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# Assessment of Temperature and Rainfall Variability and Its Impact on the Climate of Delhi (1961–2010)

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**Abstract--** The focus of this research is to analyze the long-term variability in temperature and rainfall in the National Capital Territory of Delhi for the period 1961-2010. The analysis utilizes homogenized monthly and annual station data from the two stations, Palam and Safdarjung, to investigate temporal trends, inter-annual variability and changes in extreme events. In terms of methodology, approaches to the analysis employ linear trend estimation, as well as climatic extremes indices, including the number of hot days and heavy-rainfall days. The results show that there is a statistically significant upward trend in annual mean temperature, more notably an increased rate of warming during pre-monsoon and winter seasons. In contrast, rainfall exhibits no consistent monotonic increase or decrease in annual totals; however, evidence indicates a rise in rainfall intensity and enhanced interannual variability. These observed patterns underscore the growing challenges of urban heat stress, water resource management, and the need for climate-resilient adaptation strategies in Delhi.

**Keywords--** Climate variability, Temperature trends, Rainfall variability, Extreme weather events, Spatio-temporal analysis, Monsoon variability, Statistical trend analysis.

## I. INTRODUCTION

Climate change has emerged as the most pressing environmental challenge confronting the contemporary world, with its impacts being particularly evident in rapidly urbanizing regions. Indian metropolitan cities, including Delhi, are highly vulnerable to the multifaceted consequences of a changing climate. Delhi, the second largest urban agglomeration in India after Mumbai, is especially at risk due to its demographic pressure, rapid urban expansion, and geographical location. The city is expected to experience profound and far-reaching impacts of climate change, which are already manifesting in diverse sectors.

Widespread and alarming problems exist in water resources, agriculture, forests, and biodiversity, which will be affected by changes to temperature and precipitation. Climate change is also a public health and urban infrastructure risk, as well as a risk to environmental sustainability. The increased frequency of heat waves, the deterioration of air quality, and inconsistency in rainfall are likely to exacerbate vulnerabilities and have the greatest impact on the most vulnerable populations.

There is a scientific consensus that the climate system is warming and there is apparent evidence of this from different observational datasets. The average temperature of the air and the oceans is increasing, the snow and ice mass is receding, and there is an increase in mean sea level. What this demonstrates is that this is a global phenomenon.

For Delhi, these changes translate into heightened urban heat stress, increased flood risk due to extreme precipitation, and growing challenges for sustainable resource management. Addressing these impacts requires evidence-based research on local climatic trends, which can inform adaptive policies and strengthen resilience in India's national capital. The climatic transformations observed in Delhi are largely attributed to the unabated emission of greenhouse gases (GHGs), particularly carbon dioxide (CO<sub>2</sub>) and methane (CH<sub>4</sub>), into the atmosphere. These emissions primarily originate from anthropogenic activities, including the combustion of fossil fuels, unmanaged landfills, and the increasing vehicular traffic characteristic of large metropolitan regions. The persistent release of such pollutants has been instrumental in altering Delhi's climate system, exacerbating temperature rise, and contributing to variability in precipitation patterns.

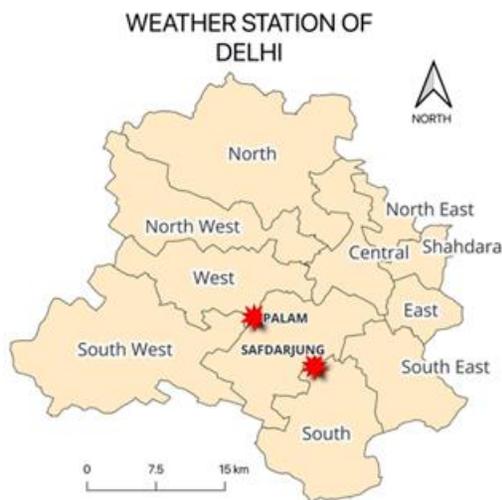
Since the pre-industrial era, the concentration of GHGs has steadily escalated, intensifying climate vulnerability across both global and regional scales. In the context of Delhi, this vulnerability manifests through heightened risks such as extreme heat events, deteriorating air quality, irregular rainfall, urban flooding, and associated public health concerns. The resulting environmental stress poses serious challenges to ecological sustainability, socio-economic stability, and the overall resilience of urban systems. Furthermore, marginalized populations are likely to be disproportionately affected, thereby magnifying issues of environmental justice.

Given the magnitude of these challenges, the formulation of a comprehensive climate change strategy for Delhi has become imperative. Such a strategy must integrate both adaptation and mitigation measures within the broader framework of urban development planning. Adaptation efforts should focus on enhancing resilience to climate-induced risks through improved infrastructure, sustainable water and energy management, and strengthened public health systems.

Simultaneously, mitigation measures—such as reducing fossil fuel dependency, expanding green spaces, and promoting clean energy transitions—are essential to curb emissions. An integrated, city-wide climate action plan is therefore critical to safeguard Delhi’s environmental and developmental future.

## II. STUDY AREA

Delhi, situated in northern India between 28°24'–28°53'N and 76°50'–77°20'E, covers 1,483 km<sup>2</sup> and borders Uttar Pradesh, Rajasthan, and Haryana. Two meteorological stations operate in the region: Safdarjung (216 m) within the city and Palam (233 m) near the airport. Geographically, Delhi lies on the right bank of the Yamuna at the edge of the Gangetic plains, flanked by the Aravalli hills to the south and west. Its largely flat topography includes low ridges regarded as Aravalli extensions.



## III. LITERATURE REVIEWS

A comprehensive climate vulnerability assessment of Delhi is undertaken by the Government of Delhi as part of the State Action Plan on Climate Change (SAPCC). Through multiple consultations with governmental and non-governmental organizations, and their experts, various sectors were identified as highly vulnerable to the impacts of Delhi’s climate change. These sectors include health, water resources, energy, agriculture and biodiversity, urban planning, and transport. Each of these sectors is influenced by climatic changes, this might be either directly or indirectly, and together they define the extent of Delhi’s climate vulnerability.

### 1. Health

Climate-induced changes in temperature and rainfall patterns have increased the prevalence of heat stress and climate-sensitive distress in Delhi. Intensifying the heatwaves contribute to heat strokes, eye ailments such as cataracts, skin disorders, and respiratory illnesses. Approximately half of the city’s population resides under informal settlements, which are disproportionately exposed to these health risks (Delhi Govt. Report, 2010). Moreover, the accumulation of solid particulates in Delhi’s atmosphere contributes to respiratory problems, acid rain, and long-term pulmonary damage.

### 2. Water Resources

Freshwater scarcity remains one of Delhi’s most pressing challenges. Rapid population growth, coupled with rising temperatures, has intensified demand for water. Increased rainfall variability has led to higher surface runoff and reduced groundwater recharge, thereby lowering water quality and availability. In addition, the growing frequency of high-intensity rainfall events has heightened the risk of flash floods, threatening both infrastructure as well as livelihoods.

### 3. Energy

The demand for electricity in Delhi is has grown multiple times which has direct impact on rising temperatures. Increased use of cooling devices such as air conditioners and fans has resulted in escalating energy consumption, thereby reinforcing greenhouse gas emissions. A study by Gupta (2011) at the Indian Statistical Institute projected that a 1°C increase in temperature could raise electricity demand by over 5 million kWh by 2015, with further increases expected in subsequent decades. This trend underscores the cyclical relationship between energy consumption and climate change, with urban households increasingly reliant on thermal comfort technologies.

### 4. Agriculture and Biodiversity

Delhi has witnessed a gradual decline in agricultural land, decreasing from more than 30% in the 1990s to around 23% in 2010 (Economic Survey of Delhi). Crop yields of staple crops such as wheat, maize, paddy and bajra are increasingly vulnerable to rising temperatures and erratic rainfall. Declining productivity not only threatens local food security but also necessitates higher dependence on overall food imports, which in turn increases emissions from transportation. Moreover, shifts in climatic conditions are accelerating biodiversity loss and altering natural ecosystems within the city.



#### *5. Urban Planning*

Urban planning faces critical climate-related challenges in the domains of land use, infrastructure, and solid waste management. Rising temperatures and rapid urbanization have accelerated land degradation and reduced moisture availability, particularly in forest and agricultural zones. Climate variability shortens the lifespan of critical infrastructure such as transport, health, and communication systems. Inadequate solid waste management, especially during heavy rainfall, results in clogged drains, water contamination, and an increased prevalence of vector-borne diseases.

#### *6. Transport*

The transport sector contributes nearly 30% of Delhi's total greenhouse gas emissions which largely due to vehicle growth rate exceeding population growth four times. This has intensified the urban heat island effect and exacerbated air pollution. Transport infrastructure is highly susceptible to damage from extreme rainfall events, which not only deteriorate roads and bridges but also increase the frequency of traffic disruptions as well as accidents.

Delhi's climate vulnerability is multidimensional, affecting both natural as well as human systems. The identified sectors highlight the urgency for integrated adaptation and mitigation strategies within Delhi's developmental framework. Without timely interventions, the combined pressures of population growth, rapid urbanization, and climate variability will significantly undermine the city's environmental sustainability and resilience.

#### IV. METHODOLOGY

The variability of Delhi's changing climate was assessed using long-term meteorological records from the Safdarjung and Palam stations. Climo graphs based on IMD data provided a visual representation of climatic fluctuations

between 1961 and 2010. To establish baseline patterns, annual and monthly means of temperature and rainfall were calculated for both Palam and Safdarjung. Correlation coefficients were then derived to examine the statistical relationships between temperature and monthly rainfall across different time intervals, thereby highlighting possible interactions between thermal and precipitation regimes.

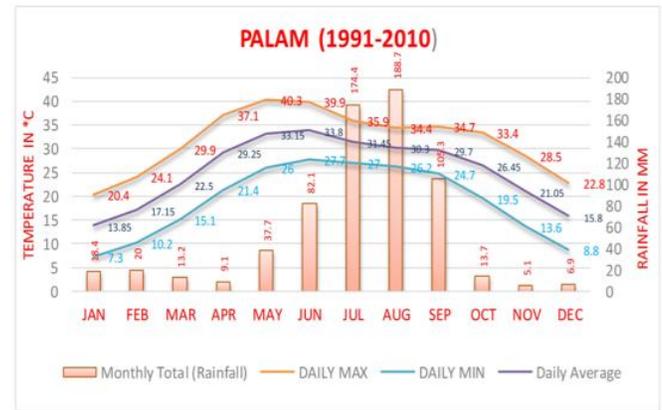
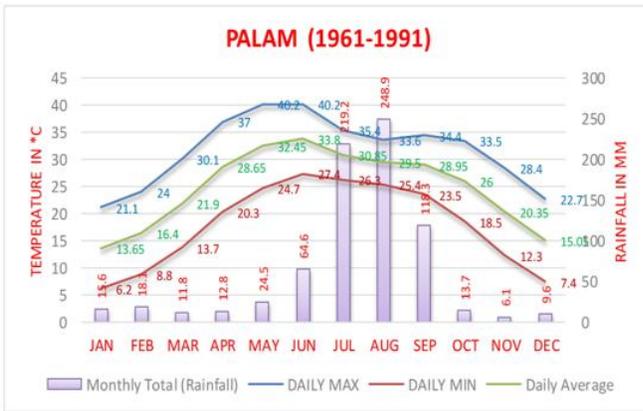
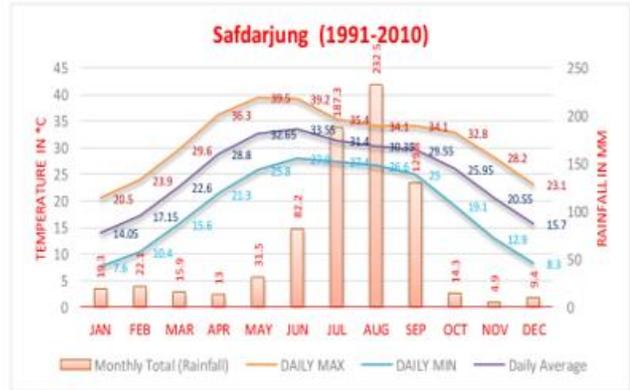
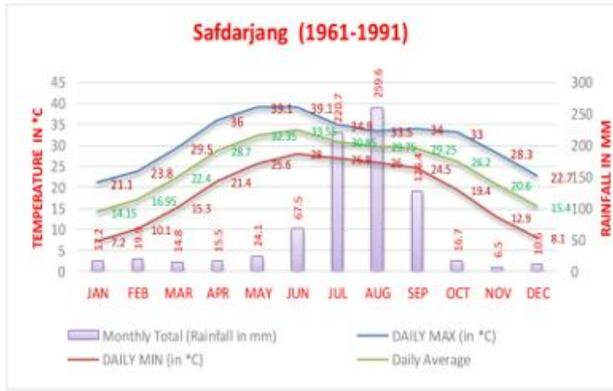
Using these mean values, the annual and monthly percentage distribution of temperature and rainfall is estimated to determine the seasonal contribution to Delhi's overall climate variability. This approach offered broad insights into seasonal dominance and inter-seasonal variability. To capture the degree of fluctuation more precisely, measures of variability such as standard deviation and variance were applied, covering temperature, rainfall, humidity, wind speed, and cloud cover. These statistical indicators clarified the extent of departure from long-term averages, enabling a better understanding of climate instability.

For improved interpretation, compound bar diagrams and line graphs were constructed to depict temporal fluctuations. These visual tools complemented the statistical results and provided a clearer picture of the changing climatic conditions in Delhi over the study period.

*Database: - Indian Meteorological Department of Delhi, Newspapers, Generals and some Govt. Published Reports.*

#### V. DATA ANALYSIS

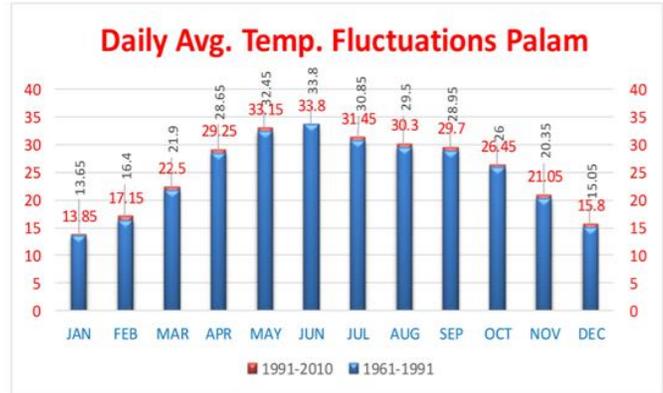
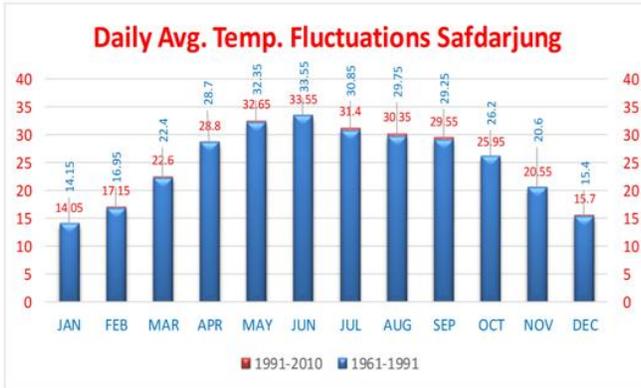
Delhi's climate can be seen as an overlap of monsoon-influenced humid subtropical (Cwa) and semi-arid (BSh according to the Koppen climatic classification). In Delhi there are two weather monitoring stations, one at Safdarjung inside the main city and another at Palam on its outskirts near the Airport. The readings of Safdarjung station are taken for the city, whereas the readings at Palam station are taken for the Airport. The manipulated readings for both the stations are as follows: -



**Graph: - Showing Mean temperature and rainfall distribution of all the twelve months at Safdarjung and Palam Airport during 1961-2010.**

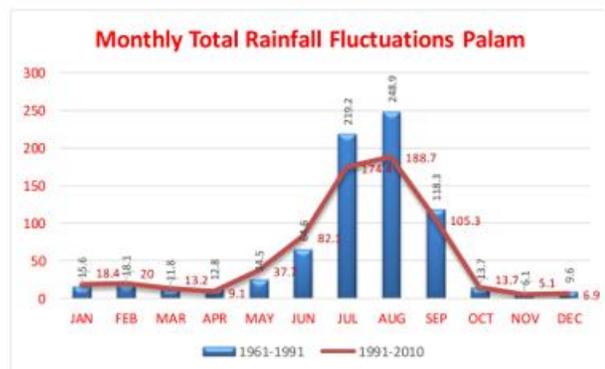
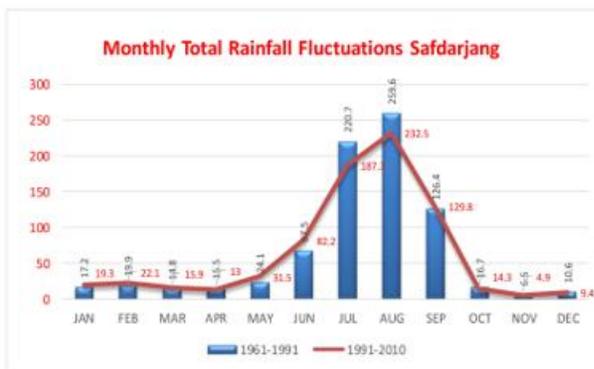
The above climate graphs represent the average temperature and rainfall distribution during 1961-2010 for both the stations of Delhi. In these climate graphs, Lines indicate the daily maximum, minimum and average temperature in °C whereas the bar diagram shows the monthly total rainfall in millimeters. Similar station graphs are following the same pattern but the slight change in values brought huge climatic differences for the last six decades.

The similar trend can also be easily noticed by annual percentage of temperature and rainfall during the Early June to September months. During these months Southwest Monsoon starts showing their effect on the climate of Delhi. Monthly mean temp. of June month is highest for both the stations. These compound bar-graphs show the actual number of fluctuations in temperature at both the stations of Delhi.



In this graph, the red tip of each bin indicates the differences where August month has the highest differences (At Safdarjung 0.6°C and Palam 0.8°C). Where June month shows zero difference during 1961-2010. There is no negative difference found at Palam Airport but in case of Safdarjung October (-0.25°C) and January (-0.1°C). This scenario witnesses the rising temperature extremes in Delhi. We calculated the correlation coefficient between temperature and rainfall for any specific period is positive which indicates the direct relationship of both the variables. Correlation coefficient became stronger from 0.5 to 0.56 of Safdarjung and similar relation is for Palam Airport too. Daily average temperature gradient gradually changes season-wise.

January is the coldest month, and June is the hottest month of the year for all the time periods during 1961-2010. Palam Airport experiences a bit lower temp. in January month and higher temp. in June month than Safdarjung, this is due to greater altitude of Airport. Sum of monthly mean temp. for both the stations raised during different climatic periods, which is for Safdarjung 300.1°C to 302.3°C and for Palam 297.5°C to 304.5°C. Rise in the temp. extremes (higher during summer months and lower during Winter) on both station's readings, which is observable by above percentage distributions. While temp. deviation (0.3) and variance (0.09) is highest in August whereas lowest deviation is found in the months of January and March (0.05). Where there are zero deviations and variance for the June month.

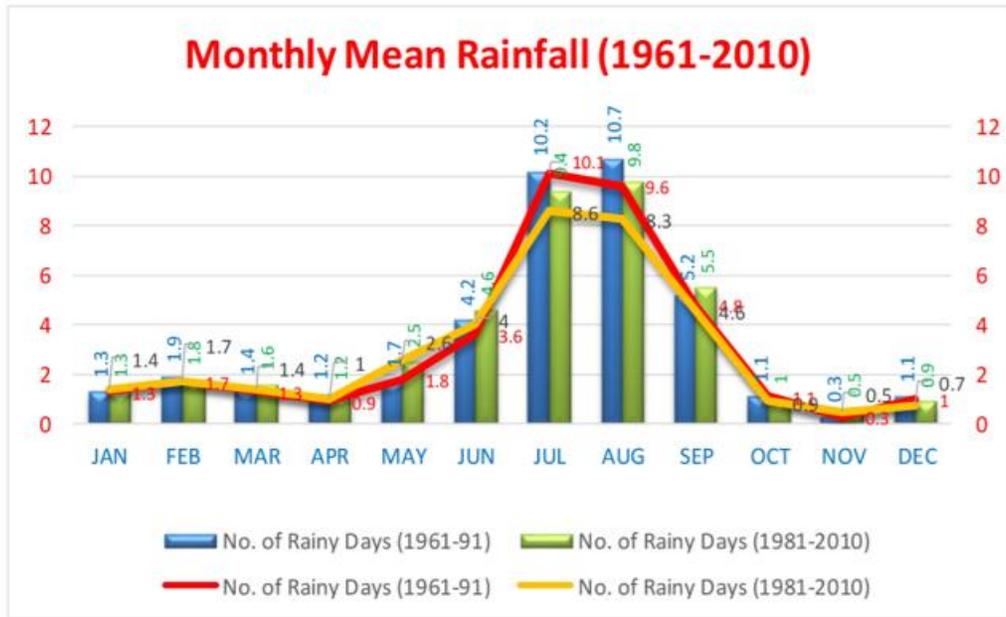


With the help of monthly total rainfall graphs, rainfall has also been observed having unique trends in Delhi during the last five decades. The monsoon starts in late June and lasts until mid-September, with about 799.5 mm (about 2.62 ft) annual rainfall has decreased to 762.2 mm (about 2.5 ft) at Safdarjung. This difference is larger at Palam Airport (Southwest Delhi), which is basically influenced by intensive desertification encroachment.

August is the wettest and November falls the lowest. August and July accounts for more than 60% of annual rainfall during 1961-91 whereas this figure fell up to 55% during 1981-2010. Where the great deficit has been observed during the July, August and September months. There is a small rise in precipitation during the early and late monsoonal period towards the end of September, moisture content in the air begins to fall and monsoon ends by early October.

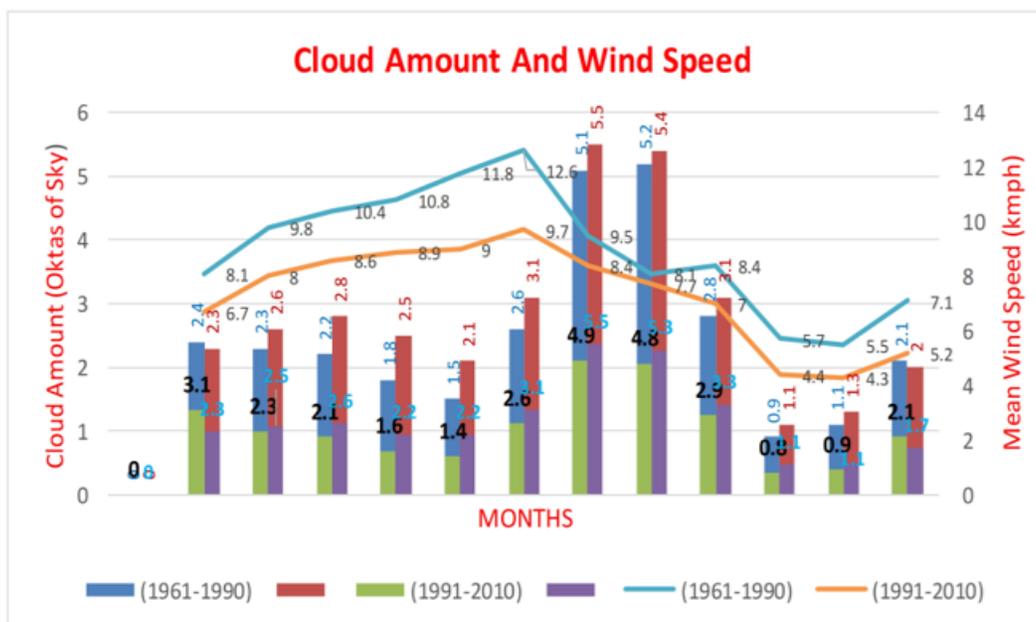
But many a time there are highly fluctuations observed due to western disturbances over Delhi climate. The monsoons receded in late September with average

temperatures sliding from 28 to 20.7°C during 1961-91 but which changed into 29.5 to 22°C. Here, in this graph, bins represent the Safdarjung records and lines are for Palam.



This graph shows how the number of rainy days decreased over the last six decades. The amount and frequency of precipitation dropped during 1981-2010. Moreover, the monthly total rainfall deviation and variance is higher during summer for months July and August (13.5-16.7) whereas March (0.55) month is recorded for lowest at Safdarjung.

But this deviation is recorded quite stronger up to 30.1 at Palam Airport. November month's rainfall pattern has been seen without any deviation since 1961 around this Airport region. Between summer and winter, the climate varies greatly in terms of temperature and precipitation.

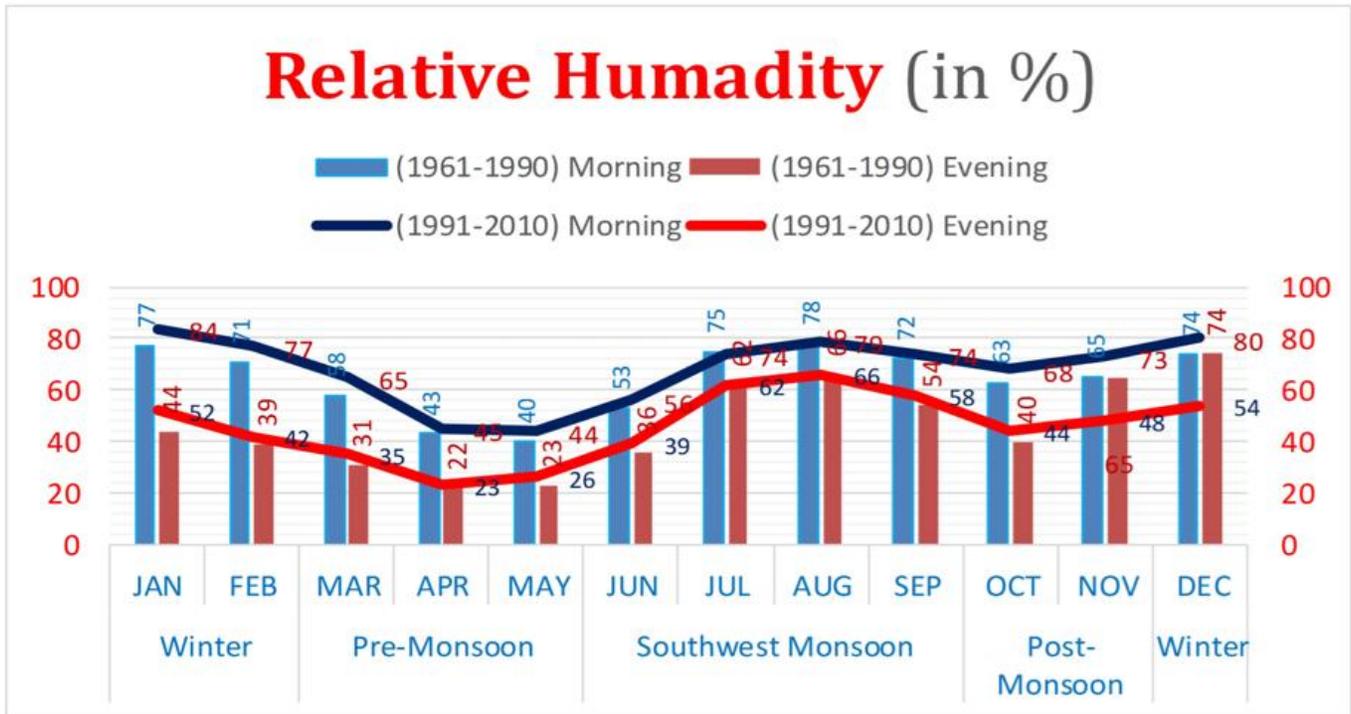


Delhi's humid subtropical climate differs largely from the humid subtropical climates of several other Indian cities. In this graph, compound bins show the total cloud amounts at morning and evening time whereas lines represent the wind speed in kmph during 1961-2010. We find negligible deviations in evening cloud amounts whereas morning clouds seem to be deviated more frequently. Month (May and August) has deviation up to one whereas February and December months recorded zero deviations during 1961-2010 in total cloud amounts.

Between 1981 and 2010, monthly average wind speeds in Delhi exhibited a significant increase, with the maximum rise observed in June and the minimum in August (+0.4 kmph). Analysis of long-term variability (1961–2010) reveals the highest deviations in May (1.4 kmph) and June (1.45 kmph), while August recorded the lowest deviation (0.2 kmph). This variability is largely attributed to the hot, dry continental winds, locally known as the loo, which originate from the Thar Desert and traverse the West Asian region before intensifying heat and aridity over Delhi.

Summers are further characterized by frequent thunderstorms and severe dust storms, often associated with cumulonimbus cloud formation. These dust-laden winds reduce visibility, impart a yellow haze, temporarily lower temperatures, and are frequently followed by thunderstorm activity.

Such climatic extremes are exacerbated by rapid industrialization and the increasing concretization of Delhi's land surface. The southern part of the city has been particularly affected, showing signs of advancing desertification over the past three decades. This process has also influenced Delhi's monsoonal rainfall, which remains lower compared to national averages. Elevated concentrations of dust aerosols in the lower troposphere inhibit cloud formation and reduce monsoon precipitation, particularly in the industrially developed suburbs of Faridabad, Gurugram, and Noida.

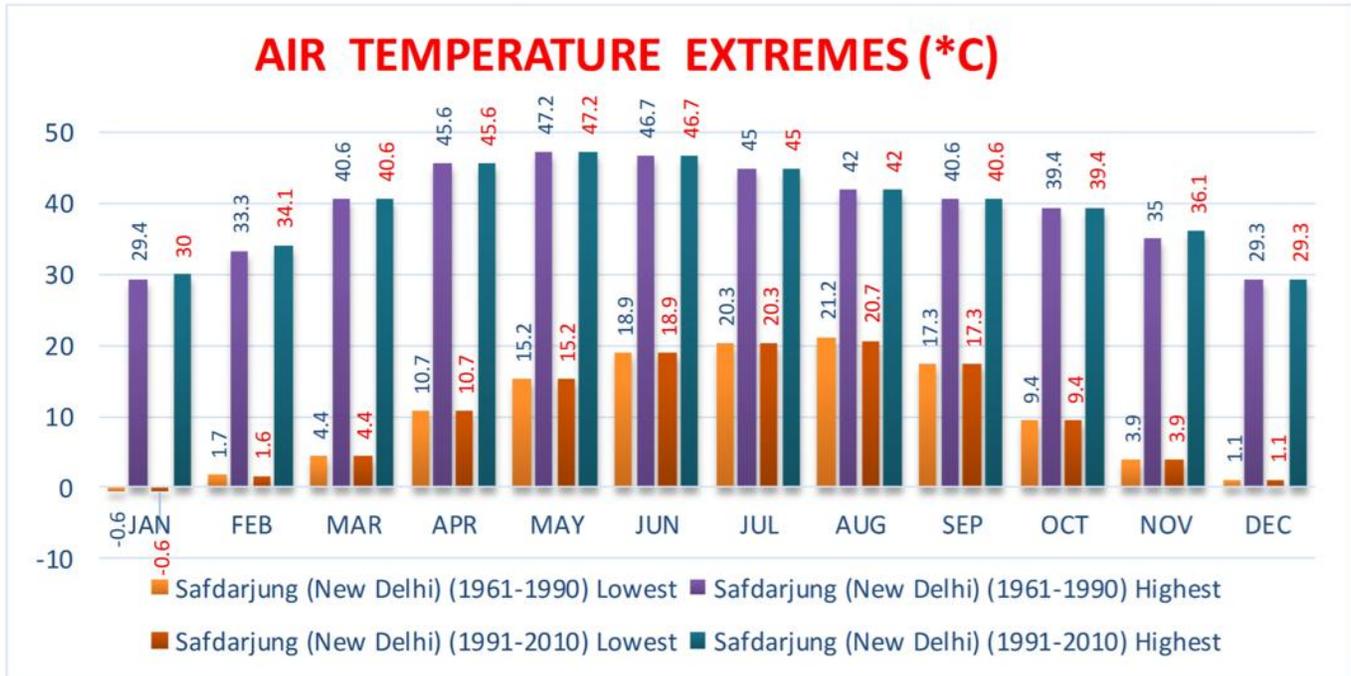


In this humidity graph, bin shows the readings of relative humidity during 1961-81 while lines are for 1981-2010.

As we know humidity is higher in the morning and reciprocal for evening. We observe the relative humidity has significantly increased (Morning and Evening both) during the last three decades. Where the difference is maximum at morning in November and January month which is by 8 and 7 percent respectively whereas maximum for evening is found in Winter (December +20%) growth. As we see the line graphs are parallel during the beginning and ending months of a year but there is less variation during scorching summer whereas May month records lowest percent of relative humidity in a year. We find zero evening deviations in the month of July and August whereas morning deviation is lowest too during these summer months which is 0.5. Relative humidity during post monsoon period (Nov and Dec) has abruptly increased up to 20% and showing highest deviation up to 10.

We noticed the most significant wind patterns that influence Delhi's climate are the Western Disturbance and the Southwest monsoon winds. Since the onset of disturbances, the depression has drifted more eastward (and is the reason for cyclonic occurrences in Eastern Coastal areas of Delhi) than earlier. There are no moisture-laden gusts in the air to increase the humidity levels. In consequence, the air is reasonably dry during the daytime. In addition, Delhi experiences a semi-arid climate for most of the summer season. Since the 1970s, the frequency of heat waves has grown. Whereas the daily maximum and minimum monthly temperatures have increased by roughly 1°C, rainfall has increased in the opposite direction. Here we also marked the temp. begin to dip around mid-June, while humidity gradually rises.

*Increased Temperatures and Extreme Events*



Delhi, located in the landlocked northern plains of India and surrounded by Uttar Pradesh, Haryana, and Rajasthan, experiences climatic influences shaped by its proximity to both the Himalayas and the Thar Desert. This unique geographical position exposes the city to extreme weather conditions. Climate change is projected to intensify these extremes, resulting in more frequent hot days, prolonged heat waves, droughts, declining groundwater levels, crop failures, and increased vulnerability to natural disasters. An analysis of temperature records from Safdarjung station (1961–2010) reveals extremes ranging from 0.6°C to 47.2°C. Heat waves are most frequent in May, less so in June, and rarely observed in April and August. May records the highest temperature extremes, while August shows the lowest. Recent winter trends indicate a decline in mean temperatures, potentially linked to desert influences and rapid industrialization.

Pre-monsoon months demonstrate the highest temperature extremes, as the sun’s position near the Tropic of Cancer results in stronger terrestrial radiation and elevated atmospheric heat. Although climate models project increased summer rainfall under warming conditions, observed rainfall in Delhi has declined. Meteorological analyses further reveal significant shifts in minimum and maximum temperatures, cloud cover, and relative humidity. Rising greenhouse gas concentrations may lead to an overall warming of 2–4°C in Delhi’s climate system.

*Climate change Action Plans*

Delhi’s State Action Plan on Climate Change (SAPCC) was developed in accordance with the concepts and recommendations of the National Action Plan on Climate Change (NAPCC). As the report says the revised *Climate Change Agenda for Delhi (2009–2012)* outlined 36 priority measures, providing a framework for coordinated actions across government departments, stakeholders, and civil society to address climate challenges.

Key initiatives by different organization include the **Solar Mission** which promotes solar energy in accordance with NAPCC’s mitigation goals. Energy efficiency measures like rooftop solar generation, LED adoption, cool roof technology, green buildings, and waste-to-energy initiatives have been implemented to enhance energy conservation. The Sustainable Habitat Mission focuses on improving building efficiency, advancing solid waste management, and shifting modes of transportation toward public systems, along with a scheduled action plan to combat air pollution. The Green India Mission has expanded Delhi’s effective green cover from 26 km<sup>2</sup> to 300 km<sup>2</sup> in 15 years, now making up 20.22% of the city. Plans are in place to increase this to 25% by 2030 through annual plantation drives of 10 lakh trees and 5 lakh shrubs, along with afforestation of 49.77 hectares of degraded forest land. The **Water Mission** emphasizes restoring the Yamuna’s water quality through wastewater recycling, pollution control, and regulatory monitoring.

Lastly, through the Climate Change Cell and MGICCC, the Strategic Knowledge Mission promotes research, awareness, and cooperation in addition to eco-friendly practice campaigns. The SAPCC as a whole takes a methodical approach to mitigation and adaptation, guaranteeing sustainable urban growth despite climate change.

#### VI. CONCLUSION

Climate change in Delhi, India's administrative capital, is especially pertinent considering the city's high population growth rate, urbanization, industrialization, and large-scale infrastructure growth. Such influences have disproportionately impacted the city's temperature and precipitation patterns. Increased greenhouse gas emissions, untreated refuse, smog buildup, and low public awareness have further exacerbated the city's environmental illness. The increased atmospheric concentrations of smog and suspended dust particles increase the absorption of land radiation, which amplifies local warming impacts. Counteracting these issues needs to be implemented urgently in vulnerable sectors. The Department of Forests and Environment and the Central Pollution Control Board need to implement and enforce sustainable transport, construction, industry, health, and biodiversity conservation guidelines.

Over the past five decades, climatic variables in Delhi have undergone remarkable transformations. Continuous warming trends coupled with declining rainfall have intensified climate variability in Delhi. The city is increasingly influenced year by year by western disturbances originating from arid regions, in comparison to moderating effects of the northeastern Himalayas or Tibetan. Most rainfall continues to occur during the southwest monsoon; however, its variability has enhanced remarkably. Observed reductions in total cloud cover and rainfall, along with their significant changes in wind speed and humidity, indicate a transition toward more arid and dry climate. Such deviations have far-reaching implications for both natural systems as well as human well-being, exposing Delhi to risks of desert-like climate characterized by temperature extremes and rainfall scarcity. Establishing reliable correlations between temperature and rainfall variability is essential for developing predictive models for city, supporting Delhi's planning, resource management, and adaptive governance in the context of climate change in Delhi.

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