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Air quality monitoring in Chennai, India, in the summer of 2005

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Abstract

During the summer of 2005, concentrations of surface ozone (O_3), oxides of nitrogen (NO_x), respirrable suspended particulate matter (RSPM) and total suspended particulate matter (TSPM), relative humidity (RH), wind speed (WS) and wind direction (WD) were collected over successive periods of about 24 h at five sites. UV photometric ozone analyzer was used to measure the concentration of surface O_3. The study deals with the characteristics of hourly and daily mean surface O_3 under different climatic conditions, such as temperature, relative humidity, wind speed and wind direction and other pollutant concentrations. The maximum hourly O_3 concentration reached 53 ppb on 17th May. The ground-level O_3 concentration in Chennai varied between 2 and 53 ppb. The concentration of NO_x and O_3 were below the prescribed limits. The TSPM values were exceeded the National Ambient Air Quality Standards (NAAQS) at Koyambedu, Mandaveli, Taramani and Vallalar Nagar study area.

Keywords: Surface ozone; Ambient NO_x; Respirrable suspended particulate matter; Total suspended particulate matter; India; Relative humidity

1. Introduction

Ozone (O_3) is a gas that occurs both in the earth's upper atmosphere, in the region known as stratosphere and at ground-level, the region known as the lower troposphere or planetary boundary layer. Surface O_3 is also a greenhouse gas that traps radiation at 9.6 μm [1] emitted by the earth. An increase in surface O_3 might contribute to a warming of the earth's atmosphere. A high concentration of surface O_3 has adverse effects on human health including chest pain, throat irritation, congestion and coughing. It also damages vegetation and ecosystems [2]. It leads to reduced agricultural crop and commercial forest yields, reduced growth and survivability of tree seedlings, and increased susceptibility to diseases, pests and other factors, such as harsh weather. Those suffering from respiratory diseases, such as asthma are particularly at high risk of being affected by oxides of nitrogen [3].

Surface-level O_3 is a secondary pollutant. It is formed through a series of photochemical reactions, when volatile organic compounds (VOCs) and nitrogen oxides mix in the air and react chemically in the presence of sunlight [4,5]. These pollutants are known as primary pollutants/or ozone precursors. Common sources of volatile organic compounds include motor vehicles, gas stations, chemical plants and other industrial facilities. Solvents, such as dry-cleaning fluids and chemicals used to clean industrial equipment are also sources of VOCs. Common sources of nitrogen oxides include motor vehicles, power plants and other fuel burning sources. Allen et al. [6] and Bhugwant et al. [7] have reported that combustion processes from traffic and/or trash burning mainly emit these O_3 precursors. Levy et al. [8] have studied the downward transport of O_3 from the stratosphere and stratosphere/troposphere exchange adds a small amount of ozone to the boundary layer. Meteorological parameters like wind speed, wind direction, temperature and relative humidity have a great influence on O_3 concentrations [9]. Particularly on most of the summer days, O_3 levels are most strongly influenced by meteorological condition [10]. Anthropogenic SO_2 and NO_x emissions are chemically converted to sulphuric and nitric acids in the atmosphere in the gaseous (primarily via reaction with OH) and aqueous phases. These acids are responsible for acid rain, stone leprosy and decrease in the soil alkalinity [11–13]. As per 1995, Chennai has the highest per unit area NO_x emissions (170 t/km^2) [14]. Particulate matter in air causes acute and chronic respiratory disorders and lung damage in humans. It is also a suspected carcinogen.

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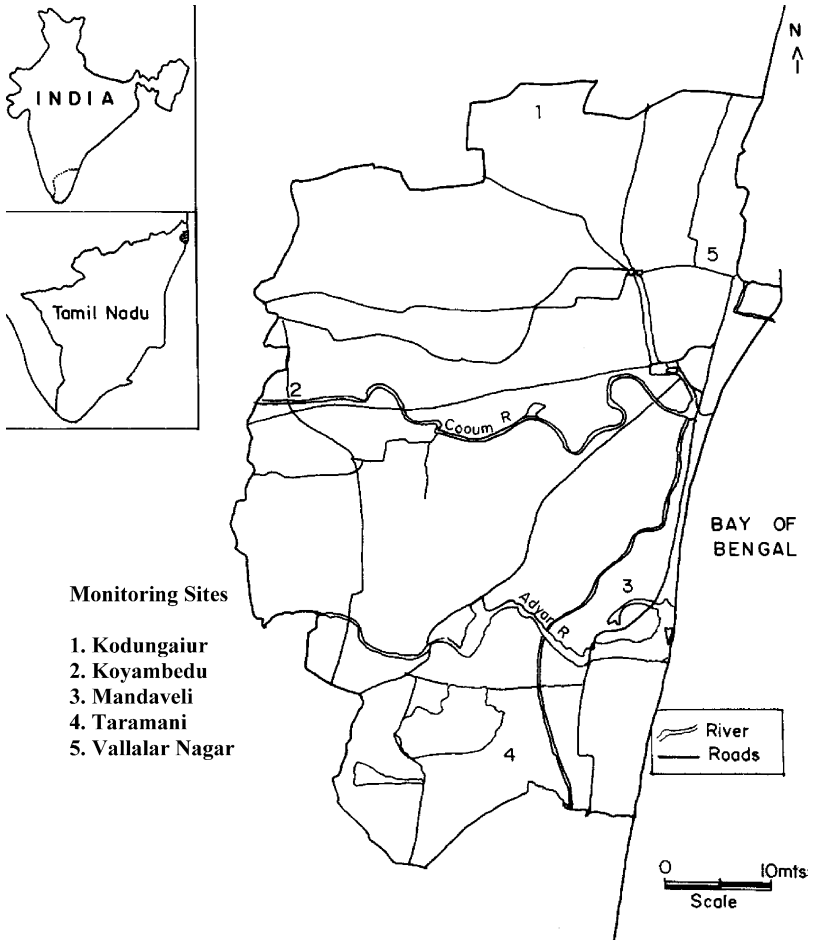

Fig. 1. Location map of the observation site at Chennai.

In recent years, a limited numbers of studies have analyzed on the seasonal variation in surface ozone and its precursor in urban areas in India [15,16]. The surface ozone link between urban and forest sites in India, was presented previously by Khemani et al. [17], who reported highest O_3 concentrations in winter in Pune. In the urban environment of Delhi ozone concentration in the ambient air was varied from 9 to 128 ppbv at four different sites during 1989–1990 [18]. Some studies have indicated that the effects of O_3 on vegetation were quite severe in India [19] and other parts of Asia [20,21]. To the best of the author's knowledge, no measurements have been carried out over Chennai metropolitan area. In summer months, O_3 pollution is a concern because strong sunlight and hot weather results in harmful O_3 concentrations in the air. Hence, the surface O_3 concentration was observed at five different sites during summer 2005 in Chennai.

2. Experimental procedure

2.1. The study area

India is a tropical country. Particularly the southern part of India is a peninsular surrounded by three major seas. Chennai formerly known as Madras is the fourth largest city in India. It is located (13°05′N and 80°18′E) on the southeast peninsular India. The city is 19 km in length and extends inland to about 9 km at its widest. Its irregular shape covers about 174 km^2. It is a fairly low-lying strip of land, its highest point being only 60 m above the sea level. It is the 41st metropolitan city in the world. The measurements were made in May, which is the summer season and has a maximum temperature of around 41 °C and average 33 °C. As per the 2005 census, Chennai has a population of 7.45 million [22].

2.2. Description of sampling sites

Five sites were selected for Ambient Air Quality (AAQ) monitoring in Chennai (Fig. 1). The selected sites were places of maximum population, heavy traffic, commercial areas with industries. A random selection sampling has been carried out at all the sites.

Table 1 shows the location, monitoring period and classification of site for O_3, NO_x, PM and relative humidity monitoring stations in the Chennai region. Geographical locations of the sampling sites were measured using GPS instrument.

2.2.1. Kodungaiur (S_1)

Kodungaiur is an industrial area in North Chennai. Further North Chennai Petroleum Corporation Limited (CPCL) Manali, located within 5 km from the station, is a major industrial source

Table 1
Details of air quality monitoring station in Chennai, India.

Site	Code	Latitude (N)	Longitude (E)	Site classification	Monitoring period (08:00 to 06:00)
Kodungaiur	S_1	13.136851	80.2538	Industrial area	17.05.05 to 18.05.05
Koyambedu	S_2	13.07224	80.20174	Commercial area	25.05.05 to 26.05.05
Mandaveli	S_3	13.02596	80.26618	Commercial area	31.05.05 to 01.06.05
Taramani	S_4	12.98112	80.23949	Residential area	03.06.05 to 04.06.05
Vallalar Nagar	S_5	13.10571	80.28016	Traffic island	04.07.05 to 05.07.05

of NO_x. The NO_x emission from the co-generation power plant at CPCL is 65 ppmv. There is also a municipal solid waste-dumping site nearby where the waste has been indiscriminately burnt.

2.2.2. Koyambedu (S_2)

Koyambedu is a busy commercial zone located in Western Chennai. It consists of Asia's largest bus terminus and also a wholesale vegetable market. The market disposes off nearly 100 t of pure organic wastes and the area is busy throughout the day with movement of people, vehicle and goods.

2.2.3. Mandaveli (S_3)

Mandaveli is located in Central Chennai, 2 km away from the seacoast. This particular sampling point has the bus terminus; petrol bunks and hospitals are located in its proximity. The site has been selected to indicate ozone concentrations in the vicinity of a hospital.

2.2.4. Taramani (S_4)

This site is a residential area. It is a suburb of Chennai. It consists of huge office buildings for many IT/business process outsourcing (BPO) companies.

2.2.5. Vallalar Nagar (S_5)

Vallalar Nagar is located in North Chennai. This site is in an area of dense population with very heavy traffic, busy pavements, crowded housing and very little greenery. This is the world's largest and the first power plant in India operating a two-stroke diesel engine for power generation.

2.3. Measurement techniques

O_3, NO_x and TSPM/RSPM were measured on consecutive days at each site in turn, for 24-h throughout the early summer season. During each period, measurements were taken at different locations.

2.3.1. Ozone monitoring

An analyzer from Environment S.A. (Module O_3 42 M) France has been used for the measurement of O_3 through the site. Its calibration was performed using a built in ozone generator, before taking the readings in the field. The minimum detectable limit of the instrument is 1 ppb.

In all the five stations the monitor was housed in a building situated at the site. Air samples were continuously drawn in at an approximate height of 10 m through Teflon tubes by a pump housed inside the monitor. The inlet probe was carefully placed in a horizontal arc without any restriction. The automatic analyzer continuously monitors the surface O_3 at every 2-min time interval and stores the information in a RAM data logger. The data thus collected are averaged automatically at the end of every 15-min and displayed and were then noted separately. Each hourly ozone concentration is the average of four 15-min measurements taken during an hour, and reported as the hourly concentration. Hourly ozone concentrations are reported to the nearest ppb. Average data for 8-h were calculated using Microsoft Excel for comparison with manually collected data on NO_x and other pollutants.

2.3.2. Nitrogen oxides

Ambient air was continuously drawn into 25 ml of sodium hydroxide solution at a flow rate of 1 LPM for 8 h and Jacobs and Hochhesier method in the laboratory estimated it. Sodium hydroxide solution forms a stable solution of sodium nitrite. The nitrite ion produced during sampling was determined colorimetrically [23] by reacting the exposed absorbing reagent with phosphoric acid, sulsulphanilamide and *N*-(1-napthyl) ethylenediamine dihydrochloride producing an azo dye. The absorbance of the colour was read at 540 nm. The range of the analysis was between 0.01 and 1.5 μg/ml.

2.3.3. Particulate matter

High volume air sampler was used for the monitoring of particulates. Before sampling, the Whatman filter GFA (20.3 cm × 25.4 cm) of the high volume sampler was kept at 15–35 °C, 50% relative humidity for 24-h and then weighed. The filter was placed into the high volume sampler and air was drawn through a 406.5 cm^2 portion of the filter at the flow rate of 1.70 m^3/min. The rate of flow was checked with rotameter. The filter was removed after sampling for 24-h and equilibrates for another 24-h under the same or identical conditions. The filter was weighed again. The difference was the amount of particulate matter per unit volume of air. From the following equation, the respirrable suspended particulate (RSPM) matter and total suspended particulate matter (TSPM) were calculated.

$$\text{RSPM} = \frac{\text{final weight of filter paper} - \text{initial weight of filter paper} \times 1000 \times 1000}{\text{retention time} + \text{air flow}}$$

TSPM = filter paper average + pouch average.

2.3.4. Meteorological parameters

Dry bulb and wet bulb temperature was noted at 1 h interval using cyclic hygrometer at the five sampling sites. From the val-

Table 2
National Ambient Air Quality Standards (NAAQS) air pollutants [24]

Pollutants	Averaging time	Concentration in ambient air (ppb)		
		Industrial area	Residential, rural and other areas	Sensitive area
Oxides of nitrogen NO_2	Annual mean	40.8	30.6	7.65
	24 h	61.2	40.8	15.3
Respirrable suspended particulate matter (RSPM)	Annual mean	183.6	71.4	35.7
	24 h	255	102	51
Total suspended particulate matter (TSPM)	Annual mean	61.2	30.6	25.5
	24 h	76.5	51	38.25

ues relative humidity was calculated. The precession and accuracy of this instrument was checked with Indian Meteorological Department, Meenambakam, Chennai. Hourly wind speed (m/s) and predominant wind direction data were obtained from the Center For Wind Energy Technology (C-WET), (12°57′23″N and 80°12′55″E) Pallikarani. Sensors were fitted at 13 m above ground level.

As per the National Ambient Air Quality standards (NAAQS) has specified the quality necessary with an adequate margin of safety for the protection of the public health, vegetation and property. The NAAQS Standards for the air pollutants, i.e. nitrogen oxides (NO_x), respirrable suspended particulate matter and total suspended particular matter are summarized in Table 2.

3. Results and discussion

3.1. Surface ozone, meteorological parameters

Five stations were operated from 08:00 to 06:00 the following day. The 08:00 to 06:00 average O_3 concentrations was determined based on the 15-min average values recorded by the analyzer. In this study, the comparison of surface O_3 with meteorological parameters has been analyzed during the monitoring period at five sites. All parameters were averaged over a 1-h time period.

3.1.1. Kodungaiur (S_1)

In Fig. 2, hourly O_3 concentrations are shown as a function of relative humidity. The other meteorological data, i.e. wind speed and wind direction were not available on that day. In the early morning hours, O_3 concentration showed a sharp increase in ambient air and reached its first peak in 11:00–14:00 as also recorded by National Research Council (NRC) [2]. The first peak occurred at temperature of 42 °C and relative humidity of 47% (Fig. 2). Subsequently decrease of O_3 concentration may be due to the cloudy weather conditions. As mentioned by NRC a second peak was also observed in the 16:00–20:00. After that, a gradual decrease of O_3 concentration continued until the early morning of the next day.

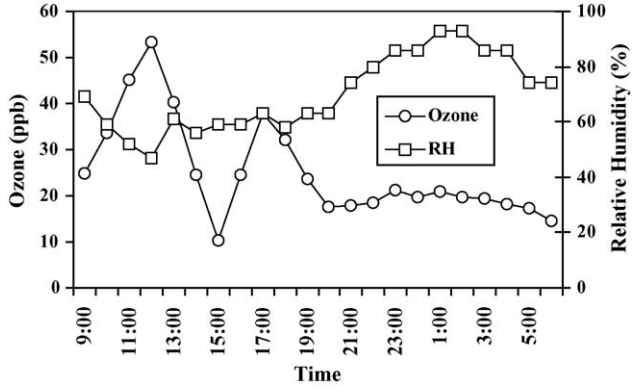

Fig. 2. Hourly variation of ozone and relative humidity obtained from 17 to 18 May 2005 at Kodungaiur.

The hourly O_3 concentration reached a maximum of 53 ppb. The temperature reached a maximum around 42 °C between 12:00 and 13:00. The air quality in the station was unhealthy for sensitive groups, being the O_3 concentration reached a maximum of 53 ppb.

3.1.2. Koyambedu (S_2)

In Fig. 3, hourly variations of O_3 concentrations are shown as a function of meteorological parameters obtained, i.e. (a) ozone and wind speed, (b) ozone and wind direction and (c) ozone and relative humidity during the period 25–26 May 2005.

The wind speed and wind direction data was not available on between 09:00 and 16:00.

The highest mean O_3 concentration 44 ppb was observed in the daytime when the relative humidity was 46%. It could clearly be noticed (Fig. 3b) that mean O_3 concentration slightly increased at 23:00–02:00, with the wind flow from 202° to 247° (corresponding to land breeze). The wind speed was observed (Fig. 3a) to be a maximum of 6.43 m/s at that time. This may be due to the site being surrounded by a bus terminus (bigger in south Asia) and vegetable market situated at SSW and WSW of the site, respectively.

3.1.3. Mandaveli (S_3)

In Fig. 4, hourly variation of ozone concentrations are shown as a function of meteorological parameters obtained, i.e. (a) ozone and wind speed, (b) ozone and wind direction and (c) ozone and relative humidity during the period 31-May to 01-June 2005.

It is observed from Fig. 4a, that the wind speed was initially low (=3 m/s) up to 09:00–11:00 and thereafter, increased and reached a maximum around (=9 m/s) 13:00–17:00. The increase in wind speed also added some precursor from surrounding to the measurement site and resulted in a higher O_3 concentra-

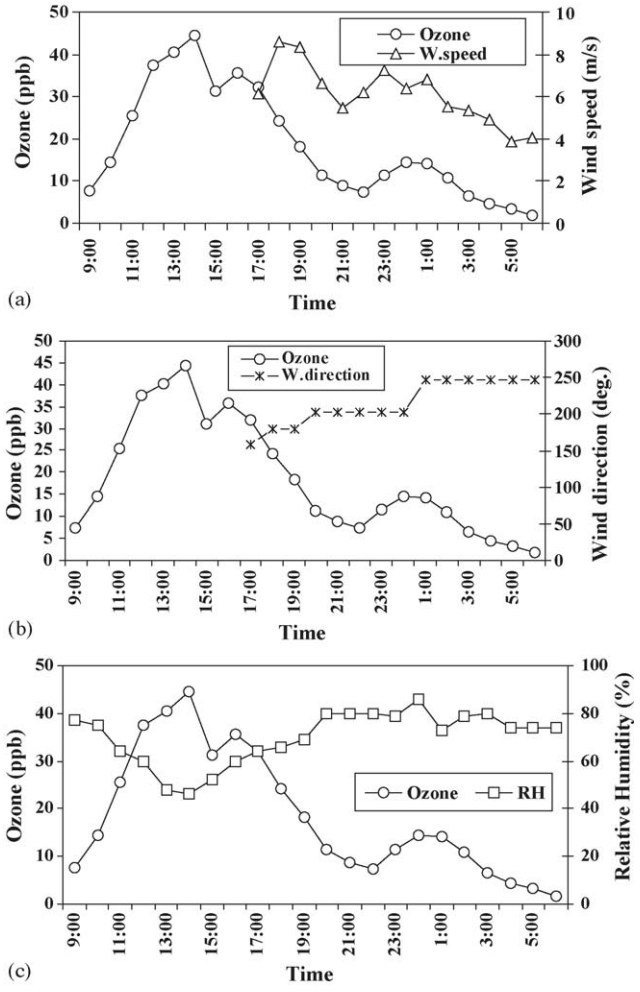

Fig. 3. Hourly variations of ozone and meteorological parameters obtained from 25 to 26 May 2005 at Koyambedu. (a) Ozone and wind speed, (b) ozone and wind direction and (c) ozone and relative humidity.

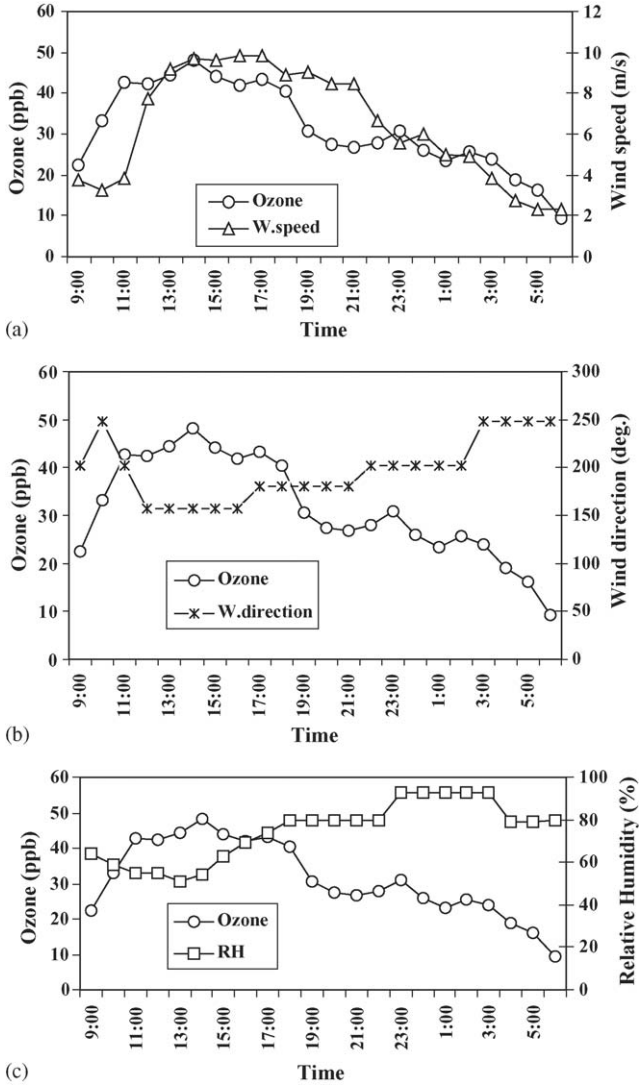

Fig. 4. Hourly variations of ozone and meteorological parameters obtained from 31 to 1 May June 2005 at Mandaveli. (a) Ozone and wind speed, (b) ozone and wind direction and (c) ozone and relative humidity.

tions between 13:00 and 17:00. Ozone showed a significant positive correlation with wind speed ($R^2 = 0.54$). Satsangi et al. [25] observed similar trend in Agra, North central part of India. The daily mean O_3 concentrations were found to be high between 11:00 and 20:00 (Fig. 4b) with wind originating from the 157° to 180° (SSE-S) sector, corresponding to sea breeze. During that day, the humidity reached 93% in the early morning hours. High concentrations of O_3 noticed with high temperature and low relative humidity (Fig. 4c). High temperatures increase the emission of NO_x from soil [26], which may be one of the reasons for increase in O_3 concentration with temperature. Cardellino and Chameides [27] and Sillman and Samson [28] both defined the rates of O_3 formation with temperatures.

3.1.4. Taramani (S_4)

In Fig. 5, hourly variation of ozone concentrations is shown as a function of meteorological parameters obtained, i.e. (a) ozone and wind speed, (b) ozone and wind direction and (c) ozone and relative humidity during the period 03–04 June 2005.

On 03–04 June 2005 the 24-h mean O_3 concentration was around 30 ppb. The destruction of O_3 in the nighttime and early morning hours in this area was highly independent of wind speed (Fig. 5a). The prevailing wind blew mainly from the SSE-S sector with wind speeds up to 8.38 m/s. Simultaneously, O_3 concentration reached a maximum concentration of 52 ppb when the relative humidity was 64%, from Fig. 5c.

3.1.5. Vallalar Nagar (S_5)

In Fig. 6, daily and hourly variation of ozone concentrations is shown as a function of meteorological parameters obtained, i.e. (a) ozone and wind speed, (b) ozone and wind direction, (c) ozone and relative humidity during the period 03–04 June 2005. It can be noticed that from Fig. 6a, maximum O_3 concentration was recorded during 13:00–21:00 with the average wind speed of (=7.64 m/s). Very low O_3 concentration (3 ppb) was registered at a wind speed of 3 m/s during nighttime. Complete destruction of O_3 occurred at nighttime on 05.07.05 between

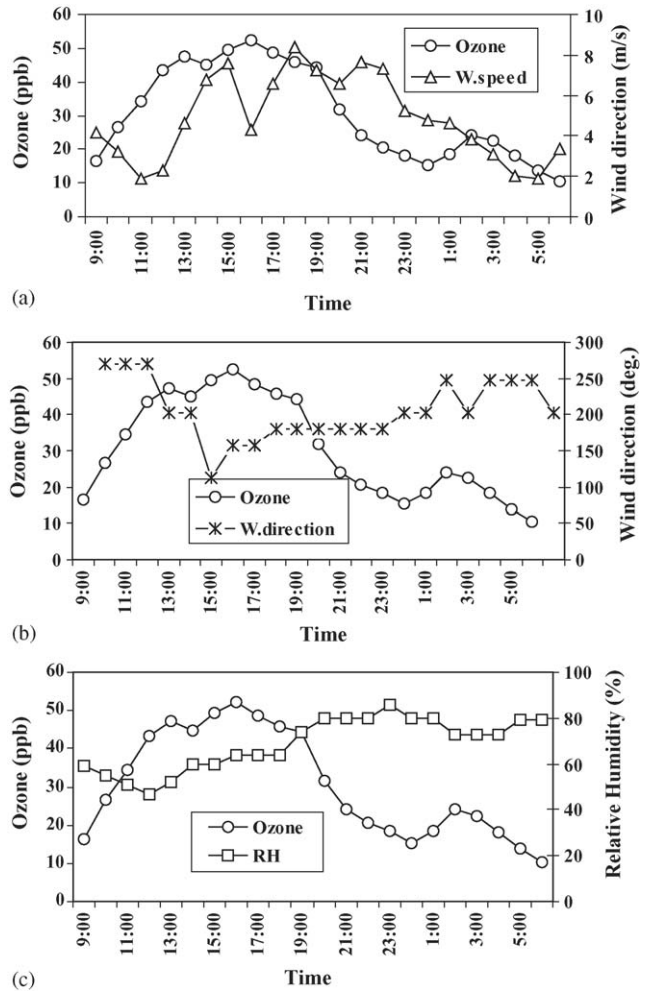

Fig. 5. Hourly variations of ozone and meteorological parameters obtained from 03 to 04 June 2005 at Taramani. (a) Ozone and wind speed, (b) ozone and wind direction and (c) ozone and relative humidity.

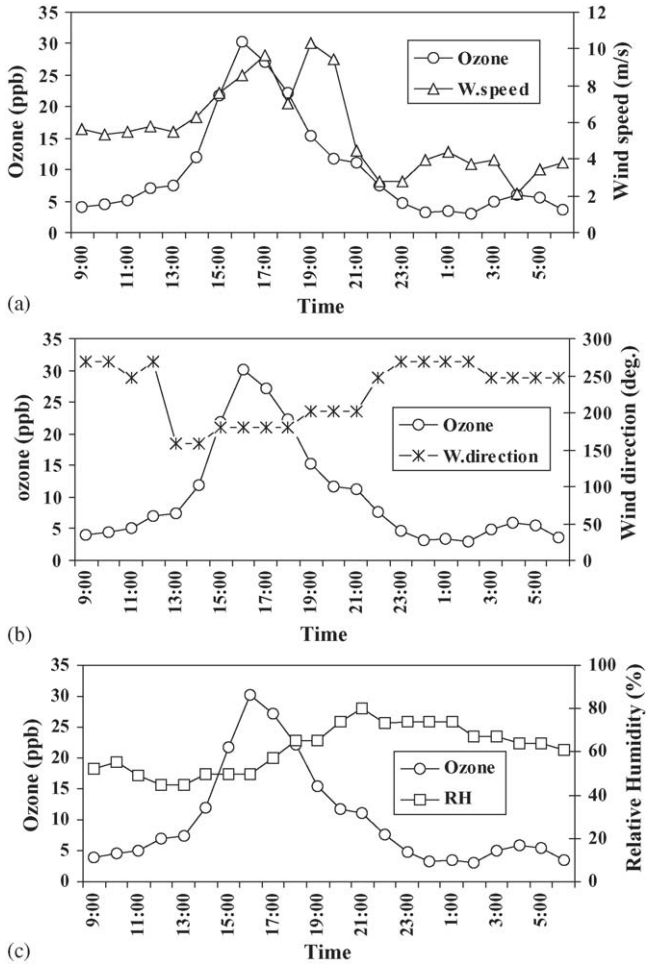

Fig. 6. Hourly variations of ozone and meteorological parameters obtained from 04 to 05 July 2005 at Vallalar Nagar. (a) Ozone and wind speed, (b) ozone and wind direction and (c) ozone and relative humidity.

23:00 and 03:00 (Fig. 6a). Daily maximum O_3 concentrations (15:00–18:00) associated with wind flow from southern direction are shown in Fig. 6b.

In all the five sites maximum O_3 concentrations were observed with low relative humidity and the wind direction is from SSE and S sector, which corresponds to sea breeze.

3.2. O_3, NO_x and PM

Table 3 lists the observed O_3, NO_x and PM concentration during the monitoring period. It gives the 8-h and 24-h mean pollutant concentrations.

3.2.1. Kodungaiur (S_1)

The industrial activities are high in this area between 06:00 and 14:00. Hence, the TSPM value (140 ppb) was high. The TSPM value this area was very close to the NAAQS standard.

3.2.2. Koyambedu (S_2)

This is a commercial area. The NO_x value recorded was almost similar to the values recorded in the Kodungaiur (S_1) and Mandaveli (S_3). The TSPM value was found to be exceeded the NAAQS standard set for residential and other areas.

3.2.3. Mandaveli (S_3)

Interestingly, the O_3 concentrations were observed to be very high between 22:00 and 06:00 at this site. The site is located very close to the sea. The lifetime of ozone is greater above water level than that of land [29]. Thus, the transportation of O_3 rich air flow from sea to site might have been possible at night time [30]. This may be reason for this particular site to show higher O_3 concentration (22 ppb) between 22:00 and 06:00 than that of other sites.

3.2.4. Taramani (S_4)

A very high 8-h mean O_3 concentration of 40 ppb was observed between 14:00 and 20:00 when the NO_x concentrations was observed to be 4 ppb. The wind direction at that particular period is only from southerly direction with mean wind speed of 6.94 m/s. The 24-h mean NO_x concentration was found to be very less when compared to the all other sites. This may be due to very low traffic activity in this site.

Table 3
Air pollutant concentrations measured from five monitoring stations in Chennai region

Time	Pollutant (ppb)			
	O_3	NO_x	RSPM	TSPM
Kodungaiur (S_1)				
06:00–14:00	37	18.3	35.19	139.74
14:00–22:00	22	9.02	28.56	52.02
22:00–06:00	18	3.21	18.87	33.15
24 h average	25	10.2	27.54	74.97
Koyambedu (S_2)				
06:00–14:00	28	12.03	20.4	123.42
14:00–22:00	21	9.84	31.62	117.81
22:00–06:00	8	9.33	11.73	28.05
24 h average	18	10.4	21.42	89.76
Mandaveli (S_3)				
06:00–14:00	38	12.64	20.4	107.61
14:00–22:00	35	10.25	17.34	59.93
22:00–06:00	22	9.58	24.48	61.2
24 h average	31	10.81	20.91	76.5
Taramani (S_4)				
06:00–14:00	36	4.69	29.58	110.67
14:00–22:00	40	4.43	28.56	90.27
22:00–06:00	18	2.6	24.99	55.59
24 h average	30	3.92	27.54	85.17
Vallalar Nagar (S_5)				
06:00–14:00	10	27	87.72	212.16
14:00–22:00	16	15.81	24.99	117.81
22:00–06:00	4	8.16	33.15	76.5
24 h average	10	16.93	48.45	135.66

3.2.5. *Vallalar Nagar (S_5)*

The TSPM at Vallalar Nagar station was found to be 135.66 ppb, which was higher than the 24-h NAAQS Standards. High levels of TSPM on that site may be due to heavy dust from GMR power plant and also heavy traffic, contributing to primary pollution. Transport activities were more concentrated in and around that site. This could be the main reason for increasing pollutant values in this site. Large emission source of NO_x in the daytime was observed at Vallalar Nagar from Table 3. Hence, very high levels of NO_x (27 ppb) between 06:00 and 14:00 lead to decrease in O_3 by 10 ppb. This may be due to destruction of O_3 by the freshly emitted NO [31]. The 24-h mean NO_x concentrations have crossed the NAAQS standards set for sensitive area.

The 24-h mean TSPM pollutant at Kodungaiur, Koyambedu, Mandaveli, Taramani and Vallalar Nagar station was found to be higher than the NAAQS standard. A maximum concentration of air pollutants was observed between 06:00 and 14:00.

4. Summary and conclusions

This paper presents the data on the measurements of surface O_3, NO_x, RSPM and TSPM concentration and meteorological parameters in five different sites of Chennai in summer 2005. The following conclusion was drawn from the present study. The mean O_3 concentration in all sites has been observed to be higher in the wind flow from SSE and S than that of the SSW and WSW. The transport of ozone rich air from the sea has been found higher on the coast than the interior. It has also been observed that surface O_3 concentration increases with the increase in temperature and decreases with increase in relative humidity. Reduction in O_3 may be due to the increase of NO_x.

The level of NO_x was below the Indian Standard levels. The daily mean concentration of TSPM was found to be above the NAAQS Standards in four sites. In Vallalar Nagar station alone the NO_x, RSPM and TSPM values were found to be higher than those of other sites.

The present work has been undertaken mainly to generate new set of data on surface O_3 and to understand the relation between O_3, NO_x, PM and metrological parameters for Chennai city. These are only preliminary findings. Hence, there is scope for further study in this area.

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