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Impact of Urban Heat Island on Meteorology and Air Quality at Microenvironment

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ABSTRACT

This study analyses the air pollution characteristics and their relation to meteorological conditions in Chennai, India. Meteorological conditions were the primary factor determining variations in daily average pollutant concentrations. The influence of urban infrastructure on meteorology is an important prediction on air quality. Understanding of the seasonal and diurnal secondary pollutant concentrations as a function of local meteorological conditions is necessary for urban air quality management. In recent past, micro-scale models for analyzing the surface layer interactions with the surrounding environment have gained attention. An attempt has been made to understand the effect of meteorology on air quality. This comprehensive study aims to assess the influence of local meteorology on urban air quality. The correlation was established between the change in meteorological parameters and mixing height on air quality at selected locations in a tropical urban environment. Results indicated the significant impact of land use patterns on the dispersion of air quality at study locations. Seasonal variations of ambient air temperatures at study locations were found to be more than 3^{o}C in summer. Average mixing height variation among the study locations was observed to be more than 200 meters in summer. Results indicated the importance of wind velocity on the mixing height at study locations. The average concentrations of air quality parameters showed significant variation among the study locations. The maximum ozone (O_3) concentration was recorded at the CBD during the afternoon, i.e. around 38.3 ppb, whereas it was 26.8 and 14.6 ppb at the RA and UBL respectively. A strong correlation was observed between ambient temperature and O_3 concentration during summer. In the winter, the average ozone concentration in all three-study locations increased to 45.3 ppb, 45.8 ppb and 58.5 ppb at UBL, RA and CBD sites, respectively. The study reveals the impact of microenvironments on the air quality.

KEYWORDS:- Mixing Height, Ventilation Coefficient, Dispersion

INTRODUCTION

Air pollution is a serious social and environmental problem in Indian cities. Several studies systematically investigated the temporal and spatial characteristics of air pollution and meteorological conditions. Meteorological conditions were more adverse for pollutant dispersion indicating the importance of air quality management in cities .Urban air pollution is increasing as rapidly as number of vehicles and population in cities increasing. The poor air quality in urban areas impact the health to the people. It is therefore important to characterize the impact of urbanization on air quality deterioration. Air quality in the urban area is deteriorating due to complex interactions between source emissions, poor dispersion conditions and increased urban warming. The characterization of ambient temperature and associated air quality at urban hotspots are essential for urban planning. The rise in ambient temperature enhances the formation of secondary pollutants. The Urban Heat Island (UHI) phenomenon, manifesting as a rise in temperature in urban zone compared to non-urban zone. The meteorological parameters affecting the UHI include topography, solar fluxes, wind speed, energy fluxes and cloud cover (Landsberg, 1981). It was suggested that a strong correlation between cloud cover and wind speed is established (Memon & Leung, 2010). The diurnal variation of temperature for these surface materials can be estimated using empirical equations (Tadeu et al., 2005). The intensity of UHI has seasonal and temporal variations. Atwater (1972) concluded that moisture content affects the daytime UHI intensity whereas nighttime UHI is due to anthropogenic heat emissions and the properties of surface materials. The UHI intensity, firstly, affects the boundary layer structure and stability in the urban area and in this way there is a possibility of accumulation and favorable conditions for transformation of reactive pollutants. Secondly, the temperature-dependent formation and destruction of secondary pollutants have a direct impact on local air quality. Thirdly, (Ryu et al. 2013) found an effect of anthropogenic heat on local air quality. A change in boundary layer height interacts with the pollutant levels. The factors enhancing the UHI formation include structure of urban canopy, heat exchange capacity of urban surfaces, the albedo of buildings, roads and roofs anthropogenic heat emissions by transportation sector (Lazzarian, 2005; Noro & Lazzarian, 2015). Built-up areas act as storage materials that warm up and store much more heat than natural cover during daytime (Sarrat et al. 2006). The albedo of roofing materials has a significant effect on the noon temperature rise in the urban area (Taha et al. 1992).

The ambient fine particulate matter ($PM_{2.5}$) and ozone (O_3) concentration in many cities of developing countries are found to be at alarming levels due to excessive pollutants added by rapid urbanization. A recent study by the Intergovernmental Panel on Climate Change (IPCC) provided a comprehensive scientific assessment of risk due to climate change caused by human activity. However, the evolution of the air quality and associated health risk in a changing climate at a local scale is far to be understood. Studies also showed that the dense vehicular traffic and local meteorology had a significant impact on both PM and O_3 concentrations (U.S. EPA, 2004). The time-series analysis attempted to study the effect of short-term repetitive exposures to particulate matter of aerodynamic diameter 10 μm (PM_{10}) on mortality rate, indicated the need of source apportionment, emissions, and cause-of-death to compare with other cities. However, few studies used different methodologies, to compare results in Asian cities with each other (Li et al. 2002).

In recent years, most Indian cities tend to be densely built with a large population and were highly polluted. The effect of local meteorology on air quality is a significant environmental problem to be addressed. Due to rapid economic growth in India, cities bring a large number of job opportunities in various fields. Because of rapid urbanization, change in surface characteristics of the land cover has observed. Chennai is one of the fast growing cities in India, the population of Chennai city has increased about 84.5 % in last two decades (i.e., from 1991-2011) with the total population crossing eight billions (Reddy et al,2019). Around 1000 square kilometers area may be considered as the metropolitan area of Chennai city by latest 2016. It is the third most urbanized and industrial city in India. The annual average temperature in the Chennai city is about 33 ^oC, it reaches 45 ±5 ^oC during summer (Bal et al., 2016) and has a semi-arid climate (Raghavan et al. 2015). Temperature and RH values remain high throughout the year (Jeganathan & Andimuthu, 2013). It is therefore essential to characterize the concentration profiles of secondary air pollutants and UHI in urban zones. And the design of local and regional air quality management plans.

Urban Meteorology

Emissions in urban spaces are a direct function of the geographical location and prevailing meteorological conditions. For example, in cities like Los Angeles or Ulaanbaatar, which form a valley terrain, irrespective of the wind patterns, the emissions tend to stay in the same area for a longer time and contribute more to the local air pollution problems. On the other hand, in cities with flat terrains like Bangkok, Beijing, Delhi, Dhaka, and Manila, the meteorology tends to have a higher impact on both dispersing and retaining the air pollution. In the recent years based on comparison, meteorological influences on ground ozone concentrations were consistent and change of meteorology characterized with temperature and humidity has been reported. Ozone formation controlled by ozone precursors and meteorological conditions, the variation of ground ozone concentrations was examined and a notable upward trend of ozone concentrations was reported in the literature (Cheng et al, 2019). The contribution of meteorological conditions to ozone formation could be influenced significantly by seasonal and synoptic meteorological conditions. Anthropogenic emissions were the major cause for long-term ozone formations. Enhance ozone concentrations increasingly heterogeneous distribution of different ozone formation regimes.

The fundamental parameters in the movement of contaminants are the wind, its speed, and directions, which in turn depends on the vertical and horizontal temperature gradients, both at the regional and local level. In other words, the higher the wind speed, the higher is the turbulence and the more rapid and complete is the dispersion of the air pollutants. Temperature inversions are inessential because they suppress vertical dispersion of pollution and often trap pollution near the surface where people live. Sinking air associated with ridges create subsidence inversion. It can limit daytime mixing depth and plays a vital role in pollutant concentrations. The consequences of UHI affects the boundary layer structure and atmospheric stability in the urban area and in this way there is a possibility of accumulation and favorable conditions for transformation of reactive pollutants. The temperature-dependent formation and destruction of secondary pollutants have a direct impact on local air quality.

It was reported that the change in boundary layer height interactions alters the pollutant concentrations (Ryu et al., 2013). The correlation between poor dispersion conditions and PM_{10} reported in (Lu, Deng et al.2012), that the PM concentrations are observed higher during the lower mixing height. Various factors effecting the inland boundary layer conditions and marine boundary layer conditions have been discussed in (Iyer and Raj, 2013). Dispersion conditions play a significant role in primary and secondary pollutant concentrations. In the USA, it was reported that boundary layer suppression caused pollutants to be trapped close to the surface (Yang et al. 2031). In coastal regions, the marine atmospheric boundary layer (MABL) and ocean upwelling affect the local air pollution. Global climatic simulations have shown that temperature, humidity, and boundary layer depth can cause changes in local air quality (Tagaris et al. 2007). Several studies in the past indicated that the local ambient air temperature, relative humidity, and other meteorological parameters have a significant effect on local air pollution. Change in surface temperature profiles in an urban area, and the boundary layer structure modifies the local circulations influencing pollutant concentrations (Swamy et al., 2017). Diurnal temperature variation of different land covering materials has a significant effect on local ambient air temperature profiles (Yang et al. 2013).

Interactions of Air Quality with Meteorology

The strong meteorological influences on multiple airborne pollutants, ozone pollution by heat-island effects, and contingent meteorological approaches can be effective for managing ozone concentration in mega cities. Air pollution is often intensifying in urban areas, dense buildings is constrain on pollutant dispersal. Characteristics of stability conditions and turbulent urban boundary layer are important factors of air pollution investigations. An atmospheric stability and air pollution level in the urban was an interesting investigation. High vehicular density in urban zones, emissions of primary and reactive pollutant concentrations are high in these areas. Additionally, heat-stressed vegetation is known to emit increased quantities of biogenic volatile organic compounds, which are precursors to secondary aerosols and ozone (Loreto and Schnitzler 2010) formations. As a consequence of the complex interactions of volatile organic compound emissions, atmospheric chemistry and dynamics as well as plant physiological processes, the formation of secondary air pollutants and their troposphere concentrations (e.g., ozone, aerosols) during heat waves are currently insufficiently understood (Monks et al. 2009). Transformations of the reactive pollutants were influenced by UHI intensity in urban zones (Li et al. 2016; Lai and Li 2016). Model studies also described that the surface level heat island is enhancing the ozone (O_3) formation (Ryu et al. 2013; Ryu, BikeandLee. 2013; Chen et al. 2020).

Meteorological influences on air quality were generally similar and presented no clear spatial patterns. The influence of temperature was the most important influencing factor for ground level ozone. The influence of humidity, wind speed, wind direction and air pressure on ground ozone concentrations impacts significantly.

Community Modeling and Analysis System (CMAS) model coupled with the Weather Research and Forecasting (WRF) model (Lioa et al., 2014;Chen et al.2017) has predicted that the increase in local temperature is increasing the O_3 concentration by diluting the NOx availability. The stable atmospheric condition leads to the poor dispersion, the interactions of primary pollutants and favorable meteorological conditions worsen the air quality. The relation between air pollutants concentrations as a function of meteorology at different seasons was discussed.

Moreover, the concentration of air pollutants is observed to be lower above the boundary layer (Sujatha et al. 2016). Increase in surface Ozone (O_3) concentration along with growing atmospheric primary pollution has reported. Health risk assessment studies have been undertaken to understand the effect of exposure to higher O_3 concentrations on human health. The study revealed that local ozone concentrations were well correlated with the temperature profile in California. Ozone and $PM_{2.5}$ formations were simulated with changes in emission levels with Meso-scale Models (MM5, SMOKE and CMAQ) (Lakshmi et al. 2013). It was observed that NOx emissions and biogenic VOC emissions reduced with a reduction in Ozone (O_3) concentrations. Another study concluded that high temperature and VOC emissions would be responsible for high $PM_{2.5}$ concentration (Lioa et al. 2014).

A meso-scale model coupled with a chemical transport model demonstrated that the interaction between local temperature and primary pollutant concentrations alters the local air quality with increase in secondary pollutant concentrations (Martilli et al. 2003). Sensitivity analysis in models indicates that biogenic emissions, which lead to both ozone and particle formation upon atmospheric oxidation, are a fundamental uncertainty in understanding atmospheric pollutant levels during heat waves (Vieno et al. 2010).

Chennai is often affected by the sea breeze, an increased aerodynamic roughness due to urbanization can weaken penetration of the sea breeze into the urban area. Therefore, it is essential to characterize the seasonal variations of interactions of land cover and meteorology with the air pollution levels in the coastal city. The interactions of marine boundary and air pollution levels had not been studied

extensively in a tropical climate. The influence of microenvironment infrastructure on diurnal variations of meteorology and local air quality is a significant research gap to be addressed. Annual and seasonal temperature trends of the national capital region in Delhi were discussed in (Mohan, Kandya, & Battiprolu, 2011). Ryu et al. 2013 concluded that due to change in urban surface local meteorology and air quality had been significantly affected. High ozone episodes are observed at urban hotspots due to anthropogenic heat emissions because of stable atmospheric conditions are reported.
In the present study characteristics of local dispersion conditions of different built up locations studied in the city of Chennai, India. For the analysis continuous ambient air quality monitoring at the study locations carried out in summer and winter seasons have been done. Correlation has established between the obtained results of the diurnal local ambient air temperature profile and air quality.

MATERIALS AND METHODOLOGY

Three study locations with different characteristics of land covers, diurnal meteorology, and air quality were considered in the present study. Field measurements for Mean Radiant Temperature (MRT) were carried out for summer (May–June) and winter (Nov–Dec) seasons. These measurements mainly focused on major surface cover types available at the sites. Diurnal variations of MRT of different surface materials and ambient air temperature profiles at various heights from ground level were also monitored. Besides, local air quality monitoring was also carried out at study areas. The main focus of the present work is to understand the relationship between various factors that are affecting the local air quality in the considered urban zones. Local circulations and pollutant concentrations impact on local air quality at a scale of one square kilometer has been studied.

Study Area Description

Three locations of Chennai city area were selected based on the percentage of land use (Figure 1) representing Central Business District (CBD), Residential Area (RA) and Urban Baseline (UBL) sites.
Central Business District (CBD): T Nagar is a typical urban area with dense buildings and heavy vehicular traffic. The latitude and longitude are given as 13°2'11.61"N and 80°13'58.39"E respectively.

Residential Area (RA): Royapuram is located in the northern part of Chennai. This site is located very near to the sea coastline with moderate-densely built-up area and vegetated land covers. The latitude and longitude of Royapuram site are 13° 6′ 14.51″ N, 80° 17′ 37.18″ E respectively.

Insert figure 1

Urban Baseline (UBL): IIT Madras campus, with natural land cover representing a background area, Latitude, and Longitude of the this is 12°59'29.54"N and 80°14'1.20"E respectively.

Insert figure 2

The selection of the locations is based on the fact that these locations are significantly differing in land covers and traffic emissions. The area under consideration is one square kilometer at each study location. Sky view factor and land cover for these areas vary according to the local characteristics of land use (Figure 2) as determined using Arc-GIS. The CBD site has been chosen, where more than 85±5% land cover is changed from natural soil to concrete surface; remaining area is either green cover or soil cover. The RA site is the area with 14±3% of asphalt cover and 10±0.5 % of vegetation/soil land and remaining is the constructed land. An important factor of this site is the sea breeze interaction with measurements. UBL area has less than 30±1.5 % constructed land covered.

Field Measurements

Mean Radiant Temperature

During ten days continuously hourly averages of surface temperature (MRT) of different materials were captured using the thermal image instrument; one hour on each of the different surfaces. A Fluke makes thermal imager of model Ti105 was used. The IR thermal imager measured the MRT of the materials of interest (the instrument's range was from -20 ^{o}C to 150 ^{o}C with an accuracy of 2%).

Surface temperature measurements have been carried out at 15 places at each location from 14th May to 25th May 2016 and 5th Nov to 18th Nov 2016 at UBL site for two seasons, from 26th May to 8th June 2106 and from 20th Nov to 1st Dec 2016 at the RA site, and from 10th June to 25th June 2016 and 2nd Dec to 15th Dec at the CBD site. The measuring points were chosen where the sunlight passes for a long time.

Air Quality and Meteorology

Continuous monitoring of hourly averages of (1) air temperature at 2 meters height, (2) air temperature at 10 meters height, (3) concentrations of NO, NO_2, O_3 (in ppb), and $PM_{2.5}$ (in µg/m³), (4) wind speed (m/s) and direction was made at fixed locations in the three study regions for different seasons. Continuous ambient air quality monitoring stations (CAAQMS) are located at UBL site (near Gandhi road, IIT-M) and RA site (Royapuram), mobile monitoring van has been used for the air quality measurements at CBD location. Same kind of instruments was used in three selected zones (Table 1).

Insert table 1

Ambient air temperature monitoring at 2 meters height was done using TSI instrument, IAQ-CALC of model 7545 (accuracy ±0.6 ^{o}C). Real-time atmospheric air temperature monitoring was done. At each study location, an average distance of 2 - 2.5 kilometers was traveled for capturing the air temperature data at 2 m height. All air quality measurements were done during the same period as the surface temperature monitoring.

Mixing height was calculated using the local temperature trend at each location. The intersection of dry adiabatic lapse rate (DALR) and environmental lapse rate (ELR) at 6.00 hrs is the mixing height at that particular time. The product of mixing height and velocity at that location at a particular time gives the ventilation coefficient at instance.

The comparison has been done for seasonal air quality with the interaction of various landscapes and meteorological conditions (Figure S1).

RESULTS

Characterization of Mean Radiant Temperature

The diurnal variations of mean radiant temperature (MRT) for different land covers (Figure 3 for summer (a) and winter (b)) are trending the same as the characteristics of the thermo physical properties of the surface covering materials (Table 1). The surface temperature was higher during daytime for the two seasons from morning (i.e. 08.00 to 17.00 hrs) to evening.

In the summer season, at noon (13.00) concrete and road (asphalt) were showing the highest surface temperature of 70 ±2 ^{o}C, followed by soil 60 ±3^{o}C. However, after 15.00 hours there was a sharp fall in soil surface temperature, indicating the volumetric heat capacity of the soil material is relatively less compared to that of concrete and asphalt. At the same time, during the late afternoon, concrete and asphalt temperature profiles were still higher due to the higher volumetric heat capacity of these materials. The same trend in surface temperature profile was observed for winter months.

Insert table 2

The results indicated that after sunset i.e. 18.00 hrs surface temperatures of concrete and asphalt materials were more than 3 ^{o}C higher than the soil surface temperature in the summer season. All three surfaces were reaching a uniform temperature at early morning hours (5.00 hrs). A similar trend was observed during the winter season.

Insert figure 3

Weighting the temperature profiles of the different types of land cover by the land cover fractions of each study site (Figure 3) we calculated weighted average diurnal variations of surface temperature profiles (Figure 4). It was observed that the average surface temperature at CBD site was high followed by RA and UBL. The same trend was observed for both seasons indicating that the seasonal average surface temperature potential was not varying significantly. The reason was that the solar radiation flux did not show much variation (5 to 6 Kwh/m^2/day) between the seasons (http://mnre.gov.in/sec/solar-assmnt.htm).

Insert table 3

It can be observed that the average surface temperature profiles among the seasons were not varying more than 1^{o}C. Summer season average surface temperature profile for different land covers has been indicated in Table 3. Winter season temperature profiles of land covers have been indicated in Table 4.

Insert table 4

The weighted average mean surface temperature profile of the study locations was calculated by using the land cover fractions of each study site. Table 5 indicating the surface temperature characteristics of study locations during the summer season. It can be observed that the maximum temperature difference among the study locations was observed to be more than 8 ^{o}C at CBD followed by 5 ^{o}C at RA with UBL.

Insert table 5

Insert figure 4

Meteorological parameters

The urban site shows the higher air temperature throughout the day than the other two study regions (Figure 5). The maximum occurs in summer at 12.00 hrs. The temperature difference between urban and background sites was more than 2 ^{o}C, whereas it was even higher after sunset. The temperature variations after 18.00 hours indicate the intensity of UHI. During this time, the temperature at an urban site was around 3 ±1 ^{o}C higher than in the other two study regions (Table 6). During winter the variations of air temperature between the study regions were less because the wind was coming from the southwest direction that has the lower temperature and is not influenced by the local surface characteristics.

Insert figure 5

Insert table 6

Vertical temperature profiles were important in determining the temperature trend at selected locations. Real-time temperature monitoring at a height of 10 meters above the ground demonstrates that urban site temperature is much higher (more than 4 ^{o}C) than in the other two study regions. This could be due to a cumulative effect of land cover change, local heat emission sources, and heavy vehicular emissions at the urban site. In contrast, the variation in diurnal temperature profile during winter among the regions was equal or less than 1 ^{o}C.

The seasonal variations of relative humidity for selected locations indicated (Figure 6) that, during the summer season the maximum (i.e. 85 %) RH value is at early morning around 6.00 hrs., at background site with a daily average of 69.5 % followed by urban 66.4% and sub-urban sites 59.7%. The RH is higher at background site than in other study regions indicating that the evapotranspiration from land cover and wind direction had a significant effect.

In the winter season (Figure 6 b) the maximum RH value was recorded 94% ±2 for both background and urban locations with a daily average of 71.2% and 72.12%. For the sub-urban site, which is located very next to the coast, the RH fluctuations were not significant throughout the day (62 ±2.4%).

Insert figiure 6

The average wind velocity in the study region for summer season was found to be 1.22 m/s, 1.6 m/s 1.03 m/s for CBD, RA and UBL sites, respectively (Figure 7). Apart from the land use pattern at study regions building density at the three study locations are different. A 3D CFD model has been used to find the Sky view factor (SVF) in the study regions that amount for CBD, RA, and UBL site to 0.544, 0.7 and 0.357 respectively.

Insert figure 7

For winter the daily average wind velocity was reported as 1.01 m/s 1.7 m/s and 1.12 m/s at CBD, RA, and UBL sites respectively (Figure 8).

Insert figure 8

Mixing Height

Mixing height is one of the key components affected by surface modifications in urban areas. Ryu et al. (2013b) concluded that the atmospheric boundary layer (ABL) height influences the ozone (O_3) concentration in the urban zone during nighttime. Meteorological parameters and precursors transformation at nighttime is an important parameter for O_3 concentration. During a lower ABL condition, the destruction of ozone is less, so this is another important parameter for considering the ozone concentrations during nighttime. Early in the morning, higher O_3 concentration was observed due to background concentration and lower mixing height. By using monitoring temperature trends at each study location, mixing height calculations were estimated by considering environmental lapse rate (ELR) at 6 a.m. with dry adiabatic lapse rate (DALR) for every hour in a day. It can be seen from Figure 9, that mixing height variation is a function of the percentage of land use change. For the urban baseline (UBL) site, maximum mixing height (MH) was about 1000 meters, whereas for the central business district (CBD) site the maximum mixing height (MH) was about 1200 m, and for the residential area (RA), it was 1000 meters. At the CBD site after sunset, the mixing height was significantly higher than 100 m. This indicates that the temperature variations were potentially affecting the stability of the atmospheric conditions. Winter season was similar for all three-study locations with maximum height variation up to 600 meters observed in the afternoon.

Insert figure 9

Ventilation coefficient (VC)

Mixing height and wind speed determines the ability of vertical mixing and horizontal mixing of air pollutants in the study area. The seasonal variations of ventilation coefficients have been calculated using the IMD Chennai report (2009) for mixing height and the average wind speed conditions during the monitoring period (Figure 10), represents the seasonal variation of VC for Chennai city. It is clearly observe from the plot that the variation in dispersion conditions varying with season.

Insert figure 10

During summer the average ventilation coefficient was around 1311 m^2/s, with a maximum of 2215 m^2/s in the noon, whereas it is around 1059 m^2/s during winter with a maximum of 1865 m^2/s. Calculations of VC have been made for three study regions using the local wind velocity conditions during the monitoring period for two seasons. Results are indicating that the change in local infrastructure altering the local dispersion conditions. It is indicating that the CBD site is having the more VC relative to the other two study locations, for different seasons. It is because the high building density in the CBD site is alerting the wind speed at this site. Whereas in summer at the RA site, located very next to the coast is having the higher VC due to higher wind speed. The average wind speed at UBL, RA and CBD sites is 1.03, 1.57 and 1.3 m/s respectively in summer. In winter at all three-study locations, it is around 1 ±0.1m/s.

Air Quality

For CBD and RA study locations, the trend of daytime atmospheric O_3 concentration was increasing, reaching a peak at midday (Figure 11). During summer the maximum ozone (O_3) concentrations were recorded at the CBD site during the afternoon i.e. around 38.31 ppb, whereas it was 26.8 and 14.6 ppb in RA and UBL sites, respectively. The reasons might be higher temperature trends and vehicular emissions in CBD sites compared to other study regions. In winter season the average ozone concentration in all three-study locations was increased as 45.3 ppb, 45.83 ppb, and 58.5 ppb UBL, RA and CBD sites, respectively.

Insert figure 11

Ozone is a secondary pollutant and its concentration depends on the precursor concentrations (NO and NO_2, see Figure 12 & 13). In summer the NO_2 concentrations are around 20 ppm in all three-study locations indicating that the transformations of NO to NO_2 and vice versa were rapid during summertime. During the daytime the concentration of NO_2 was more in UBL than at CBD and RA sites. This is due to a high rate of formation of NO_2 from NO, temperature and humidity at UBL site. The rate of hydroxyl ion formations and transformations NOx concentrations depends on the ambient temperature during daytime. The concentration of NO_2 was decreasing rapidly soon after the sunset, indicating a dissociation of NO_2 at nighttime. For CBD and UBL locations the average wind direction was from land breeze direction, whereas for RA location during the majority times wind came from the sea breeze side. The trends of the NO_2 and O_3 concentrations during summer depend on the emissions, wind patterns, temperature and transformation reactive pollutants.

Insert figure 12

In the summer the hourly average variation of NO values indicates higher concentrations at RA followed by CBD and UBL sites (Figure 13). Sea breeze and vehicular emissions were the major causes for higher NO concentration at the residential area site. It was clear from this plot that, though the NO concentration is high at RA, ambient temperature and humidity conditions are enhancing the NO to NO_2 formation during daytime. The morning peak and evening peak of NO concentration in the residential site was mainly due to the sea breeze and vehicular emissions. Whereas in winter NO concentration among three study locations was not exceeded 20ppb, but the NO_2 the concentration at CBD was observed to be higher than RA and UBL. This is due to land cover surface temperature fluxes amplify the NO_2 formations and higher wind speed conditions (see Figure 7 & 8 for local wind velocity and wind direction).

Insert figure 13

The one-hour average $PM_{2.5}$ concentrations (Figure 14) were reaching a morning peak at 8.00 hrs. and evening peak at 19.00 hrs. due to heavy conditions of traffic at these time slots. Meteorological conditions affected gas pollutants more significantly than

PM (He et al. 2017). Residential Area is showing the highest concentration among the study regions.

Insert figure 14

Results from the monitoring data indicated that the impact of O_3 concentration was positively correlated with local mixing height Table 7. This is because of local ozone concentration is a function of meteorology, precursor concentration, advection and dispersion conditions. Advection due to the background concentration was accounted. A positive correlation between O_3 and temperature indicated the impact of local temperature on the Ozone concentration (Chen et al.2020). At the same time the formation of O_3 will be high during daytime. This will increase the O_3 concentration at the study locations.

Insert table 7

Discussion

Mean radiant temperature

The intensity of temperature variations among the different surface materials was higher in winter than in summer. This indicates that the solar flux and moisture content in the atmosphere was influencing the surface temperatures profiles of different materials.

Meteorological parameters

From the wind direction plot (Figure 7 & 8), it can be observed that, apart from the land cover change, the sea breeze plays a significant role on local ambient air temperature for the residential site in summer. That may be the reason for the lower temperature when compared to CBD and UBL sites.

In summer during daytime wind direction was from east side i.e. sea breeze, in winter it was from south-west direction (land breeze) at the RA site.

In summer RH trends at different locations are strongly affected by the temperature profile. In contrast absolute humidity indicates the water vapor content. As the temperatures are high in summer the vapor content in the air is higher during the same period except in UBL site. In summer the moisture content of soil and plants respiration causes high RH and absolute humidity values.

Wind speed and wind direction plots indicate a clear seasonality. Among the three-study locations the RA site is situated very next to the coast, at this site the seasonality in wind direction was observed more clearly than in other two study locations. The wind rose plots (Figure 7 & 8) suggest local air circulations in the study region, but at CBD and RA sites the monitoring stations are located very next to roads. Due to this, the traffic flow is affecting the wind direction patterns in these regions.

Air quality

Air quality measurements indicate that the concentrations of reactive pollutants (NO_2 and O_3) profiles depend on the meteorological parameters than the precursor's concentrations. This suggests that apart from the primary pollutant concentrations, local meteorology is affecting the secondary pollutant. Favorable conditions in each season are responsible for higher NO_2 and O_3 concentrations, during daytime concentration of O_3 is increasing and then decreasing with the solar flux. After sunset the formation of photochemical O_3 will not take place, the decrease in O_3 concentration trends are observed after sunset (i.e.18.00 hrs.). The dissociation of O_3 is a function of temperature (thermal decomposition), as the surface temperature and ambient temperatures are high in the central business district and residential area sites, a sharp decrease in O_3 concentrations was observed during the same. Pearson correlation coefficient for three study regions demonstrated that in summer ambient air temperature and O_3 concentrations are well correlated. In summer dispersion of pollutants was stronger than in winter season. Assimilative capacity and mixing height variations (Figure S2) in these seasons are significantly different for Chennai. For detailed results of correlation coefficient refer supplementary data.

Summary and Conclusions

Present study examined the correlation between individual meteorological parameters and O_3 concentrations. This study indicated that meteorological influences on O_3 concentrations varied significantly across seasons. Previous studies generally selected different research periods and meteorological factors, making the comparison of findings from different studies. Similar to previous studies conducted at the local scale, this research further indicated that meteorological influences on O_3 concentrations were of notable seasonal and spatial variations. This research revealed the influence of individual meteorological factors on O_3 concentrations. The higher O_3 concentrations, the stronger influence meteorological factors exert on local O_3 concentrations, dominant meteorological factor related to geographical conditions. For heavily polluted winter, coastal area and the dominant meteorological driver for O_3 is wind speed. The influence of temperature, mixing height and wind speed on local O_3 concentrations is much larger than that of other factors, and temperature exerts the strongest and most stable influences on O_3 concentrations in all seasons. The influence of individual meteorological factors on concentrations extracted in this research provides more reliable reference for better modeling and forecasting local and regional ozone concentrations. The surface temperature measurements suggested that the land cover alters the local energy balance. Thermo physical properties of the surface materials together with local meteorological parameters influenced the diurnal temperature profiles. Seasonality of wind direction and wind speed was varying significantly with study region. Local temperature profile acts to enhancing the secondary pollutants formation during summer; it means that there is an important parameter that has to be addressed based on the percentage of land use pattern on the local temperature. In winter higher O_3 concentrations at Residential Area and Central Business District zones occurred due to poor dispersion conditions and land breeze effect (upstream concentration). Apart from these measurements the reason for higher secondary pollutants concentrations during winter season indicates the depression in mixing height influencing the air quality. The most serious air pollution was observed in CBD, followed by RA and UBL at the study locations. The average concentration of O_3, increased significantly in winter season at the study locations in Chennai. Determines the formation, dispersion, transportation and accumulation processes of pollutant were positively correlated with temperature and mixing layer height. The correlation with wind speed showed a significant regional difference.

At higher altitudes from the ground level, all velocity profiles follow the same trend irrespective of local roughness. Up to 20 meters height from the ground level there is a chance of the pollutant to be trapped in the breathing zone level based on the local built-up height. In summer, temperature is causing the high O_3 concentrations, where as in winter poor dispersion conditions.

Scope for future work

In order to find the exposure level of pollution in each area in future, a detailed micro meteorological study could be helpful. A detailed modeling technique can be helpful to simulate the local meteorological and chemical transformations on air quality will be useful to compare.

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Table 1 List of Measuring Instruments

Air Quality Measurements	Instrument Name	Working Principle
NO_x	**AC32M**	Chemiluminescence analyzer
Ozone (O_3)	**O342M**	UV absorption analyzer
$PM_{2.5}$	**CPA**	Optical Counter Measurements

Table 2 Thermo physical properties of Surface covering materials

Material	Albedo	Emissivity	Volumetric Heat Capacity ($Jm^{-3}K^{-1}$)
Soil	0.05 to 0.2	0.98	1.21
Asphalt	0.2	0.9	2.25
Concrete	0.3	0.9	2.08

Table 3 Characteristics of surface temperatures of different materials in summer

Material	Minimum Temperature	Maximum Temperature	Day average
Soil	24.07	52.20	35.59
Asphalt	28.65	67.02	44.53
Concrete	29.50	67.90	46.07

Table 4 Characteristics of surface temperatures of different materials in winter

Material	Minimum Temperature	Maximum Temperature	Day average
Soil	21.00	54.30	34.93
Asphalt	27.95	67.55	44.12
Concrete	25.68	69.10	45.34

Table 5 Average surface temperatures with deviation, maximum, and minimum during summer

Surface Temperature (°C)	UBL	RA	CBD
Average	39.71	43.22	45.40
Standard deviation	11.53	12.89	13.66
Minimum	26.92	28.54	29.25
Maximum	58.09	63.63	66.97

Table 6 Average and standard deviations of temperatures profiles at study locations at 10 meters height

Season	UBL	RA	CBD
Summer	29.60±2.4	29.68±1.8	32.46±2.2
Winter	22.39±2.3	22.36±2.4	21.57±2.7

Table 7 Pearson correlation coefficient between mixing height on O_3 concentration from monitoring results

	O_3	Mixing Height	Temperature	Wind Speed
UBL	0.78	0.94	1.00	0.91
RA	0.64	0.90	1.00	0.68
CBD	0.95	0.96	1.00	-0.06

An attempt has made to study the seasonal and diurnal variation of air quality levels in selected study regions with land cover change. This paper is focusing mainly on the surface temperature intensity variations with respect to percentage of land use pattern change in Chennai city, India. and subsequent effect on meteorology of dispersion conditions and air quality parameters has been studied. The relationship between local meteorology and air quality has established.

Figure1 Selected study area's map.

Figure 2 Percentage of land use patterns in the three selected study regions.

Figure 3 Mean Radiant Temperature (MRT) profiles (a) Summer season, (b) Winter season measured for different land covers.

Figure 4 Diurnal variations of surface temperature profiles calculated using the weighted average of land use availability at study regions (a) Summer season, (b) Winter season.

Figure 5 Monitoring results of temperature variations at 10 meters above from the ground level (a) Summer season (b) Winter seasons

Figure 6 Seasonal variations of monitoring results of diurnal variations of relative humidity for (a) Summer season (b) Winter seasons

Figure 7 Local wind velocity profiles in the summer season at the study locations (a) CBD (b) RA (c) UBL.

Figure 8 Local wind velocity profiles in the winter season at the study locations (a) CBD (b) RA (c) UBL.

Figure 9 Mixing heights at study areas during summer season

Figure 10 Seasonal Ventilation coefficient for Chennai.

Figure 11 Monitoring results of Ozone concentration profiles for (a) Summer season, (b) Winter season

Error bars indicating the standard deviations of concentrations.

Figure 12 Monitoring results of NO_2 concentration profiles at study region for (a) Summer season, (b) Winter season, Error bars indicating the standard deviations of concentrations.

Figure 13 Monitoring results of diurnal NO concentration profile for (a) Summer season, (b) Winter season

Error bars indicating the standard deviations of concentrations.

Figure 14 Monitoring results of $PM_{2.5}$ concentration profiles at selected study region during (a) Summer season, (b) Winter season

Figure S1 Temperature and RH profile of Chennai city.

Figure S2 Seasonality of Mixing Height for Chennai.

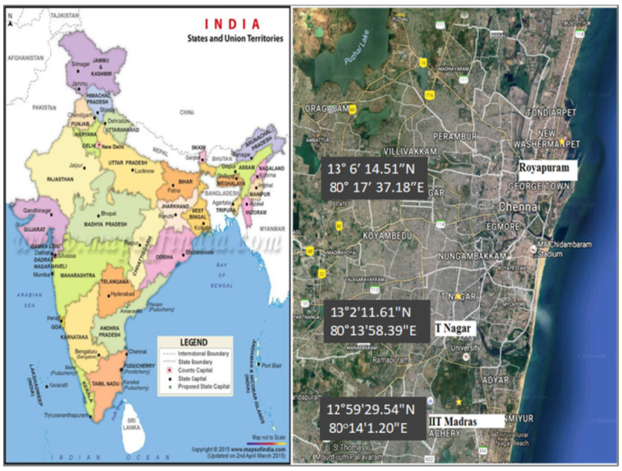

INDIA
States and Union Territories
LEGEND
13° 6′ 14.51″N
80° 17′ 37.18″E
Royapuram
13°2'11.61"N
80°13'58.39"E
T Nagar
12°59'29.54"N
80°14'1.20"E
IIT Madras
Puzhal Lake
ORAGADAM
PERAMBUR
VILLIVAKKAM
TONDIARPET
NEW
WASHERMANPET
GEORGE TOWN
Chennai
EGMORE
KOYAMBEDU
NUNGAMBAKKAM
MA Chidambaram
Stadium
T NAGAR
Anna
University
Ramapuram
ADYAR
St.Thomas
Mount-cum-Pallavaram

Fig 1

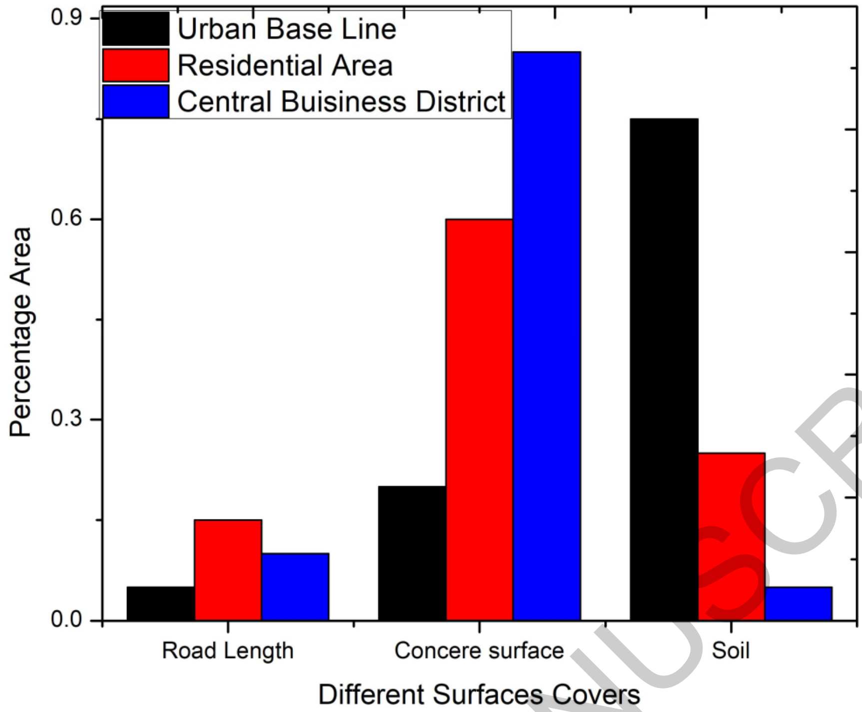
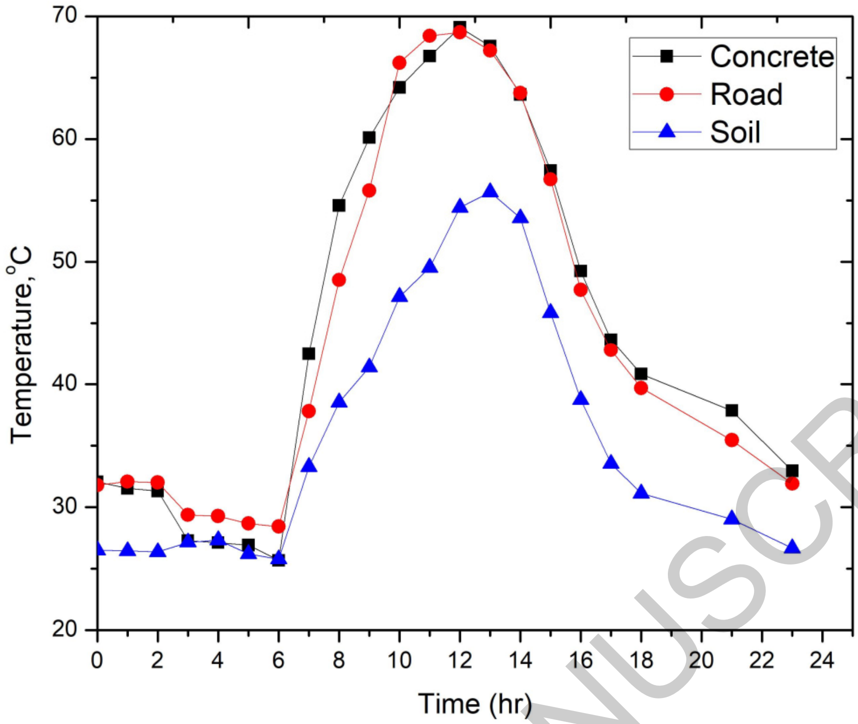
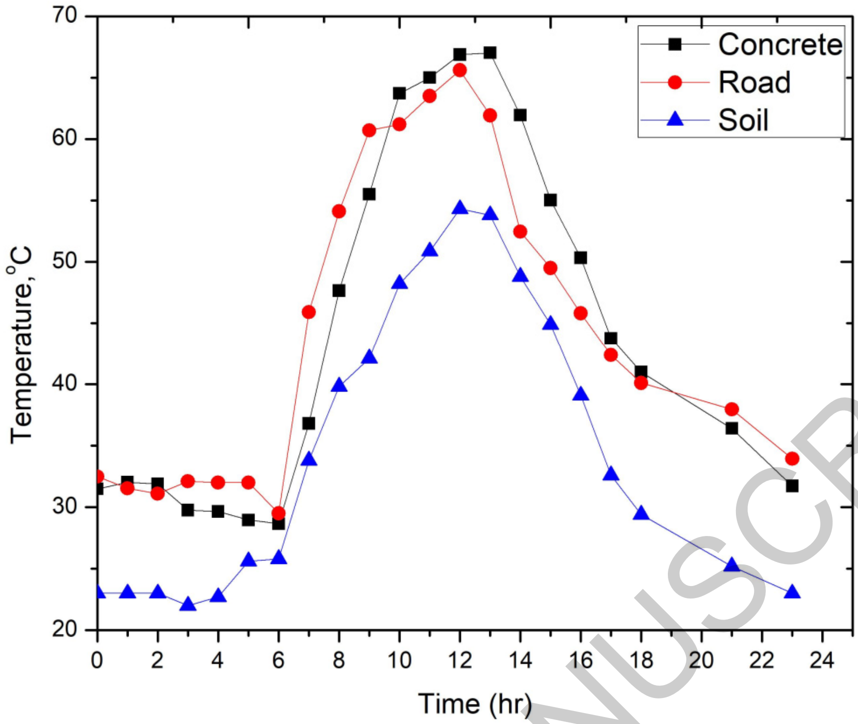

Urban Base Line
Residential Area
Central Buisiness District
0.9
0.6
0.3
0.0
Percentage Area
Road Length
Concere surface
Soil
Different Surfaces Covers

Fig 2



Concrete
Road
Soil
Temperature, °C
Time (hr)
70
60
50
40
30
20
0
2
4
6
8
10
12
14
16
18
20
22
24

Fig 3A



70
60
50
40
30
20
Temperature, °C
0
2
4
6
8
10
12
14
16
18
20
22
24
Time (hr)
Concrete
Road
Soil

Fig 3B

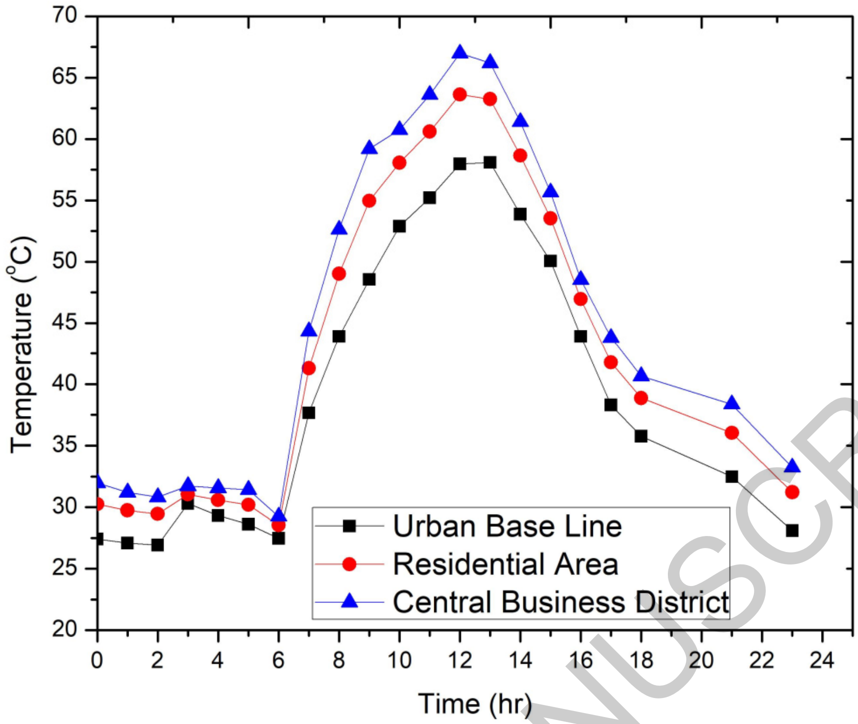
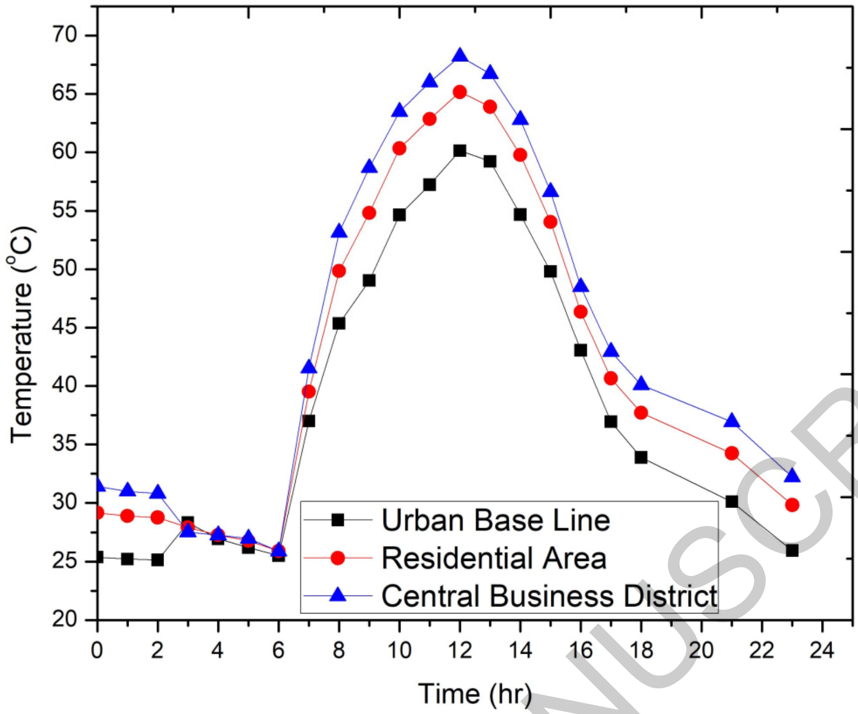
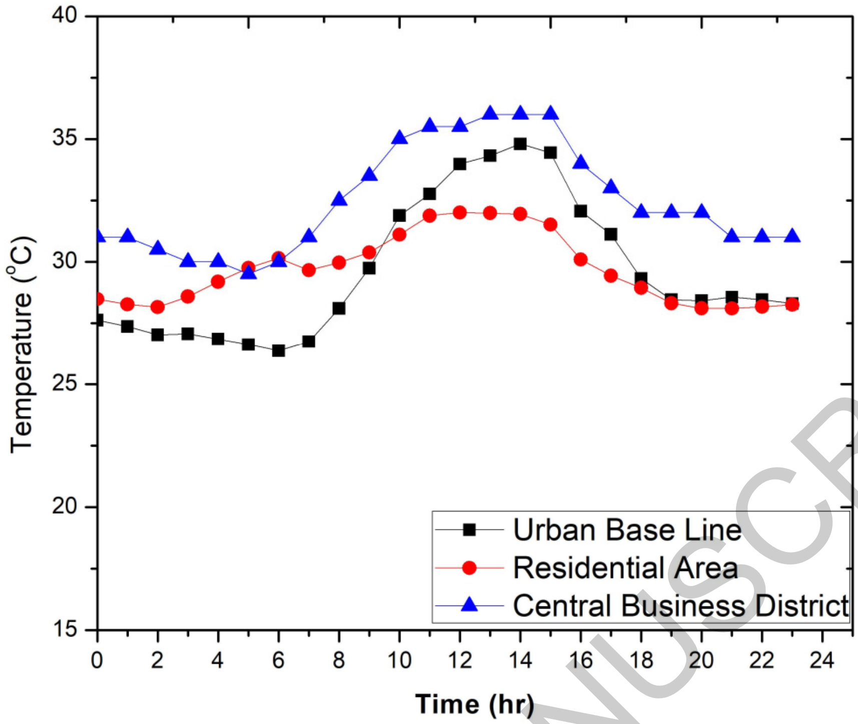

Temperature (°C)
Time (hr)
Urban Base Line
Residential Area
Central Business District
70
65
60
55
50
45
40
35
30
25
20
0
2
4
6
8
10
12
14
16
18
20
22
24

Fig 4A



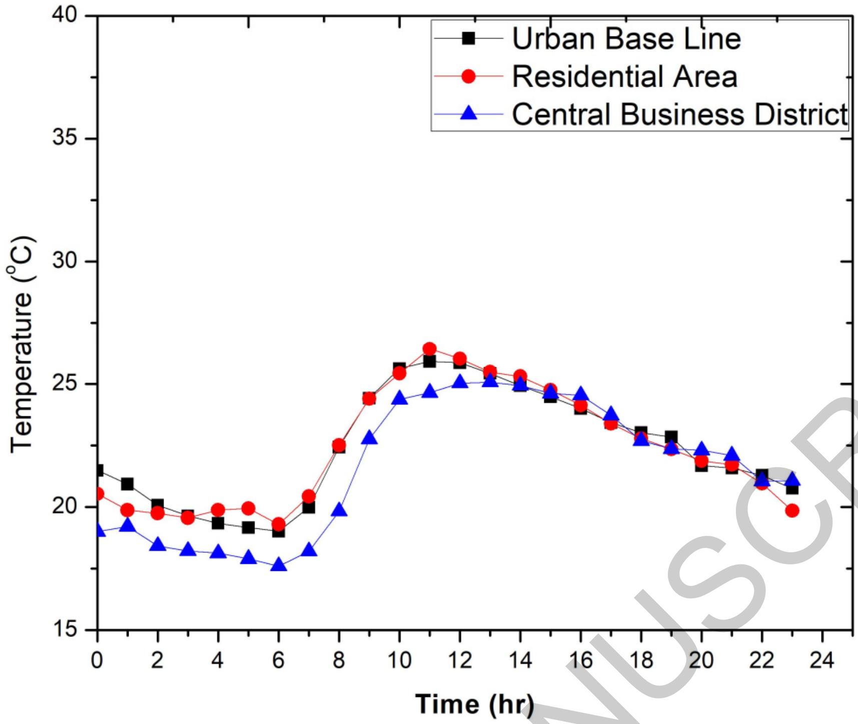
Temperature (°C)
Time (hr)
Urban Base Line
Residential Area
Central Business District

Fig 4B



40
35
30
25
20
15
Temperature (°C)
0
2
4
6
8
10
12
14
16
18
20
22
24
Time (hr)
Urban Base Line
Residential Area
Central Business District

Fig 5A



40
35
30
25
20
15
Temperature (°C)
0
2
4
6
8
10
12
14
16
18
20
22
24
Time (hr)
Urban Base Line
Residential Area
Central Business District

Fig 5B

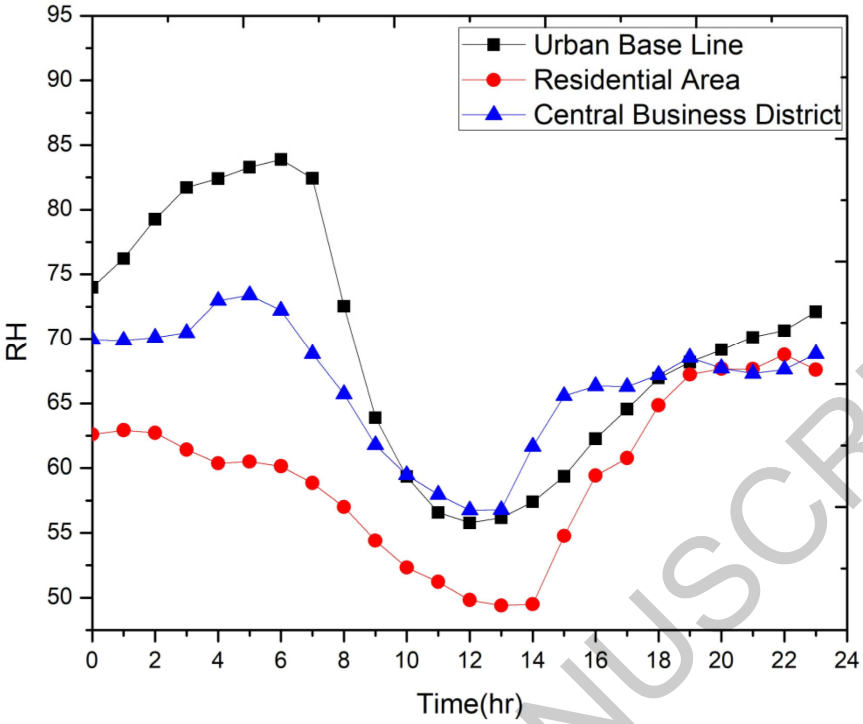
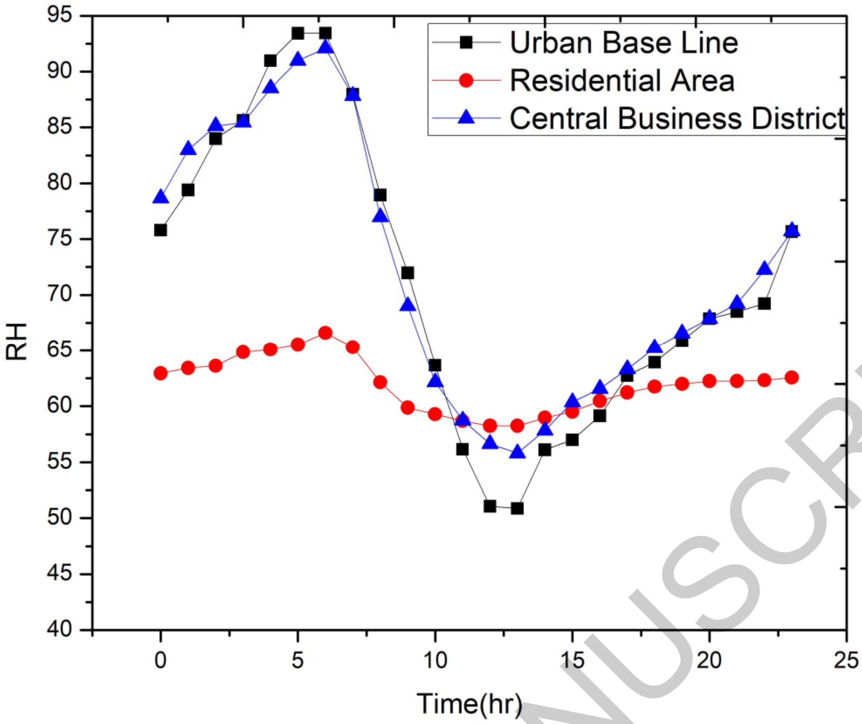

Urban Base Line
Residential Area
Central Business District
RH
Time(hr)
95
90
85
80
75
70
65
60
55
50
0
2
4
6
8
10
12
14
16
18
20
22
24

Fig 6A



Urban Base Line
Residential Area
Central Business District
RH
Time(hr)

Fig 6B

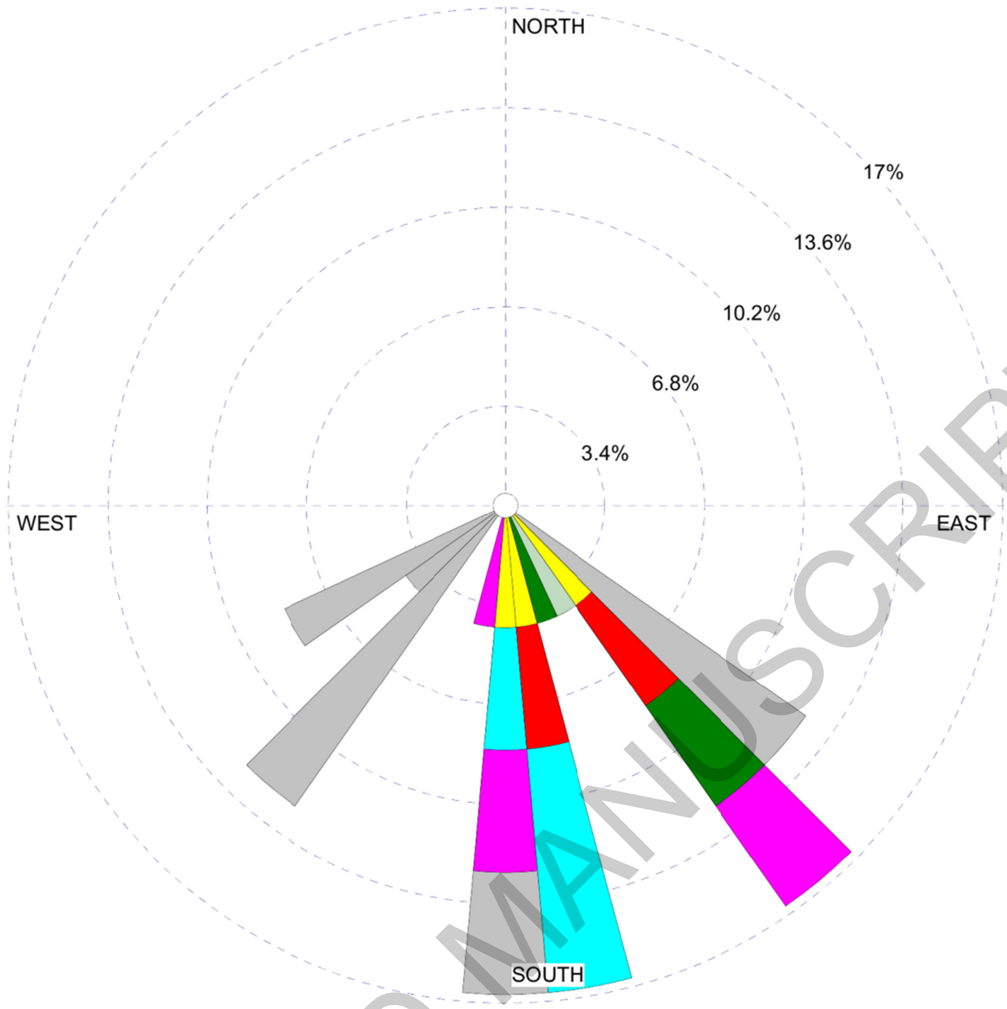


Fig 7A

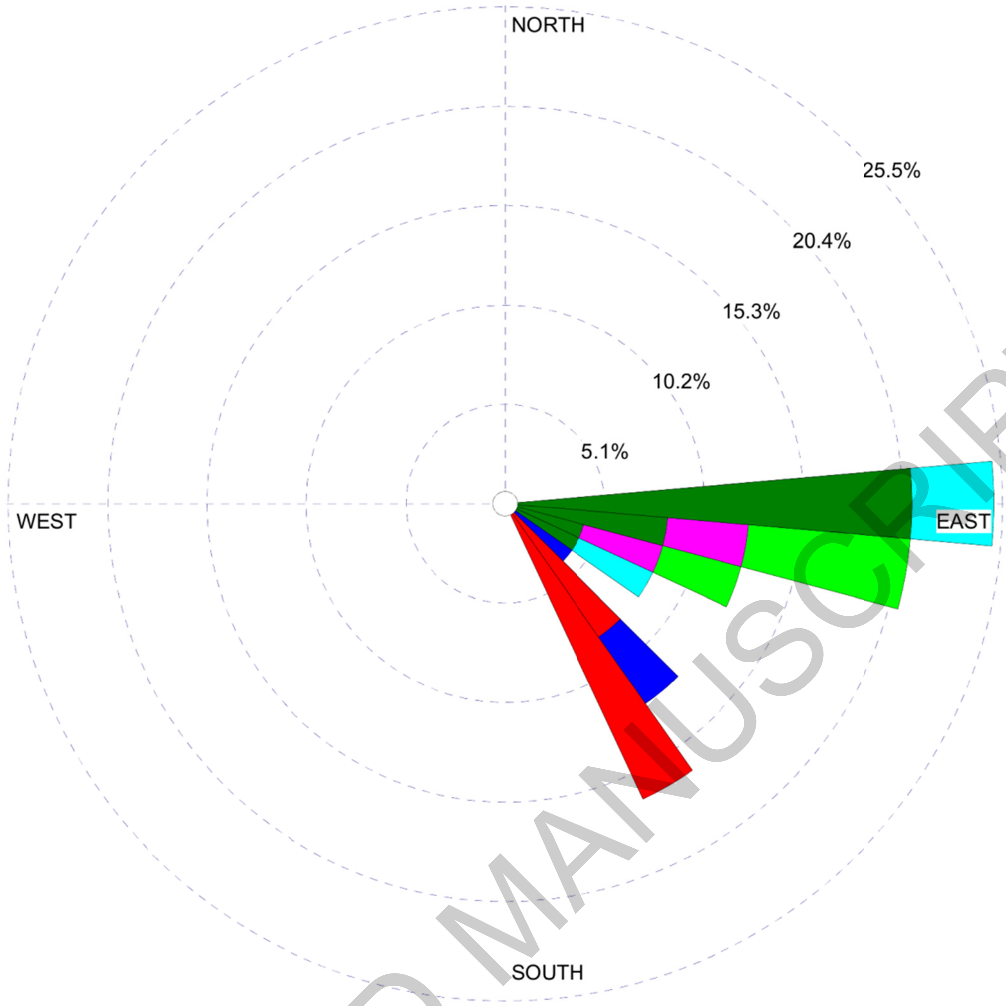


Fig 7B

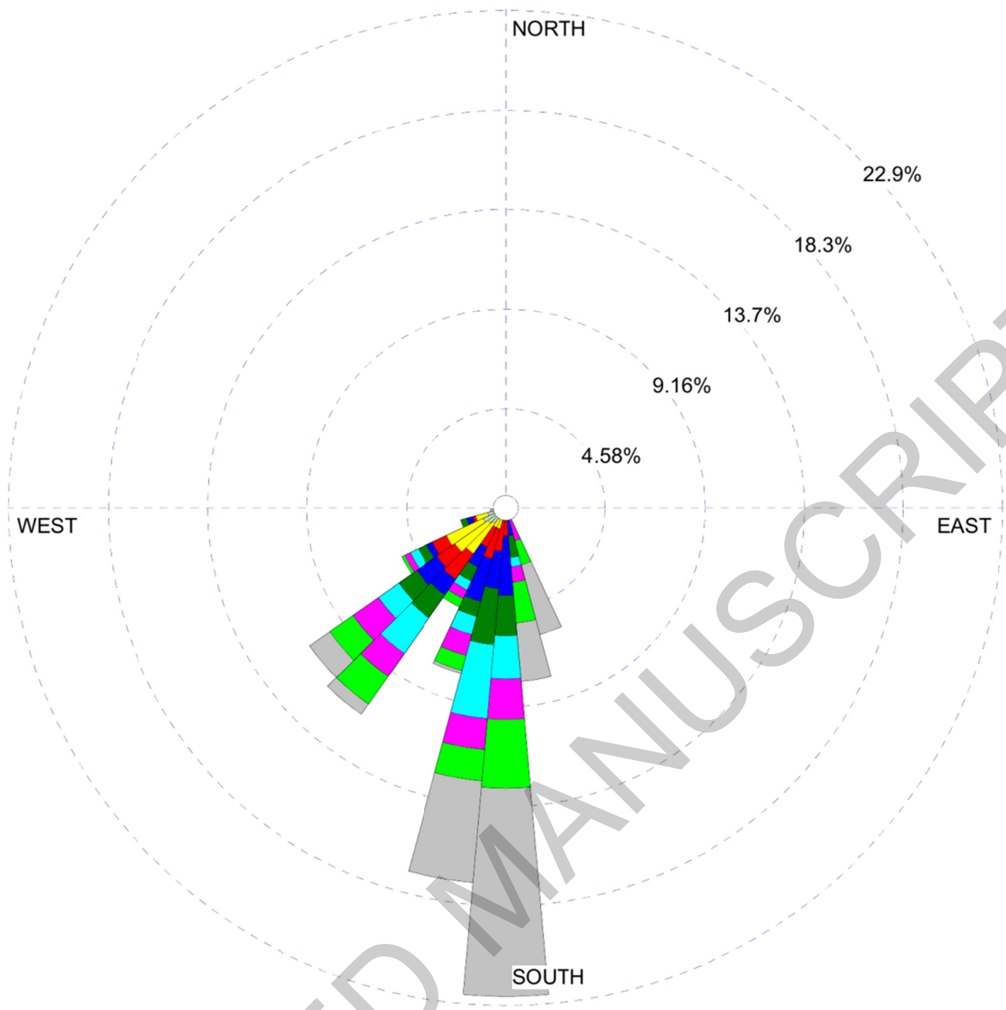


Fig 7C

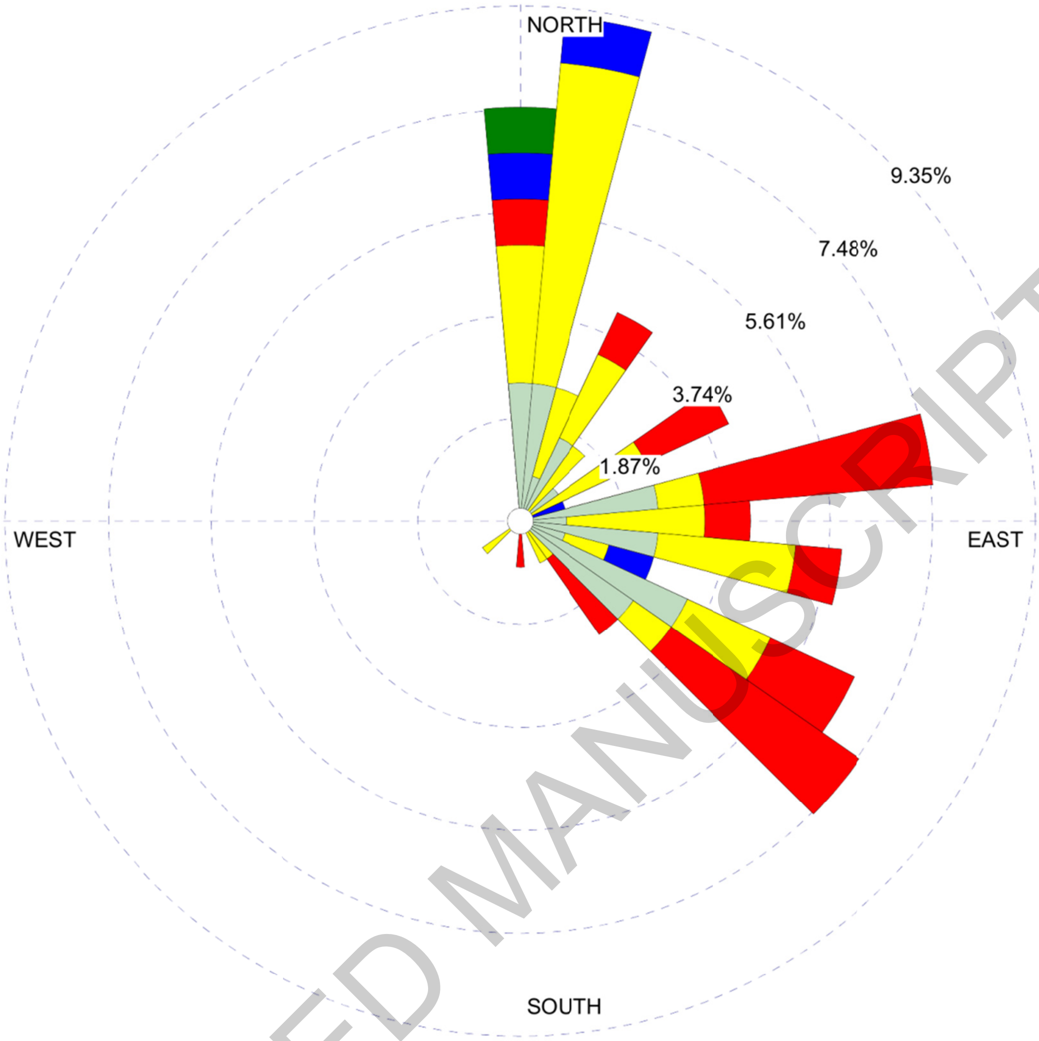


Fig 8A

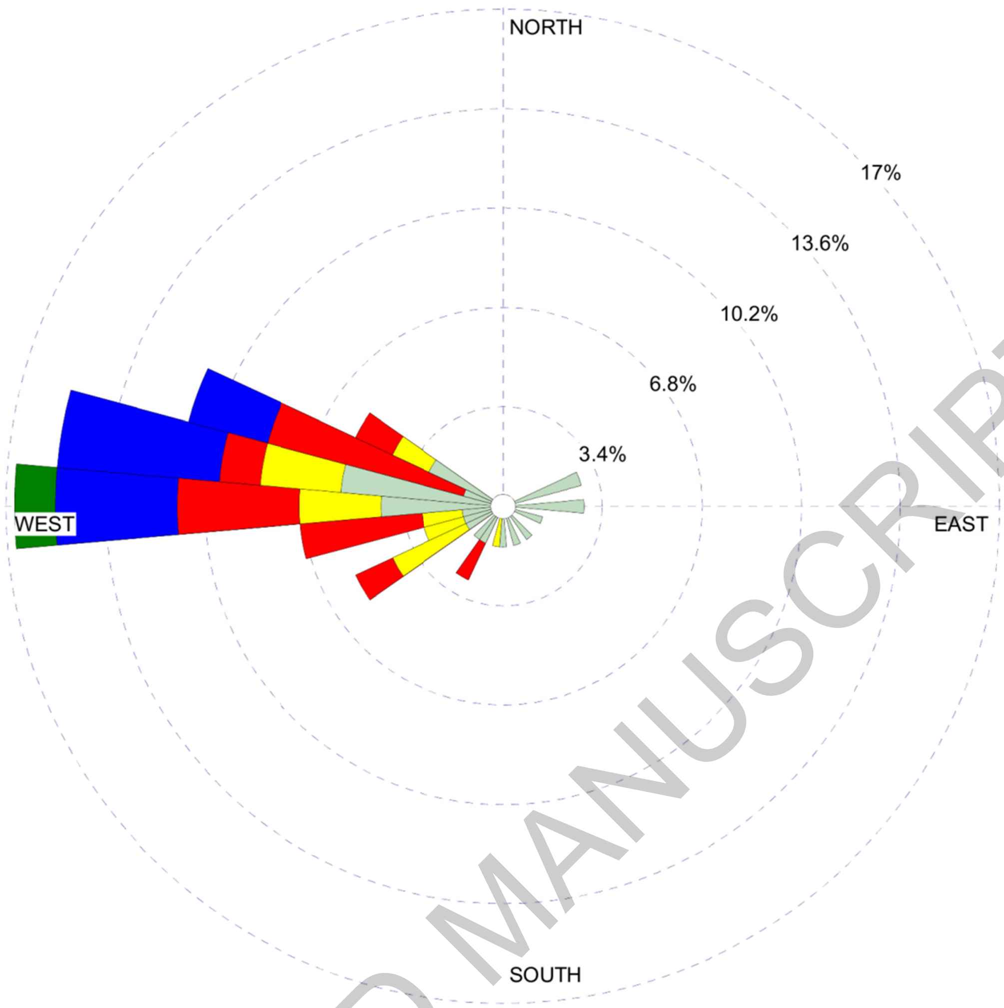


Fig 8B

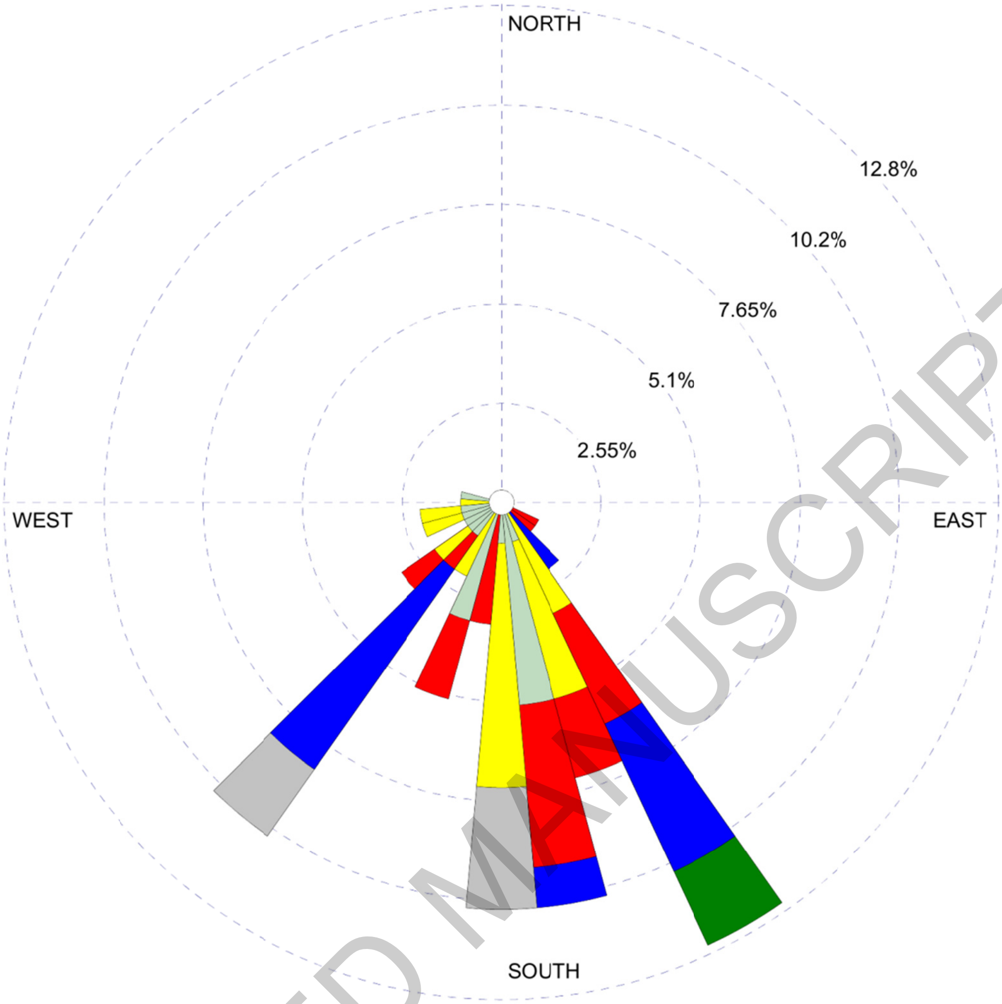
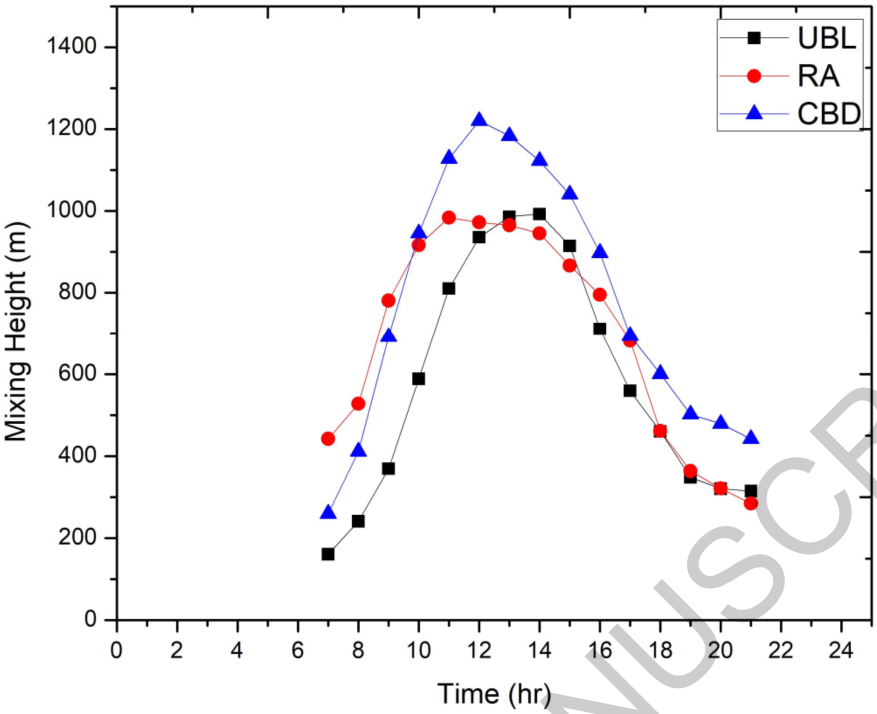


Fig 8C



UBL
RA
CBD
Mixing Height (m)
Time (hr)
0
200
400
600
800
1000
1200
1400
0
2
4
6
8
10
12
14
16
18
20
22
24

Fig 9

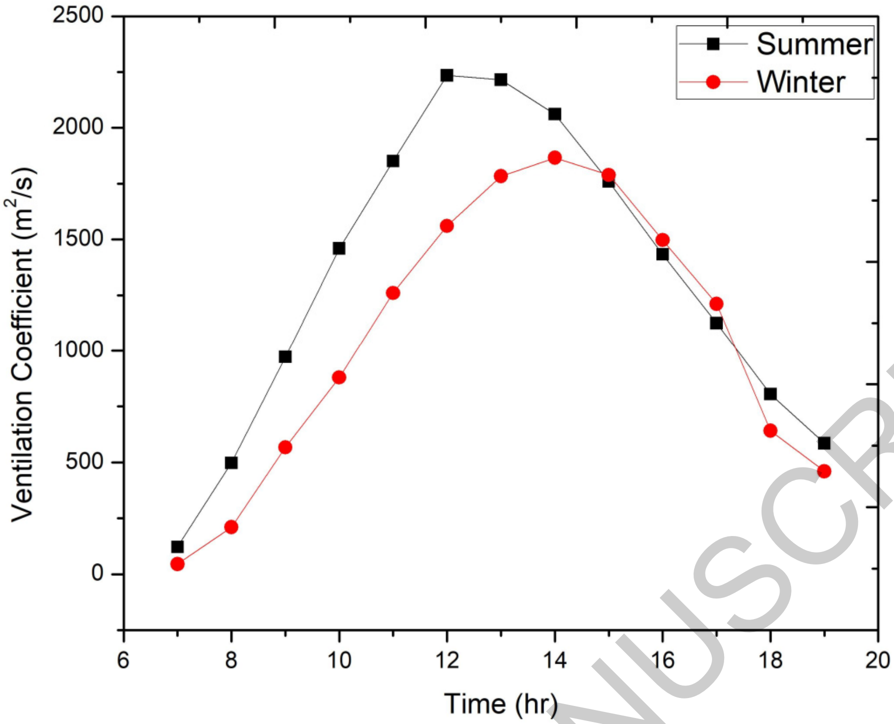

Summer
Winter
Ventilation Coefficient (m^2/s)
Time (hr)
2500
2000
1500
1000
500
0
6
8
10
12
14
16
18
20

Fig 10

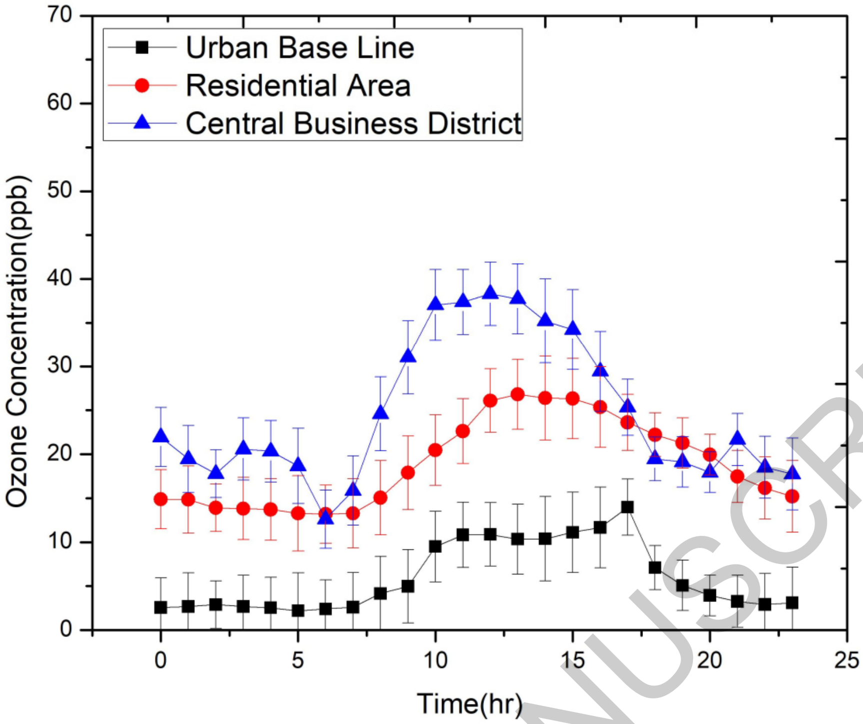
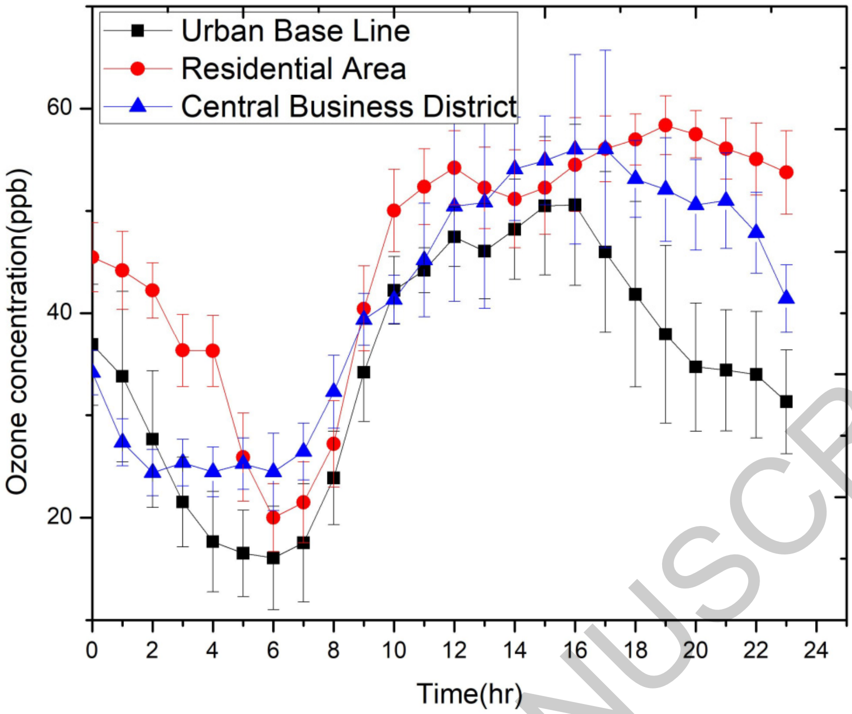
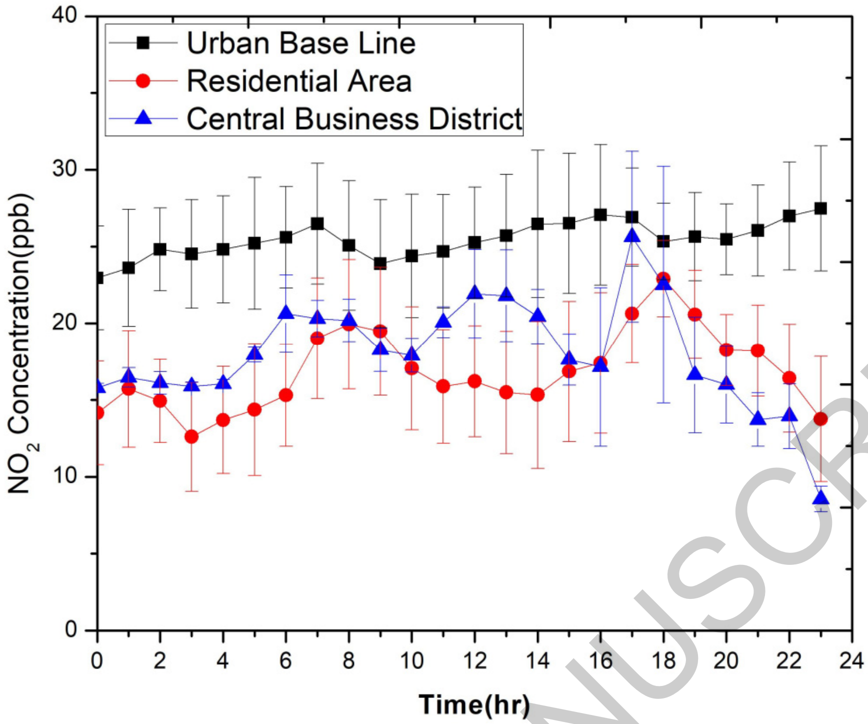

Urban Base Line
Residential Area
Central Business District
Ozone Concentration(ppb)
Time(hr)
0
10
20
30
40
50
60
70
0
5
10
15
20
25

Fig 11A



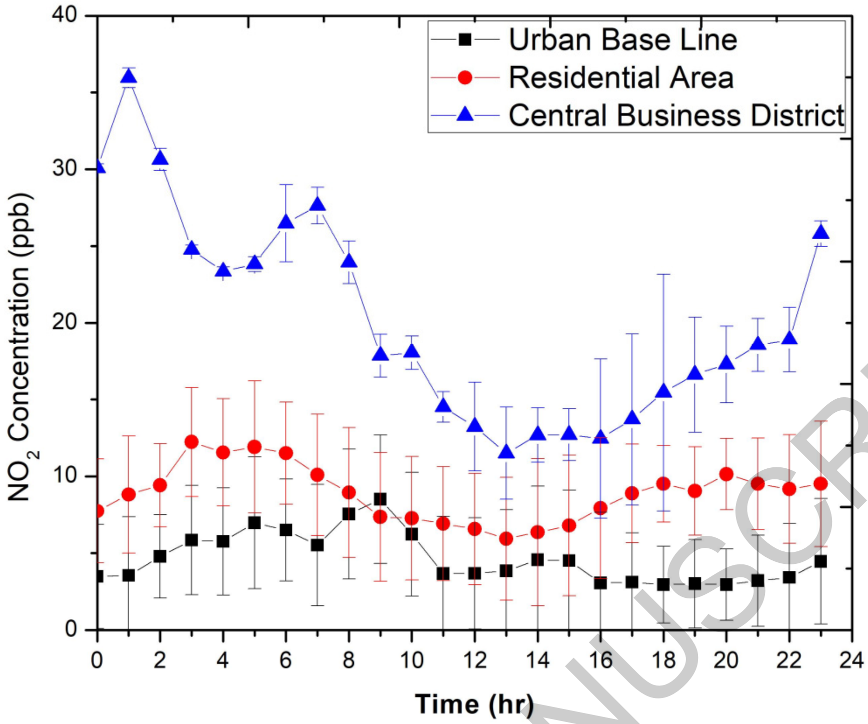
Urban Base Line
Residential Area
Central Business District
Ozone concentration(ppb)
Time(hr)
60
40
20
0
2
4
6
8
10
12
14
16
18
20
22
24

Fig 11B



Urban Base Line
Residential Area
Central Business District
NO_2 Concentration(ppb)
Time(hr)
0
10
20
30
40
0
2
4
6
8
10
12
14
16
18
20
22
24

Fig 12A



Urban Base Line
Residential Area
Central Business District
NO_2 Concentration (ppb)
Time (hr)
0
10
20
30
40
0
2
4
6
8
10
12
14
16
18
20
22
24

Fig 12B

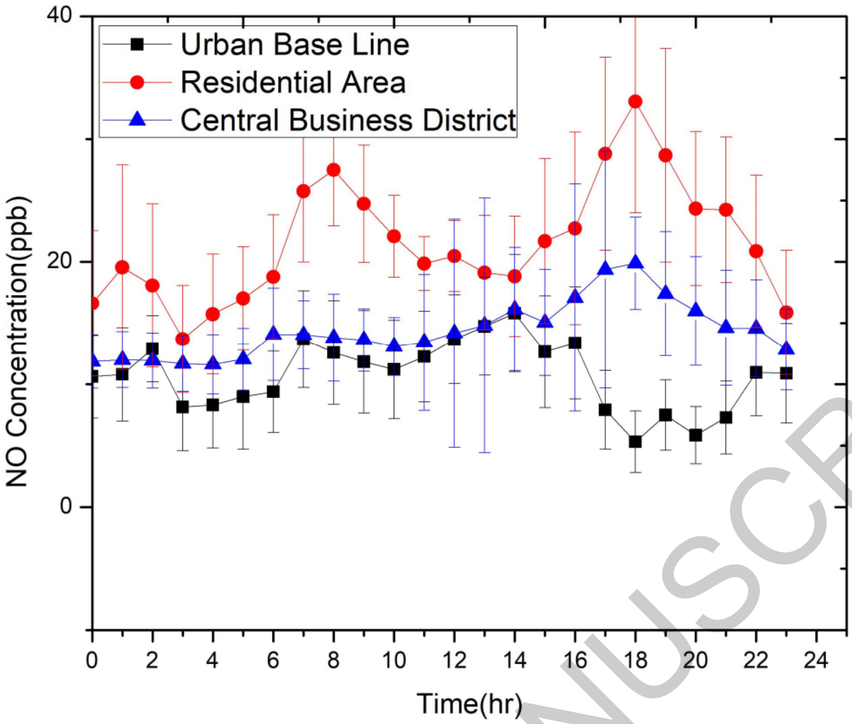
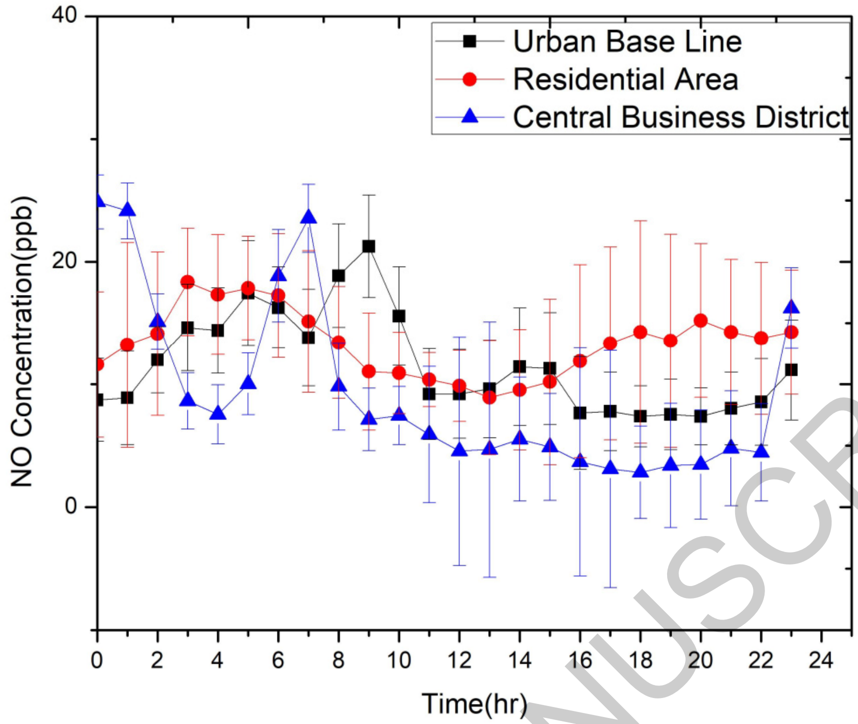
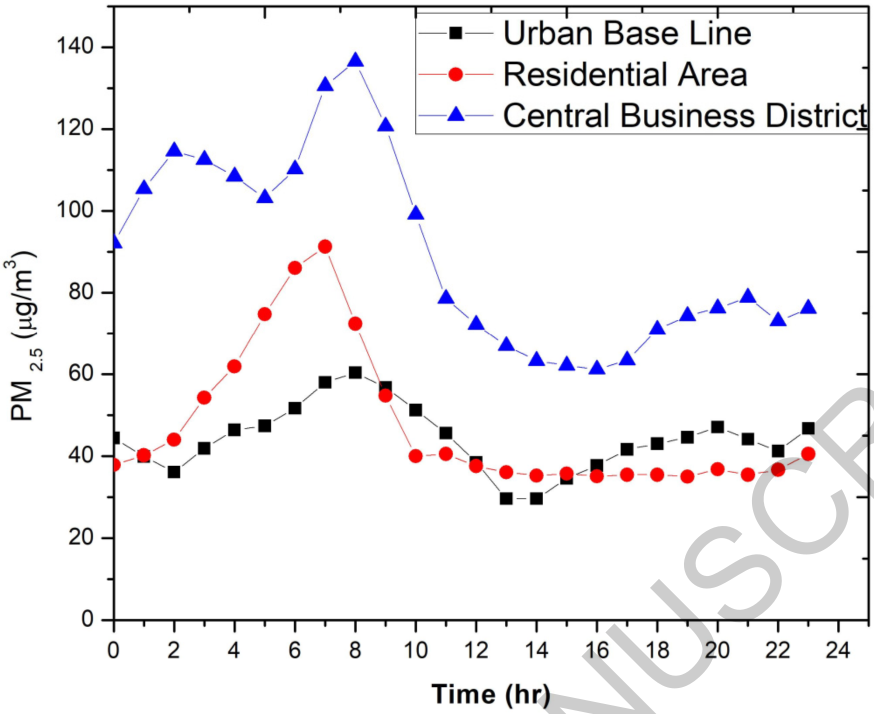

Urban Base Line
Residential Area
Central Business District
NO Concentration(ppb)
Time(hr)
40
20
0
0
2
4
6
8
10
12
14
16
18
20
22
24

Fig 13A



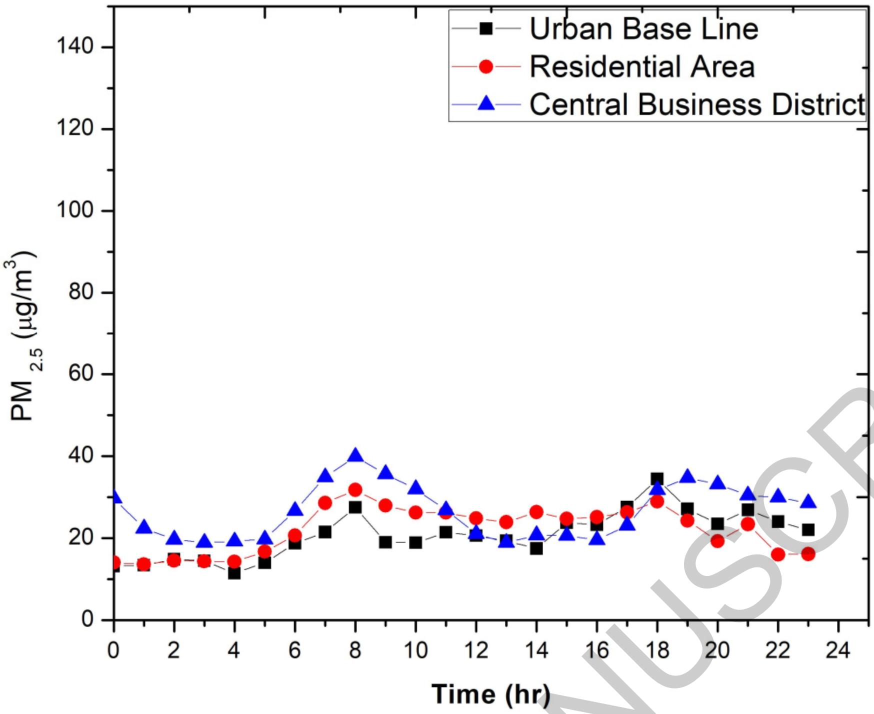
Urban Base Line
Residential Area
Central Business District
NO Concentration(ppb)
Time(hr)
40
20
0
0
2
4
6
8
10
12
14
16
18
20
22
24

Fig 13B



Urban Base Line
Residential Area
Central Business District
PM 2.5 (μg/m3)
Time (hr)
0
20
40
60
80
100
120
140
0
2
4
6
8
10
12
14
16
18
20
22
24

fig 14A



140
120
100
80
60
40
20
0
PM 2.5 (μg/m3)
0
2
4
6
8
10
12
14
16
18
20
22
24
Time (hr)
Urban Base Line
Residential Area
Central Business District

Fig 14B