Tropospheric Ozone levels in and around southern city Bengaluru, India

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Abstract

The diurnal to seasonal ozone (O_3) pre-cursors (NO, NO_2, CO, VOCs) trends over local climatic zones (LCZs) with the changes in weather patterns with respect to land cover classes determines the O_3 trends and useful for air quality management. In this work, diurnal to seasonal patterns of O_3 concentrations are analysed across the different LCZs in Bengaluru region. The Central/State Pollution Control Boards (CPCB/SPCB) operate more than 500 continuous air quality and weather monitoring stations across the India. Hourly O_3 concentration data were collected from CPCB for 5 different LCZs within the Bengaluru region over a period of four years (2019-2022). Time series analyses were conducted to examine the temporal variations in O_3 levels. The results showed significant fluctuations in diurnal trends of O_3 due to the influence of air temperature and relative humidity variations across the five LCZs within Bengaluru region. There were distinct seasonal trends in O_3 concentrations with maximum (60-65 ppb) observed during the winter and summer seasons and that of minimum concentration in the range 20-25 ppb during the monsoon months. The observed maximum ozone levels (60 -65 ppb) found to be beyond the threshold national ambient air quality standard (NAAQ) and the accumulation exposure over threshold of 40 ppb (AOT 40) during the winter and summer. The O_3 concentration trends are in line with the published research on premature mortality about 1200 annually for Karnataka state for chronic obstructive pulmonary disease owing to population exposure to O_3 beyond its threshold level of NAAQ. Also, the annual rice yield loss is about 2% (~0.1 Metric Tonne) with the AOT 40 to paddy crop for Karnataka state. Thus, O_3 diurnal to seasonal trends serve the first-hand information to local authorities for the action plan of air quality management taking into consideration O_3 precursors, wind speed, and wind direction.

Keywords: *Greenhouse gases, ozone pre-cursors, local climatic zones, CPCB*

1. Introduction

Short-lived greenhouse gas emitted largely from fuel combustions account directly or indirectly for extreme pollutant episodes that damages the crops. They also account for most of the direct damage to human health from energy consumption. These air pollutants include both health and crop damaging agents such as ozone (O_3), a secondary pollutant formed after complex photochemical reactions, and other gases that contribute to ozone formation such as carbon monoxide (CO), volatile organic compounds (VOCs), and oxides of nitrogen (NO, NO_2). Most of these precursors to O_3 also exert direct effects on crop yields and human health[1]. South Asian countries[2] (Male Declaration on Control and Prevention of Air Pollution, 2010)[2] have yet to be successful in gaining political support for action to be taken to reduce the threat posed by ground level O_3 on health and agriculture. This is a major concern for developing countries like India where economic growth has led to rapid increase in NO, NO_2, CO, and VOCs and to increased levels of O_3. The O_3 concentration is influenced by air temperature, relative humidity, solar radiation, wind speed, and wind direction[3, 4]. The weather scenarios over land covers-specific local climatic zones (LCZs)-determines O_3 and its precursors (NO, NO_2, CO, VOCs) levels.

The O_3 and its precursors trend depends on temperature and O_3 photochemical reaction rate, urban and suburban activities, and sector-specific emission factors. The analysis of O_3 and its pre-cursors over the urban and suburban LCZs within the megacities is crucial to understand the air quality scenarios. These results can be the first-hand information for planning of policy-induced air pollution control strategies. This paper presents the analysis of diurnal to seasonal patterns of O_3 across the 5 LCZs within the domain of Bengaluru region.

2. Experimental

2.1 Instruments and dataset

Large volumes of datasets for variety of weather and air quality parameters are available from the Central/State Pollution Control Boards (CPCB/SPCBs). Surface air quality dataset consists of CO_2, CO, SO_2, NO_2, O_3, PM_{10}, $PM_{2.5}$, NH_3, and Benzene. The measurements of these air pollutants along with weather parameters are conducted by CPCB and SPCBs, with the continuous air quality and automated weather monitors over more than 500 stations across India. The datasets of hourly O_3 concentrations, air temperature and relative humidity used in this paper were collected from CPCB's website[5]. The O_3 concentrations are measured using commercial ozone analyzer (model O342M, Environment SA, France) which works on UV absorption principle. The lower detection limit of the analyser is 0.4 ppb[6]. Hourly O_3

concentration data were collected for four years, 2019 to 2022 from 5 continuous air quality and weather monitoring stations within the study domain of Bengaluru region.

2.2 Study domain

Bengaluru's transformation into one of the major Information and Technology hub with the establishment of start-ups and corporate offices and industries have led to population growth, road expansion, and rapid infrastructural development. These changes in land cover impact air quality. The rapid increase in number of vehicles, coupled with rising population, has led to significant vehicular pollution. Traffic congestion results in more emissions, especially during stop-and-go situations across the junctions. The details of air quality and weather monitoring sites as shown in map (Figure 1) are tabulated in Table 1. The map in Figure 1 is created using Geographic Information System with latitudes and longitudes (Table 1) of CPCB's air quality and weather monitoring stations within Bengaluru region. Hourly O_3 concentrations, air temperature and relative humidity data collected from these LCZs are analyzed over diurnal to seasonal variations, and emission sources[7].

2.3 Weather and climatology of Bengaluru

The seasons in Bengaluru can be broadly categorized into:

1. Summer (March to May): Summers are generally warm, with temperatures ranging from 25°C to 35°C. Average annual maximum and minimum temperatures are 29.6°C and 19.2°C respectively. The mean maximum temperature of the hottest month (April) is 34°C and the coldest month (January) is 27.9°C.
2. Monsoon (June to September): Bengaluru receives the majority of its rainfall during the monsoon season. Average annual rainfall is 1004 mm. The mean monthly highest rainfall observed in September is 220 mm and lowest rainfall observed in January is 2 mm.
3. Post-Monsoon/Autumn (October to November): After the monsoon season, temperatures start to cool down gradually, and the weather becomes more pleasant. In post monsoon skies are moderately cloudy.
4. Winter (December to February): Winters in Bengaluru are generally mild, with temperatures ranging from 15°C to 28°C. Fogs occur occasionally during winter season.

2.4 Local Climatic Zone map

Local Climate Zones (LCZs) are a classification system used to categorize urban areas based on their surface cover and other characteristics that influence the local climate. The LCZs are used in urban climatology and urban planning to understand the urban heat island effect, energy consumption, and the impact of urbanization on local climate conditions. These zones are often determined by factors such as latitude, altitude, proximity to large bodies of water, ocean currents, prevailing winds, and topography. Different regions around the world can be categorized into various local climatic zones based on their unique climatic features. LCZ classification is based on 17 classes, each representing different urban and natural features[8]. These classes are denoted by numbers and labels. Understanding the specific climatic characteristics of a region helps in making informed decisions related to land use, infrastructure development, and resource management. It also plays a crucial role in predicting weather patterns and natural disasters, as well as understanding the impact of climate change on different regions. Figure 2, shows the generated LCZs classification of Bengaluru region using standard land use land cover data[9].

2.5 Methodology

Surface measurements conducted by the Central Pollution Control Board (CPCB) and the Quality Control and Quality Assurance (QC/QA) guidelines are archived[10]. The hourly data of ozone, temperature, and relative humidity during the years 2019 - 2022 were obtained from CPCB for the five stations tabulated (Table 1) as shown in Figure 1. The random fluctuations with the reference threshold value (O_3> 1000 $\mu g/m^3$) that appeared in just one hour in all five monitoring stations in and around Bengaluru have been filtered. The QC/QA were performed on the collected meteorological parameters by removing outliers with respect to technical specifications of measurement sensors, random fluctuations and single peaks right after the missing data points in time-series. The diurnal variations of ozone with temperature and relative humidity were plotted. The hourly data over different months were averaged to plot the seasonal variations as well. The months from December to February were considered as winter, March to May as summer, June to September as monsoon, and October to November as post-monsoon as per India Meteorological Department (IMD).

3. Results and Discussion

Figs 3 to 11 show the diurnal variation of ozone along with temperature and relative humidity. The diurnal variation of ozone shows a similar trend in all the sites. The ozone concentration is maximum during the afternoon hours (12 - 3 pm). This can be attributed to intense solar radiation during afternoon hours. The ozone concentration is minimum during the early morning (4-8 am) and evening hours (6-7 pm). The boundary layer of the atmosphere is well-mixed during the daytime. As the Sun sets, the boundary layer stabilizes and mixing reduces, thereby reducing the ozone concentration. This is further assisted by the absence of photochemical reactions due to reduced solar radiation. The maximum concentration of ozone varies between 60-65 ppb and the minimum varies between 20-25 ppb. For Karnataka state, premature mortality of about 1200 reported for chronic obstructive pulmonary disease with the population exposure to O_3 beyond its threshold level of national ambient air quality standard by CPCB[11]. Also, the percentage loss of rice around 2% (~0.1 Metric Tonne) with the accumulation exposure over threshold of 40 ppb (AOT 40) to paddy crop for Karnataka state[12]. Nevertheless, the LCZs specific health and vegetation impact within the Bengaluru region is out of the scope of this work and option to future study.

There are also yearly variations in this trend. The ozone concentration trend during 2019 is maximum compared to other years. The meteorological parameters considered for the study are temperature and relative humidity. The diurnal variation of temperature shows that it is maximum during the afternoon hours and minimum during the early morning and midnight. It shows a maximum of 27° C and a minimum of 20° C. Whereas, the relative humidity is maximum during early morning and late-night hours and minimum during afternoon hours. It shows a maximum of 75-80% and a minimum of 40%.

Diurnal variations of ozone and temperature follow a similar pattern in all the stations. The ozone concentration is maximum during the maximum temperature. This indicates that ozone is formed during intense solar radiation assisted by high temperature. At ground level, ozone peaks during the noon and afternoon hours due to photochemical formation and decreases gradually during late afternoon and evening hours due to dry deposition. But, the diurnal variations of ozone and relative humidity show the opposite trend. The ozone concentration is maximum when the relative humidity is minimum. The ozone concentration decreases with increasing humidity due to the attenuation of light due to absorption by water vapor, leading to a decreased O atom production by O_2 which is required to produce ozone[13, 14]. The high ozone episode days during peak summer were associated with meteorological parameters such as sunny and warm weather, with the low relative humidity[15].

Figs. 12 to 21 explain the seasonal variation of ozone with temperature and relative humidity. The seasonal variation of ozone shows a peak ranged from 60-65 ppb during the winter and summer seasons. During winter, the atmosphere tends to be more stable, leading to reduced vertical mixing of air. This stability can trap pollutants, including ozone, closer to the ground, resulting in higher concentrations. Also, the emissions from sources like heating systems and vehicular traffic may increase during colder months, contributing to higher ozone levels. In the summer, higher temperatures and increased solar radiation can promote the formation of ground-level ozone through complex photochemical reactions involving volatile organic compounds (VOCs) and oxides of nitrogen ($NOx = NO + NO_2$). The seasonal variation of ozone is minimum during monsoon season and ranged from 20-25 ppb. The monsoon season is characterized by heavy and frequent rainfall. The reduced variability during monsoon season may be first attributed to overcast sky condition leading to reduced photochemical ozone formation further being assisted by scavenging[16].

The seasonal variation of temperature shows a usual trend of maximum during the summer season and minimum during the winter season. The seasonal variation of relative humidity is maximum during the monsoon season and minimum during the summer season. During the monsoon season, which is characterized by heavy and frequent rainfall, the air become moist due to the evaporation of water from land and water bodies. The increased moisture content in the air leads to higher relative humidity levels. It is the opposite during the summer season. The seasonal variations of ozone and temperature indicate that ozone is formed maximum during the summer season when the solar radiation is more intense. Seasonal variation of ozone and relative humidity shows that ozone is minimum during the monsoon and post-monsoon season when the relative humidity is maximum. Ozone is maximum during winter and summer when the relative humidity is minimum with respect to monsoon months.

4. Conclusions

The ozone pre-cursors (NO, NO_2, CO, VOCs) concentration in presence of solar radiation determines the diurnal to seasonal trends in ozone levels across the different local climatic zones (LCZs) with the changes in weather patterns with respect to land cover classes and they are the essential ingredients for managing the air quality. The diurnal to seasonal trends of ozone concentrations based on hourly data of air quality, temperature and relative humidity at five different LCZs over a period of 4 years (2019-2022) showed the maximum (60-65 ppb) observed levels during the winter and summer seasons and the minimum (20-25 ppb) during monsoon months. The maximum ozone levels in the range 60 -65 ppb are found to be beyond the threshold national ambient air quality standard (NAAQ) and the accumulation exposure over threshold of 40 ppb (AOT 40) during the winter and summer seasons over a period of 2019 to 2022. These results corroborate published research on the premature mortality of about 1200 annually for chronic obstructive pulmonary disease owing to population exposure to O_3 beyond its threshold level of NAAQ for Karnataka state. The results are in line with the published research on annual rice yield loss of about 2% (~0.1 Metric Tonne) with the AOT 40 to paddy crop for Karnataka state. The diurnal to seasonal trends of ozone concentrations with the temperature and relative humidity across the different local climatic zones (LCZs) within the Bengaluru region serves the ready reckoner to undertake policy-induced emission control measures of ozone pre-cursors to manage quality of the air across the LCZs in Bengaluru region. The future scope can be the LCZ-specific health and vegetation impact assessments within the Bengaluru region taking into consideration diurnal to seasonal trends of ozone and its precursors as a function of weather parameters including prevailing winds.

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Figures:

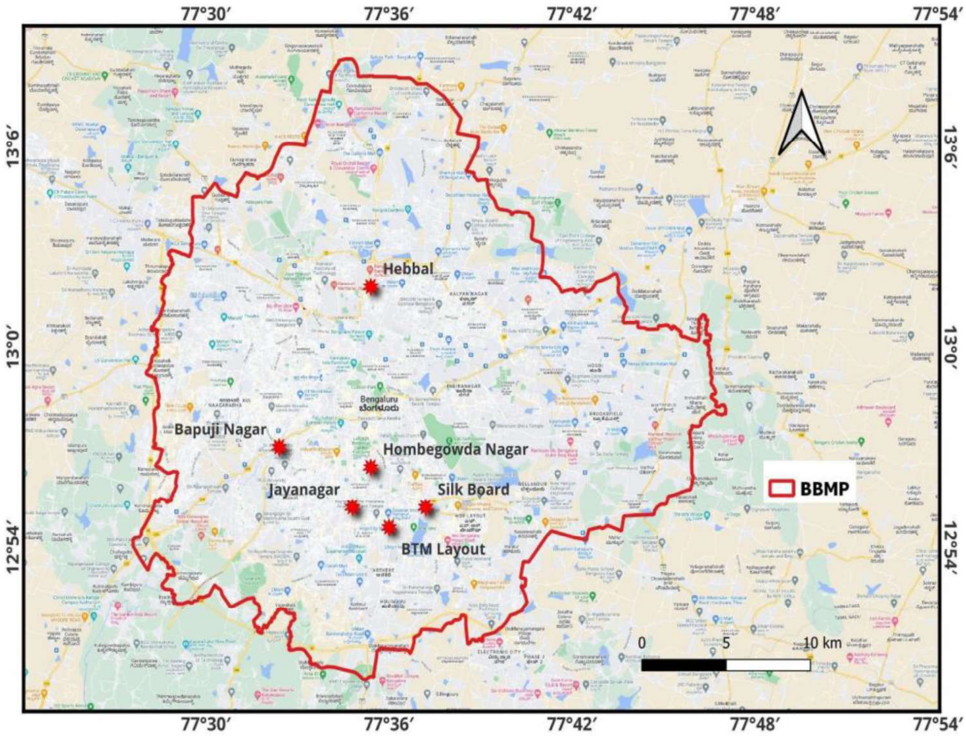


Fig. 1: Map shows locations of air quality and weather monitoring sites

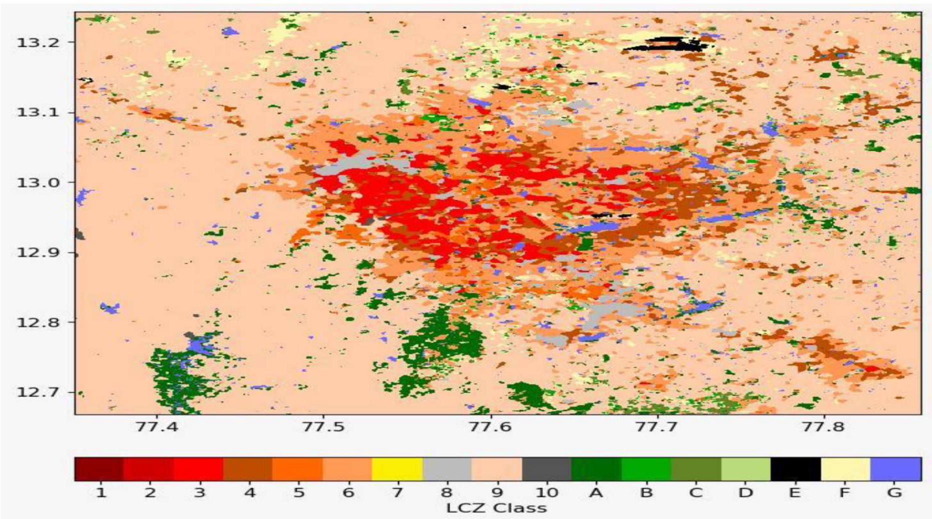


Fig. 2: Local climatic zones (LCZ) with LCZ classes (Bengaluru)

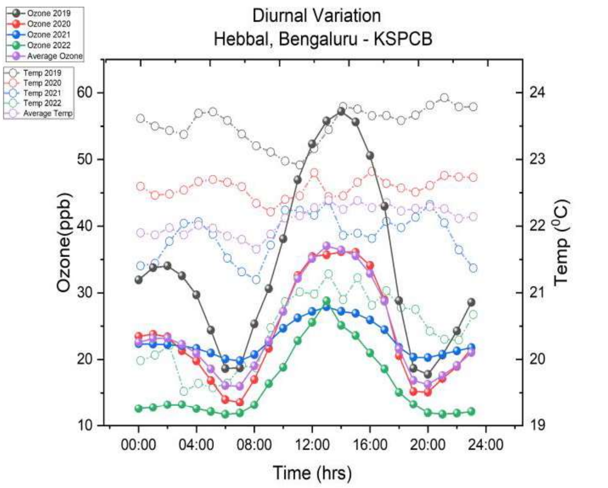


Fig. 3

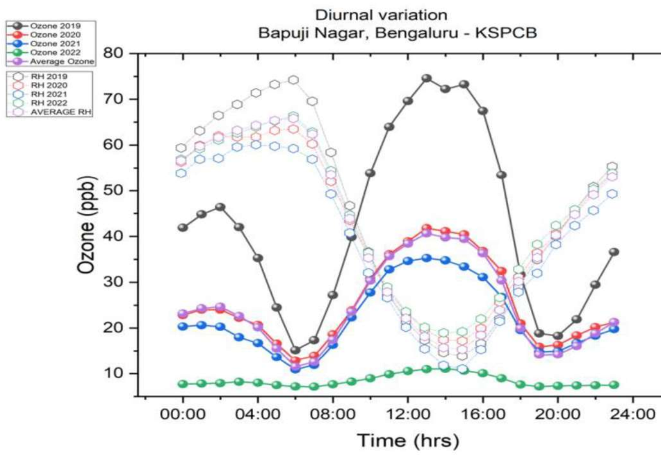


Fig.4

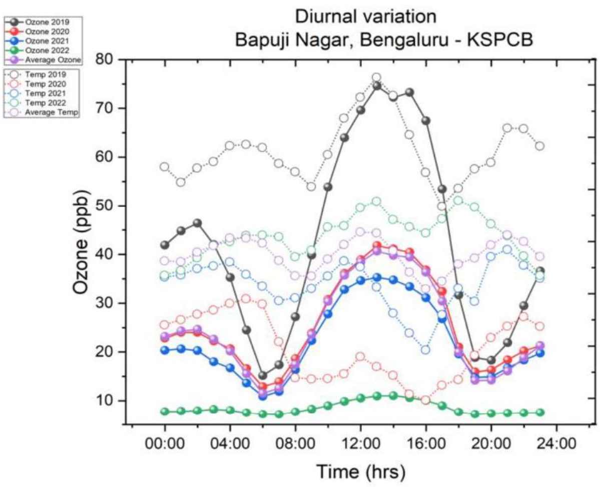


Fig. 5

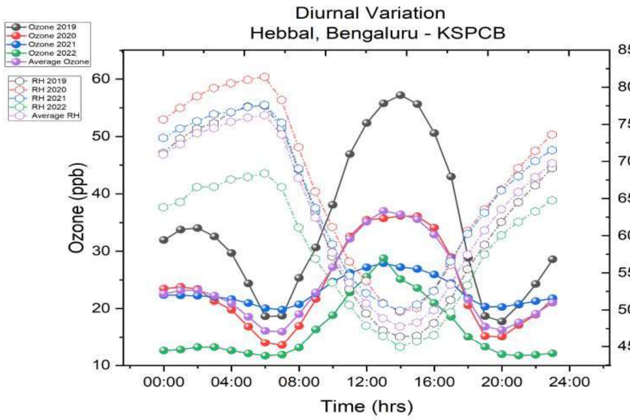


Fig. 6

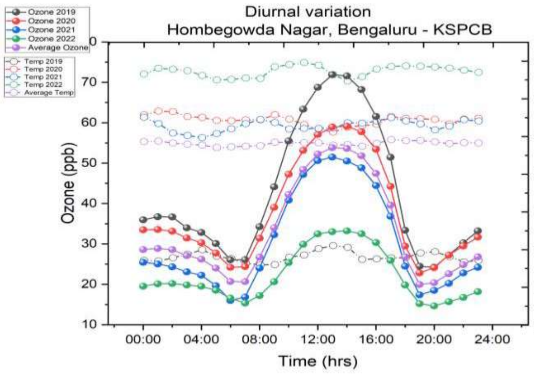


Fig. 7

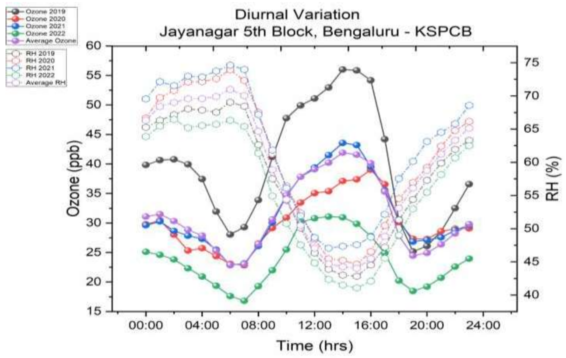


Fig. 8

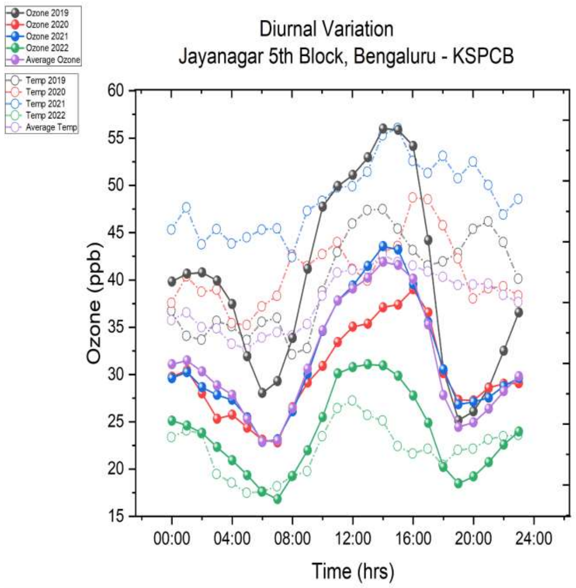


Fig. 9

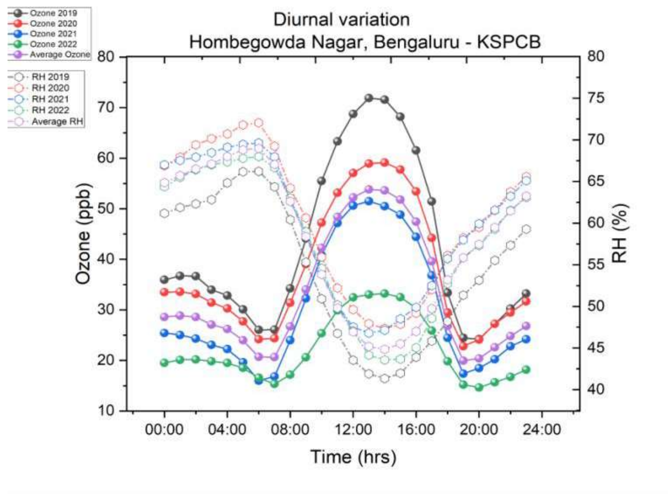
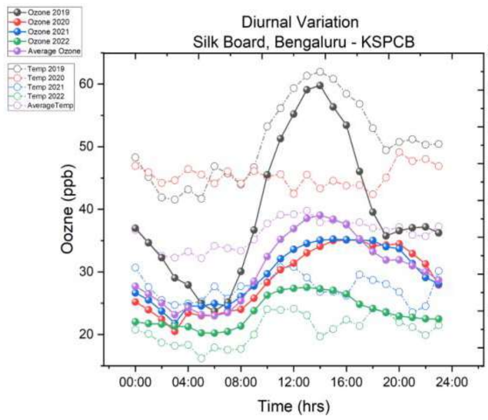


Fig.10



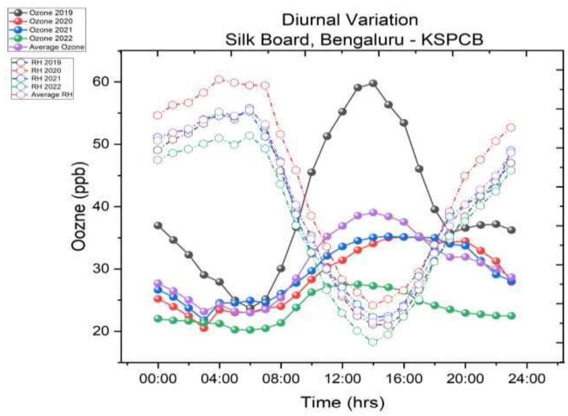


Fig. 11

Figs. 3 to 11: The diurnal variation of ozone with temperature and relative humidity over different stations.

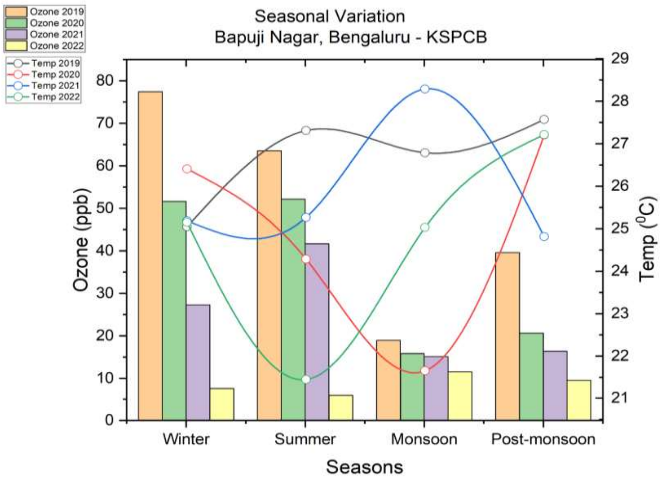


Fig. 12

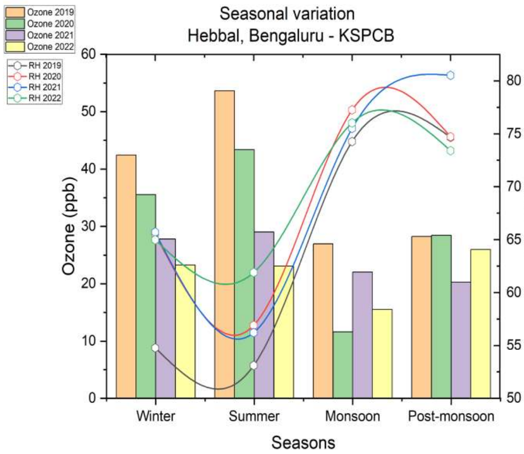


Fig. 13

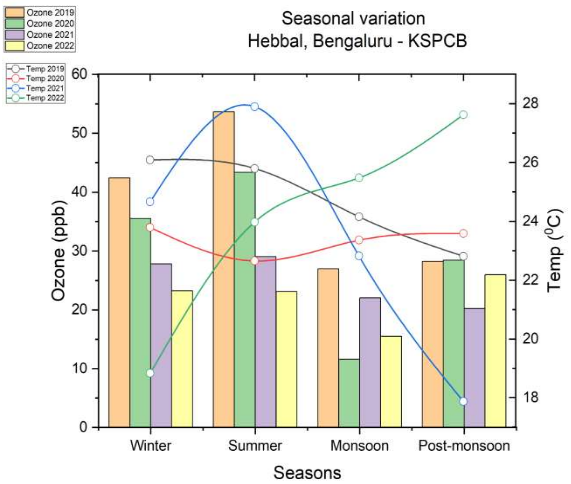


Fig.14

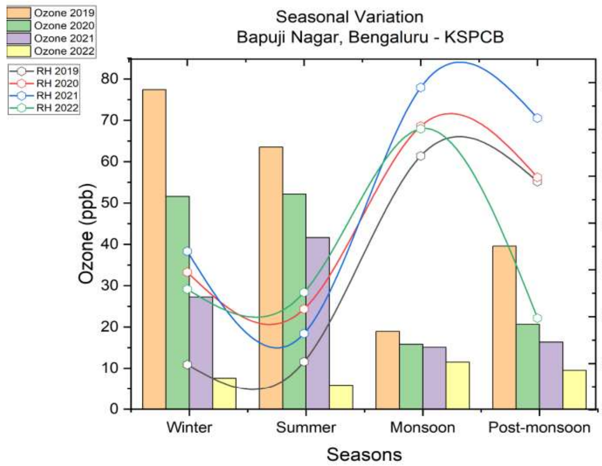


Fig.15

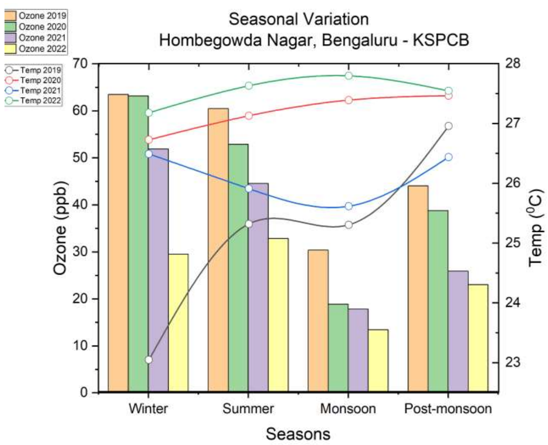


Fig.16

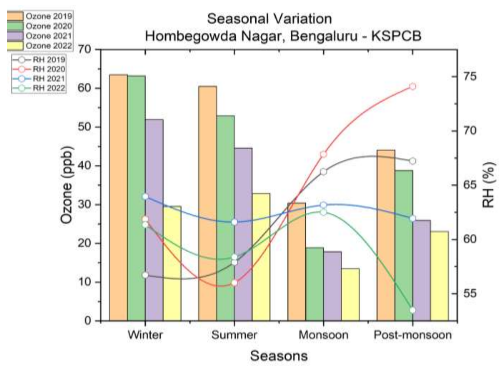


Fig. 17

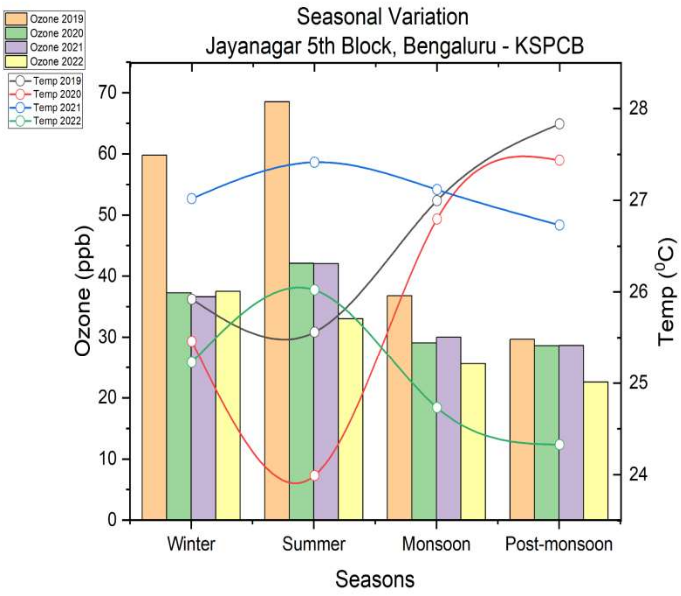


Fig. 18

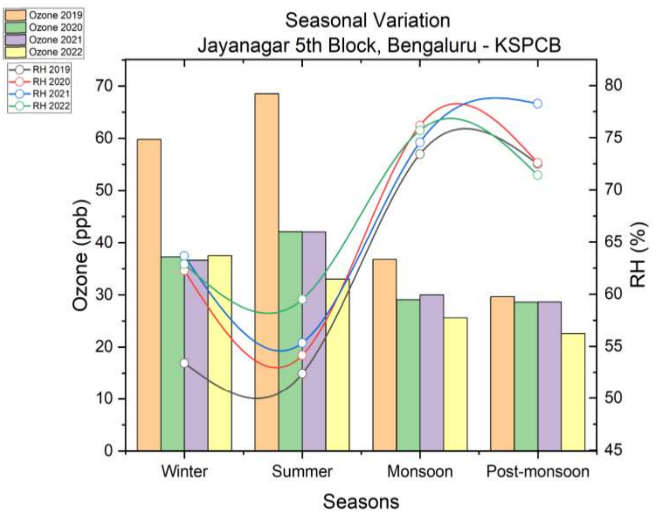


Fig. 19

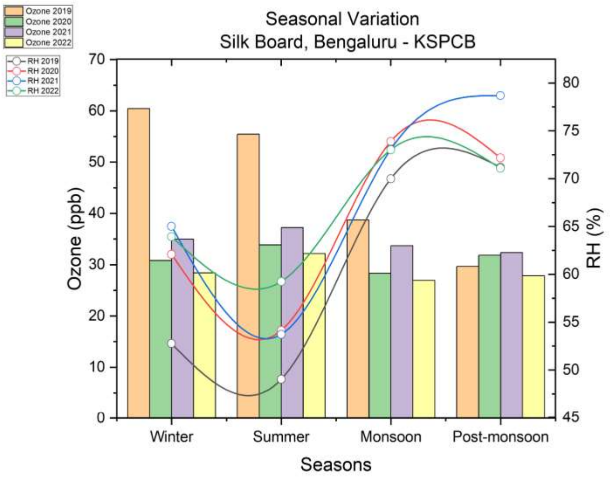


Fig. 20

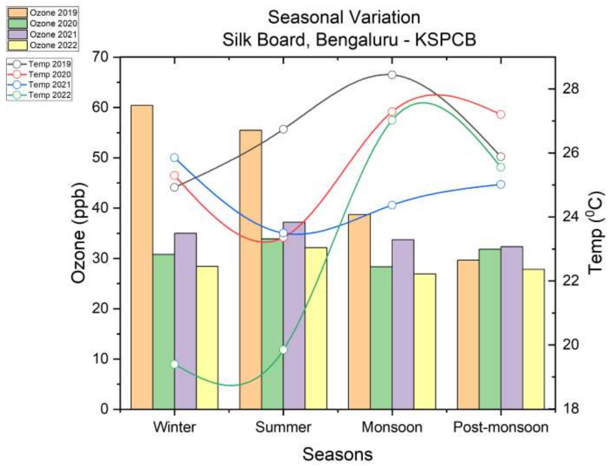


Fig. 21

Figs. 12 to 21: Seasonal variation of ozone as a function of temperature and relative humidity.

Table 1: Air Quality and weather monitoring sites in Bengaluru

S N	Sites in and around Bengaluru	Latitude	Longitude
1	Bapuji Nagar	12.951913° N	77.539784 °E
2	Hebbal 1st Stage	12.21041 °N	76.37376 °E
3	Hombegowda Nagar	12.938539° N	77.590100 °E
4	Jayanagar 5th Block	12.920984 °N	77.584908 °E
5	Silk Board	12.917348 °N	77.622813° E

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