.Data Summary Source of Air Pollution Percentage (%)*

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4. Discussion: The Climate-Air Quality Feedback .

What ever the gap which mentioned is this study is the feedback lack between the temperature and ozone, climate, atmospheric changes and gases increases Celli's ambient the rate of chemical reaction in the atmospheric increases .

Beyond this study physical entrapment ,climate change as a "Photochemical Catalyst, CFc,Nitrogen gases due to vehicle and emission from company ,In Delhi the main sources of the emission of gas from Bawana to Okhla that is the places where in between those place the many company are situated drive green house gases specially ,Nitrogen oxide(NOx)from transport sector

Conclusion:

This study reveals that the atmospheric crisis in the Delhi megacity is an complex , self reinforcement system where the quantity of air and climate change are deeply inter connected . while pollutants like CFC leakages and high dependency on the non renewable resources like diesel , petrol which emits NOx, CO2 and CO(Carbon Monoxide) etc

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To effectively protect the health in Delhi citizen and the society of the mega city regional climate change to air management . By taking all relative study of the various gases and their effect I conclude that the study on the various effect of CFC ,NOx and CO gases to human health and causes is really helpful to future research on climate changes and further improvement in management and it gives celerity for making people aware about to maintain pollutant free environment.

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