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Diurnal and seasonal Behavior of Gaseous Pollutants in Bengaluru Urban Area: A Silicon Valley of India

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Abstract

The capital of Karnataka "Bengaluru" located in the Southern part of India is still facing challenges due to atmospheric pollution. The levels are still very high over the city compared to national and international standards due to vehicular emissions. The ambient gaseous pollutants as O3, CH4, NMHC, CO, NH3, NO, NO2 and SO2 were assessed over Bengaluru since 1st January 2017 to 20th March 2018. The daily average concentrations of O3, CH4, NMHC, CO, NH3, NO, NO2 and SO2 were 35.0 ± 17.50 ppb, 412.8 ± 259 ppm, 1.1 ± 1.1ppb, 0.7 ± 3.1 ppm, 28.8 ± 15.7 ppb, 7.2± 3.1ppb, 27.5 ± 8.4 ppb and 4.8 ± 1.6 ppb, respectively. The methane values were greater during the post-monsoon season (643 ppb) followed-by winter (488.4 ppb), monsoon (333.0 ppb) and summer (286.3 ppb). However, the NMHC was highest in the summer followed by the winter (1.3 ppb), monsoon (0.5 ppb) and post-monsoon seasons (0.4 ppb). Diurnally, fast production of surface ozone (highest: +8.01 ppb h−1) was observed in between 8:00 and 12:00 hours LT because of freshly emitted precursors and photochemical reaction in this period. In evening (in between 17:00 and 19:00 hours LT), it was opposite and fast destruction of surface ozone (-7.82 ppb h-1) because of the lower production of oxides of nitrogen. The study has indicated the reverse diurnal pattern with lowest NO, NO2 and CO concentration when ozone showed the highest Peak indicating the precursor gases for ozone. To enhance the quality of air, the control strategies must be adopted to diminish the emission from source regions.

Keywords: Diurnal; Seasonal; Ozone; Precursor gases; Boundary Layer Height

Introduction

The Urban Air Pollution (UAP) is a serious worry to the environment and public health. The exponential increase in population, vehicles and industrial sectors in Urban areas are severely deteriorating the air quality. As reported by WHO, due to increased UAP over developing countries, the mortality rate is exceeding 2 million with severe respiratory morbidities [1] . The major sources of UAP are road transport, domestic, commercial, industrial activities etc. The vehicular emission contribution by megacities in developing nations is around 70–80% of air pollution. Most of the cities are using a lot of older vehicles along with bad maintenance, poor transport infrastructure and low grade of different fuels [2]. Gaseous pollutants mainly SOx, NOX, CO, VOCs etc., are highly reliable for air pollution. Besides this, the bad maintenance of roads releases more dust into the atmosphere that are significant sources of atmospheric particulate matter over the Urban environment [3]. Kandlikar [4] has suggested that the atmospheric pollutants spread non uniformly in the Urban environment from roadways, business area, industrial location and traffic intersections. In another study, Gokhale and Khare, [5] have suggested that meteorological parameters and geographical features are also considered for higher pollutant values to the spatial and temporal variations.

Materials and Methods

Study area

Bengaluru is located at about 450 km far from Bay of Bengal and also Arabian Sea and about 400 km from the Indian Ocean. Bengaluru BBMP area covers a region of 741 km2 (286 sq miles) with latitutde and longitude of 12.97°N 77.56°E. It serves as the capital city of Karnataka as well as industrial capital also. Bengaluru also described as the Garden city of India in view of large number of gardens and parks within the urban area. Bengaluru is sometimes referred as the “Silicon Valley of India” as it is a hub for many Software Companies and Information Technology. Automobiles are the primary contributors of atmospheric pollution over Bengaluru. In the current trend, the vehicles registration is rising rapidly. According to ministry of transport information, around 15% of vehicles in state are over 15 years old. Majority of middle and upper class people use their own transportation, thereby reducing the air quality in Bengaluru Urban. Apart from this, construction activities, road/highway/metro train works, garbage burning are polluting the air. Municipal solid waste (MSW) is produced around 4000-5000 tons per day within the Urban area.

Monitoring Program

In current study, the measurement of Gaseous Pollutants (GPs) was undertaken in the Southern part of India, Bengaluru, which is located inside the city. The data of GPs (NOx (NO+NO2), CO, NH3, SO2, O3 and BTEX) and Meteorological Parameters (MP) were simultaneously collected from five monitoring stations of State Pollution Control Board (KSPCB) and Central Pollution Control Board (CPCB) during 2017 and 2018 at 5 m above the ground. All stations were selected according to residential, commercial, vehicular and industrial activities. All monitoring stations were equipped with the latest online monitoring equipment along with meteorological sensors. The data of Gaseous Pollutants (GPs) are analyzed from five different locations (Figure- 1) operated by Government agencies called Central and State Pollution Control Board. The monitoring stations are chosen based on the criteria of meteorology, industrial growth, high traffic density, public complaints, population, land use patterns etc. Site classification is described in (Table 1) [6].

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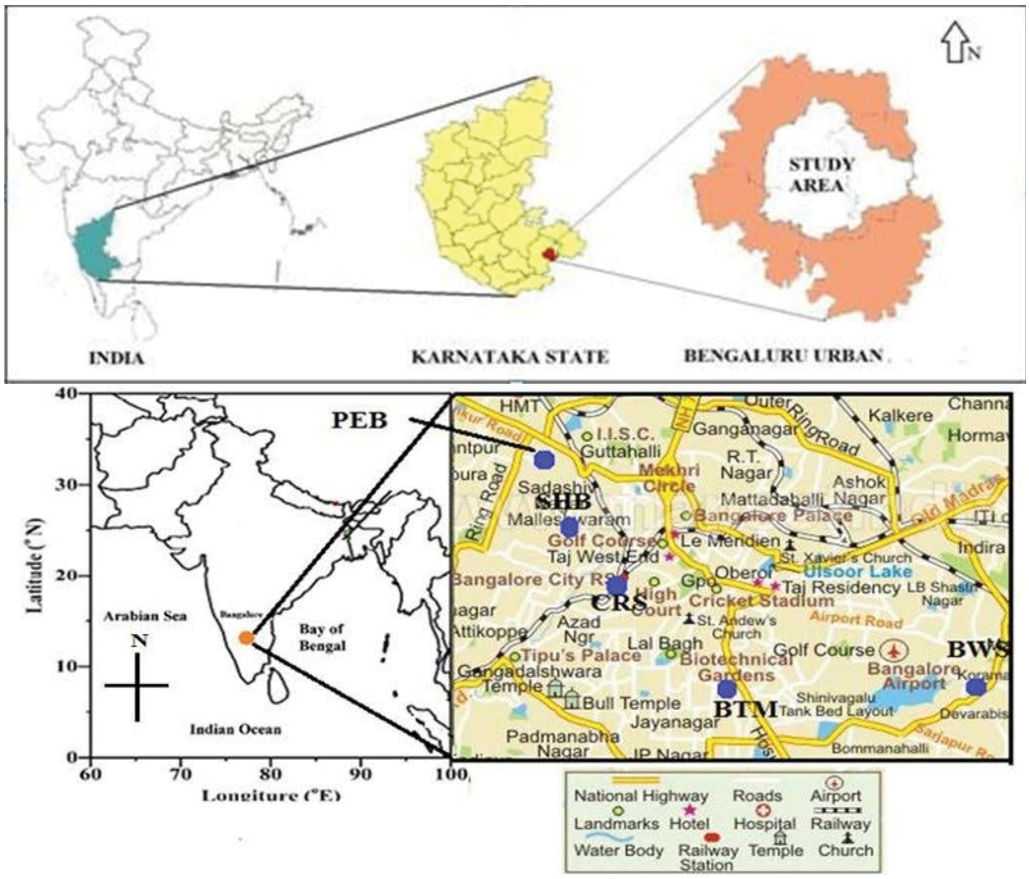

Figure 1: Sampling Location over Bengaluru urban area.

Monitoring Station	Short Name	Latitude values	Longitude values	Sampler	Land use pattern
Byrasandra Thavarekere Madiwala	BTM	12.97° N	77.59° E	GPs, MPs	Residential, Commercial
Peenya	PEB	13.03° N	77.51° E	GPs, MPs	Industrial, Residential
Kadabesana halli	BWS	12.93° N	77.69° E	GPs, MPs	Industrial, Residential
Sanegurava Halli	SHB	12.99° N	77.54° E	GPs, MPs	Residential, Commercial
City Railway Station	CRS	12.97° N	77.57° E	GPs, MPs	Commercial Residential, High vehicular density

Table 1: Detail Report of the Sampling Stations in Bengaluru Urban Area.

Results and Discussion

Ambient Concentrations of Ozone, Methane and Non methane Hydrocarbons

The diurnal and seasonal variations of gaseous pollutants as O3, CH4, NMHC, CO, NH3, NO, NO2 and SO2 were assessed over Bengaluru during study period (Figure 2 & 3). The daily average concentrations of O3, CH4, NMHC, CO, NH3, NO, NO2 and SO2 were 35.0 ± 17.50 ppb, 412.8 ± 259 ppm, 1.1 ± 1.1ppb, 0.7 ± 3.1 ppm, 28.8 ± 15.7 ppb, 7.2± 3.1ppb, 27.5 ± 8.4 ppb and4.8 ± 1.6 ppb, respectively (Figure 4). The methane values were greater during the post-monsoon season (643 ppb) followed-by winter (488.4 ppb), monsoon (333.0 ppb) and summer (286.3 ppb). However, the NMHC was highest in the summer followed by the winter (1.3 ppb), monsoon (0.5 ppb) and post-monsoon seasons (0.4 ppb) (Figure 5). The daily and monthly mean concentrations of GPs are given in Table 2 and the daily mean variations of ambient concentrations of GPs are represented in Fig. 5.

The ozone concentration over Bengaluru is within the limits prescribed by WHO (standard limit: 100 µg/m3/50 ppb) and CPCB (100 µg/m3) [7]. The lower values of surface ozone reflect the significant sink of the ozone by freshly emitted Nitric Oxide from automobiles. The WHO reported that health will be affected if the ozone level exceeds the standard level. During research study, the annual variations of O3 were observed to be high among two stations over the city side with the highest (43.1 ppb) at BTM and BWS (30.7 ppb). Seasonally, in the winter season, the average O3 values was highest (mean = 49.7 ppb) followed by the summer (33.2 ppb), post-monsoon (25.8 ppb) and southwest summer monsoon season (23.7 ppb).

The lowest value of O3 in the monsoon season was because of wash out of its precursors, on the other hand, a higher concentration

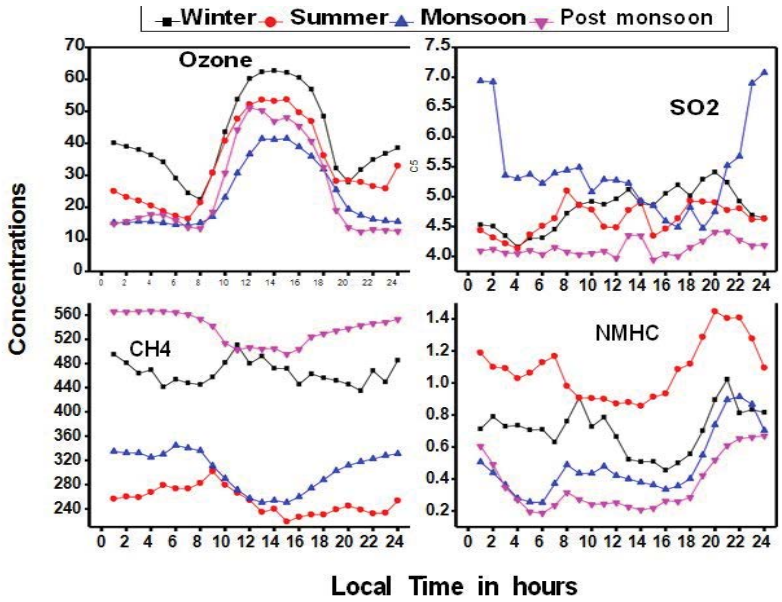

Figure 2: Seasonal Daily Variations of Surface Measured O3, SO2, CH4, and NMHC over Bengaluru Urban area.

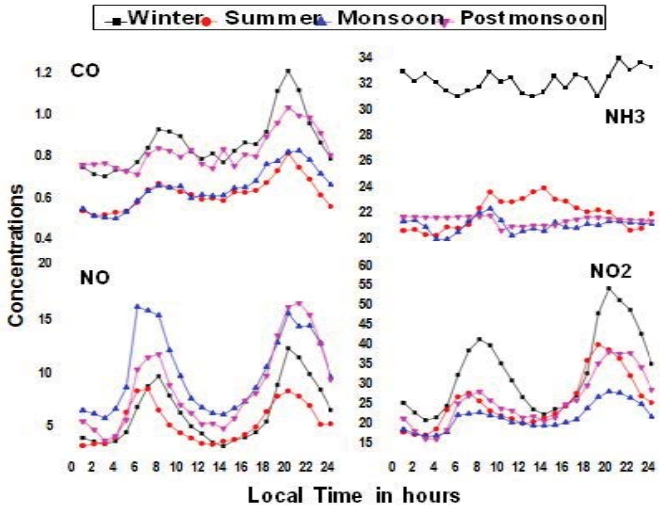

Figure 3: Seasonal Daily Variations of the Surface Measured CO, NH3, NO and NO2 over Bengaluru Urban area.

during winter period was due to large emission along with the higher photochemical reaction because of higher solar radiation and due to fuel consumed [8] . In addition to this, the higher concentration in the winter and post-monsoon season may be because of the excessive biomass burning over the study region [9] . The second highest concentration in summer was due to the photochemical reaction and stronger atmospheric vertical mixing. The present research work is in compliance with other studies conducted in Egypt, Greece and Beijing [10–12] reported that in East and South Asia, the seasonal variations of ozone are due to prevailing rainfall and wind pattern. In the onset of the summer monsoon, the stronger southwesterly carry air from the Arabian Sea to the Indian subcontinent, leading to tremendous enhancement of rainfall [13]. In East and South Asia, it was observed that the decrease in tropospheric O3 during the summer monsoon [14,19] . In addition to this, modelling studies reported that during summer, the surface ozone was minimum over Indian subcontinent [20].

The Fig. 2 shows the diurnal pattern of O3 concentration along with its precursors over Bengaluru city in four major seasons. The higher concentration of ozone was observed from 10:00 a.m. to 6:00 p.m. (varied from 59.3 to 35.7 ppb) and the lower concentration from 6:00 p.m. to 6:00 a.m. (20 ppb) as well as from 7:00 a.m. to 9:00 a.m. The ozone concentration started increasing from morning 9:00 a.m. with increase in solar radiation thereby reaching maximum at 2:00 p.m. (51.7 ppb), thereafter it starts decreasing slowly and reaches to its minimum during late evening due to the lack of solar radiation. Seasonally, the higher concentration was observed in winter and summer followed by low concentration in monsoon and post-monsoon period.

Surface ozone is formed within the atmosphere by the photochemical reaction between NO and NO2, VOCs, CO in the presence of intense solar radiation. The study noticed that the NO2 start decreasing in day hours, subsequently, O3 starts increasing

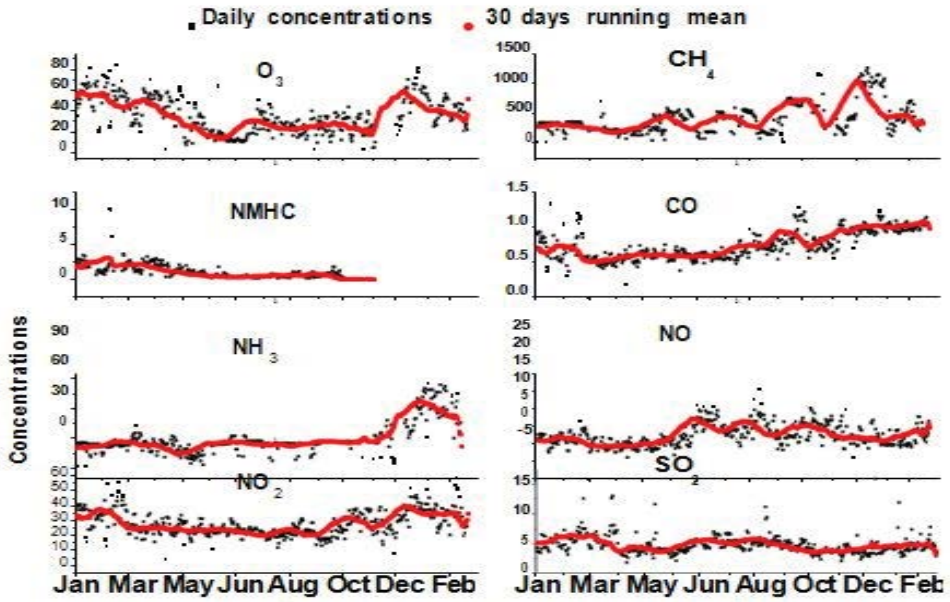

Figure 4: Daily mean of O3 (ppb), CH4 (ppm), NMHC (ppb), CO (ppm), NH3 (ppb), NO (ppb), NO2 (ppb) and SO2 (ppb) along with 30 days moving from January 1st, 2017 to 20th March 2018 over Bengaluru Urban area.

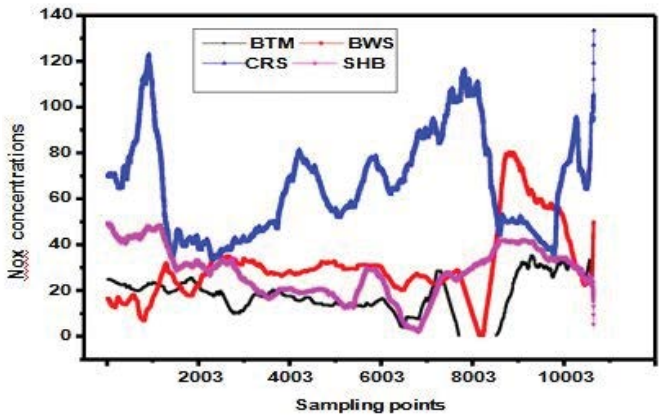

Figure 5: Hourly day-to-day Running (20-day) Concentrations of NOx for Four Sites at BTM, BWS, CRS, and SHB over Bengaluru Urban area.

Month	O_3	CH_4	NMHC	CO	NH_3	NO	NO_2	SO_2
January	54.8	630.6	2.0	0.9	36.0	6.0	35.4	4.7
February	48.6	370.9	3.0	0.9	44.0	6.3	35.7	5.5
March	42.4	274.4	2.1	0.8	34.1	6.1	29.2	5.7
April	44.1	176.5	1.6	0.6	22.4	4.2	25.3	3.7
May	27.1	305.0	0.9	0.6	14.6	4.7	23.1	4.2
June	16.0	398.5	0.5	0.6	24.7	6.6	23.5	4.2
July	22.1	287.8	0.3	0.6	25.3	11.5	22.5	5.5
August	27.6	439.0	0.5	0.7	23.2	8.5	19.5	5.1
September	21.5	266.8	0.6	0.7	21.6	10.5	23.7	5.8
October	26.1	592.7	0.7	0.9	26.3	7.7	20.6	4.6
November	25.5	720.8	0.0	0.7	25.5	10.0	31.9	3.6
December	19.0	446.9	0.0	0.9	26.0	7.0	25.0	3.6
Daily mean concentrations	**35.0 ±17.50**	**412.8 ±259**	**1.1±1.1**	**0.7± 3.1**	**28.8 ±15.7**	**7.2± 3.1**	**27.5 ±8.4**	**4.8± 1.6**

Table 2: Monthly and Daily mean concentrations of O3 (ppb), CH4 (ppm), NMHC (ppb), CO(ppm), NH3 (ppb) NO (ppb), NO2 (ppb) and SO2 (ppb) over Bengaluru Urban area.

because of its precursor and is playing a major role in the formation of NOx. The similar trend of CO was as NO which is co-pollutant produced from combustion and has a similar reverse diurnal pattern in comparison to O3 with the lowest NO and CO concentrations in the afternoon hours when Ozone indicated the highest value. Tiwari [21] has also analyzed the diurnal variability of surface ozone in Delhi, a megacity in the northern part of India and found a similar behavior of surface ozone with the highest ozone concentrations around 15:00 hrs LT (noon time). Apart from solar radiation, emissions from man-made activities, BLH, vertical convection, meteorological factors etc., are also responsible for the variations in surface O3 concentrations [22]. Lal [23] has found that the day hours concentration of the surface ozone buildup over an Urban polluted city Ahmadabad (23°N, 72.6°E) in tropical Indian region. In the evening, due to NO dominating to the NOx, the ozone concentration was depleted. White [24] reported that after sunrise, the solar radiance increases, the O3 forms and NO convert to NO2 followed by photolysis and form significant surface O3. The study has indicated the reverse diurnal pattern with lowest NO, NO2 and CO concentration. when ozone showed the highest Peak indicating the precursor gases for ozone.

Ambient Concentration of Oxides of Nitrogen

Variations of hourly and daily concentrations of NOx (NO+NO2) for four sites at BTM, BWS, CRS, and SHB are depicted in Fig. 5. The station wise mean values of NOX concentrations across Bengaluru were 17.3, 30.5, 56.9 and 28.4ppb respectively. The CRS station showed the highest concentration due to high combustion source mostly from high diesel vehicular traffic which produces more oxides of nitrogen, however, there is less variability in NOx at three stations indicating the similar sources. During winter, the average concentrations of NO2 was higher than NO. However, during other seasons, NO was higher than NO2 due to photochemical oxidization of NO to NO2 [25] (Figure 6). The air quality across the Indian cities over the residential, commercial and industrial environment have indicated a rapid increase in the NOx concentration ranging from 100 - 240 μg/m3 and sometimes it exceeds the permissible limits. Kunhikrishnan [26] suggested that in coming years it is likely to increase drastically. During the present study, the seasonal variation in the concentration of NO was highest in the monsoon (10.2 ppb) followed by post-monsoon (8.8 ppb), winter (6.3 ppb) and summer (5.4 ppb) seasons. However, the NO2 concentration was observed highest in winter (33.3 ppb), post-monsoon (26.2ppb), summer (25.5ppb) and monsoon (21.9 ppb) seasons. The ratio of NO/NO2 was significantly higher during the monsoon season (0.47) and was lower during the winter season which is totally different from other studies over another megacity. The daily mean concentration of NO2 is within the permissible limit of Indian NAAQS and USEPA standards . Ahammed [27] has indicated the yearly mean NOx concentration of ≈ 3.9 ppb in a semi-arid site "Anantapur", in India from 2001 to 2003. Singh [28] also reported similar values of NOx over Delhi (32 to 272ppb). The study has found that the high concentration of NOx was observed in CRS station due to high diesel vehicular traffic.

Ambient Concentration of Carbon monoxide

The daily variations of carbon monoxide (CO) as well as 30 days running average values over Bengaluru are represented in Fig. 3. The daily average values of CO was 0.7 ± 3.1 ppm and varying monthly from 0.59 (July) to 0.95 ppm (October). The average CO concentration is within the permissible limit of NAAQS (NAAQS: ≈ 4 ppm) and USEPA standards (35 ppm) (USEPA, 2015). Highly polluted city in India is Delhi contributing CO concentration ~ 509 tons/day from automobiles during the year of 2008–2009 [29]. Seasonally, the highest concentration was during winter (0.88 ppm), followed by post-monsoon (0.84 ppm), monsoon (0.66 ppm) and summer seasons (0.63 ppm). The mean CO concentration over Bengaluru is similar to Agra (0.71 ppm) [30]. and Kanpur (0.72 ppm) [31], and higher than Anantapur (0.44 ppm) [27], Nainital (0.28 ppm) [32] , Mt Abu (0.13 ppm) [14]. Girach [33] reported that the mixing ratio for CO over the Bay of Bengal on a ship track measurement from July to August 2009 found the values between 50.0 to 200.0 nmol mol−1 (mean 96.0 ± 25.0 nmol mol−1) which is slightly higher than standard. The study has shown a high concentration of CO in winter and post-monsoon period.

Ambient Concentration of Sulphur dioxide

During the research period, the average concentration of SO2 was 4.8 ± 1.6 ppb varied from 0.29 ppb to 41.40 ppb over Bengaluru city. Seasonally, it was highest in monsoon season (5.4 ppb) followed by winter (4.8 ppb), summer (4.6 ppb) and post-monsoon (4.1 ppb) seasons (Figs. 2 and 6) The mean concentration of SO2 is lower than NAAQS (30 ppb), WHO (20 ppb) and US EPA (75 ppb) standards. The diurnal variations of SO2 concentration over Bengaluru are represented in Fig. 4. These changes are due to the air mass arriving from another source region. During summer, winter and post-monsoon period, the SO2 showed bimodal distribution pattern. It may be explained due to higher dilution in day times, the concentration was less, however, the high concentration were observed in evening and in night times from automobile emissions. The major sources of SO2 in gas-phase over India are from the sulfur-containing fuel (mostly diesel) combustion. Garg [34] reported that around 60 percent of sulphur dioxide emission in India is from oil and coal combustion and the industrial sector contributes ~36 percent. However, the transport sector contributes only ~8% and rest of the SO2 originates from other sources as biomass, non-energy consumption etc. It was found that higher concentration of SO2 was observed in monsoon and lowest in post-monsoon period.

Ambient Concentration of Ammonia

During the study, the hourly mean concentration of ammonium widely varied from 1.6 ppb (minimum equal to detection limit) to 85.3 ppb (maximum) with median (24.6 ppb) and an average of 28.8 ± 15.7 ppb over Bengaluru city (Fig. 3). The (Table 2) shows the monthly mean concentrations of ammonium during the study. Due to industrial activities in the Urban area, the excessive ammonia is released into the atmosphere causing severe impact on regional as well as local climate. Seasonally, it was in the order of winter season (37.9 ppb highest) followed by the Post-monsoon (26.0 ppb), summer (24.5 ppb) and monsoon (23.3 ppb) season (Fig. 4.18). In the diurnal analysis, not much variations was seen in all four seasons except in winter, which is around 46, 53 and 50% higher concentrations of ammonium than summer, monsoon and post-monsoon seasons. The mean values of ammonia is lower than NAAQS (400 μg m-3) (CPCB 2015) and is similar to Delhi (20.23 ± 2.71 ppb) [35] during winter 2008. In another year long study conducted by Kapoor [36] found the higher concentration of mean NH3 (47.3 ± 13.6 ppb) over Delhi. Very high ammonia concentration (50.7 ppb) was observed in Mumbai [37] . The major sources of ammonia are from human excretion, fertilizers used in agriculture, agricultural wastes, industrial units etc. The study indicates that the high concentration was observed in winter period and similar concentrations during other seasons.

The Formation and Destruction of Ozone in Troposphere

During the study, the surface ozone (O3) and its precursors such as CO, NO, NO2, CH4, non-methane hydrocarbons: aromatic compounds (NMHC), SO2 and NH3 were measured at five different

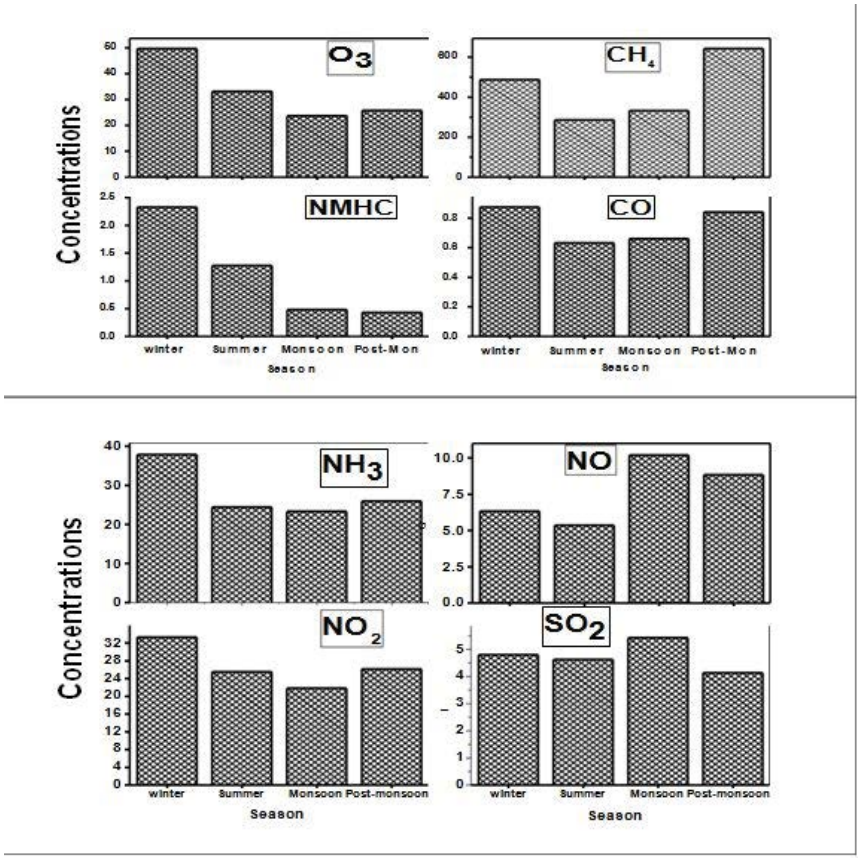

Figure 6: Seasonal variability of Surface Ozone (O3 -ppb), Methane (CH4 -ppm), Non- Methane Hydro-Carbon (NMHC -ppb), Carbon monoxide (CO - ppm), Ammonium (NH3 -ppb), Nitrogen oxide (NO-ppb), Nitrogen dioxide (NO2 - ppb) and Sulphur dioxide (SO2 ppb)

locations over Bengaluru city, India during January 2017 to March 2018. The research presents the variation of O3 and ozone precursors (also called primary pollutants), (CO, NO, NO2, NH3, CH4, SO2, and NMHC) (Figs. 2 and 3).

Variations of Methane (CH4) and Non-Methane Hydrocarbons(NMHCs)

The ambient concentrations of CH4 and NMHCs have been assessed in Bengaluru since 1st January 2017 to 20th March 2018 (Fig. 2). The daily mean concentration of CH4 and NMHCs are represented in Fig. 4. Non-methane hydrocarbons include Benzene, Toluene, MP-Xylene, O-Xylene, Eth-Benzene. The average daily values of CH4 and NMHC were 476.24 ± 282 ppb and 1.2 ±1.47 ppb, respectively, however, the contributions of Benzene (24%), was highest followed by Toluene (23%), Eth-Benzene (23%) MP-Xylene (18%), O-Xylene (12%) (Fig.7). Seasonally, the methane values are in the order of post-monsoon season (643 ppb: highest), winter (488.4 ppb), monsoon (333.0 ppb) and summer (286.3 ppb), however, the NMHC was highest in the summer followed by the winter (1.3 ppb), monsoon (0.5 ppb) and post-monsoon (0.4 ppb) seasons. The high concentration of CH4 and NMHC plays a significant role in the formation of troposphere ozone which works as an organic precursor. The mean concentration of CH4 (476.24 ± 282 ppm) over Bengaluru was significantly lower than the global mean concentration (1813.3 ± 0.62 ppm) of methane. NMHC has also shown involvement in forming the peroxy radicals that can oxidize NO to NO2 without affecting an O3 molecule, but still this chemical reaction have not been occurred in the study region due to its lower values. Nishant [22] has explained the role of NMHCs in the formation of ozone depends significantly on the reactive capacity as well as environmental conditions. The primary origin of NMHCs in the Urban atmosphere includes chemical plants, refining sectors and exhaust emissions from automobiles [38]. The nocturnal NMHC concentrations over the study region was around twice as much as day hours emission because of lower BLH, wind speed and perhaps high emissions during the night hours. A two years study of CH4 and NMHCs were conducted by Sharma [39] in Delhi from January 2012 to December 2013 and it was observed to be 2.4 ± 0.4 ppm (CH4) and 0.4 ± 0.1 ppm (NMHC) in the range of 0.5 to 2.8 ppm and 0.1 to 0.8 ppm respectively. The present study observed that CH4 and NMHCs were highest during Post-monsoon and summer period respectively.

The Rate of Change in O3 Formation and Destruction

The variations of ozone [d(O3)/dt] primarily relies on the formation and/or recycling efficiencies of OH group with another peroxy radical [31]. During the research study, the seasonal variations of ozone [d(O3)/dt] were estimated and its diurnal cycle over Bengaluru was plotted (Figure 8) (Table 2). During study period, a large variations has been observed in the diurnal rate of change of surface ozone, however, fast production of surface ozone (highest: +8.01 ppb/h) was observed in between 8:00 and 12:00 hours LT because of freshly emitted precursors and photochemical reaction in this period. During evening (in between 17:00 to 19:00 hours LT), it was opposite and fast destruction of surface ozone (-7.82 ppb/h) was observed because of the lower production of oxides of nitrogen. Seasonally, the highest

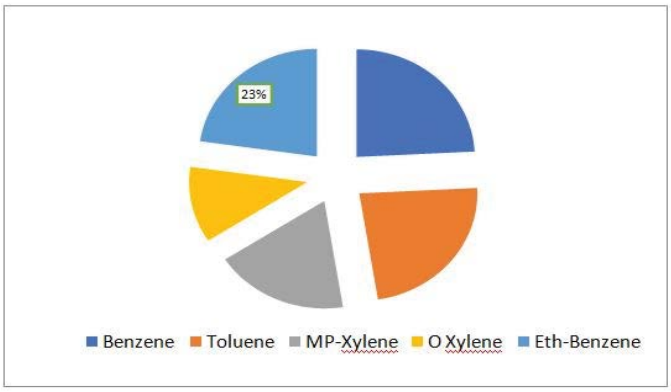

Figure 7: Percentage Contribution of Non-Methane Hydrocarbons (Benzene, Toluene, MP- Xylene, O- Xylene and Eth-Benzene) over Bengaluru Urban area.

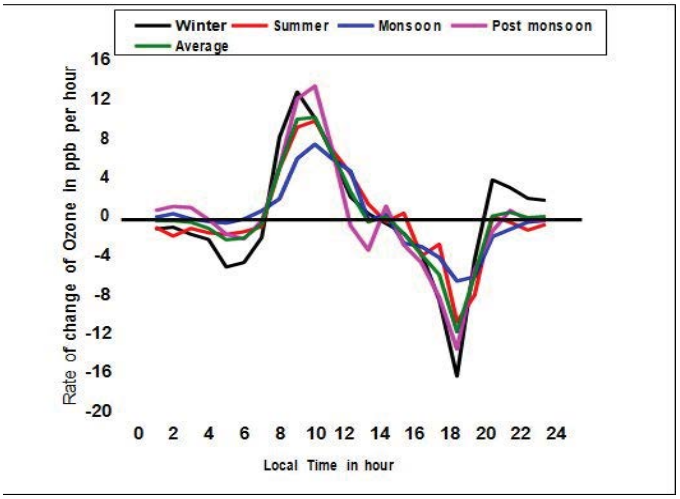

Figure 8: Seasonal Variationsof O3 from 1st January 2017 to 20th March 2018 over Bengaluru Urban area.

rates of change of ozone (9.43ppb/ h) were in between 8:00 and 12:00 hours LT in winter season followed by post-monsoon (9.42 ppb/h), summer (7.78 ppb/h) and monsoon (5.38 ppb/h) (Fig. 2). On the other hand, fast destruction of surface ozone was in the same order of winter (-9.67 ppb/h), post-monsoon (-8.97 ppb/h), summer (- 7.11 ppb/h), monsoon (-5.54 ppb/h) during morning hours (in between 07:00 to 09:00 hours LT). The large variability in the rate of change of surface ozone reflects the impact of meteorological parameters such as BLH and relative humidity. Reddy [40] has suggested that the lower mixing heights, cloud-free sky, lower relative humidity plays a key role in the increase of the rate of change of surface Ozone, especially during day. However during night i.e., 21:00 to 07:00 hrs LT: equal to zero was observed due to the surface deposition. During the monsoon period, the rate of change of O3 was less because the precursor gases get washed away by the rain. The average variations of ozone over Bengaluru is compared with high altitude (Mohal), coastal (Thumba and Thumba), semi-Urban (Pantnagar) and (Dayalbag), rural (Anantapur) and Urban (Delhi and Pune) sites in India. The mean rate of change in O3 over Bengaluru was largely different from the other studies in India (Table 3). In Bengaluru region, the rate of change of surface ozone is highest as compared to other places in India owing to fast titration of surface ozone in morning and evening hours because of higher production of oxides of nitrogen from combustion sources, vehicular emissions and lower BLH.

Conclusion

The salient findings during research are as follows:

The reverse diurnal and seasonal pattern with lowest NO, NO2, CO, NMHC, CH4, NH3 and SO2 concentrations were observed when O3 showed the highest peak indicating as precursor gases. Diurnally, fast production of surface ozone (highest: +8.01 ppb h−1) was observed in between 8:00 and 12:00 hours LT because of freshly emitted precursors and photochemical reaction in this period. In evening (in between 17:00 and 19:00 hours LT), it was opposite and fast destruction of surface ozone (-7.82 ppb h-1) because of the lower production of oxides of nitrogen. A large variability in the rate of change of surface ozone is because of the impact of meteorological parameters such as BLH, relative humidity as well as higher production of oxides of nitrogen from the combustion sources, vehicular emissions etc. The study has shown a high concentration of CO, ammonia in winter and post-monsoon period also CH4 and NMHCs were highest during Post-monsoon and summer period respectively. In Bengaluru region, the rate of change of surface ozone is highest as compared to othervplaces in India owing to fast titration of surface ozone in morning and evening hours because of higher production of oxides of nitrogen from combustion sources, vehicular emissions and lower BLH.

Sampling sites	O_3 [d(O_3)/dt] 8:00-11:00 hrs ppb h^{-1}	O_3 [d(O_3)/dt] 17:00-19:00 hrs ppb h^{-1}	References
Bengaluru	+8.0	-7.8	Present study
Mohal	+7.3	-5.9	Sharma *et al.,* 2013 [41]
Delhi	+4.7	-5.5	Sharma *et al.,* 2016 [39]
Anantpur	+4.6	-2.5	Ahammed *et al.,* 2006 [27]
Dayalbag	+2.2	-2.3	Singla *et al.,* 2011 [42]
Pantnagar	+5.6	- 8.5	Ojha *et al.,* 2012 [43]
Kannur	+4.9	-6.4	Nishanth *et al.,* 2012 [44]

Table 3: The Observed Variations of Ozone (ppb/h) over Bengaluru as well as different stations over India.

Data Availability

The data for the research work has been collected from Government bodies of Karnataka State Pollution Control Board (KSPCB) and Central Pollution Control Board (CPCB), Bangalore.

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