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Study of particulate matters, heavy metals and gaseous pollutants at Gopalpur (23°29′52.67″ N, 87°23′46.08″E), a tropical industrial site in eastern India

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Abstract:*Air pollution has become an environmental problem of public concern worldwide. In the present study, the concentration of Particulate Matter (PM_{10}), Oxides of Sulphur (SO_x), Oxides of Nitrogen (NO_x) and Ozone(O_3) have been monitored from February 2013 to May 2013 over Gopalpur village in Durgapur situated at 23°29'52.67" N and 87°23'46.08"E. Meteorological parameters like temperature, humidity, wind speed and wind direction were also simultaneously recorded over the chosen site.Various statistical tools have been used for the analysis of the obtained result. The data obtained from the field work have been compared with the secondary data obtained from Durgapur Station of Central Pollution Control Board (CPCB). The temporal variations of the concentrations of PM_{10}, SO_X, NO_X and O_3 have been explored and their relationships with different meteorological parameters have been identified. Concentration of PM_{10} ranged from 53.803 to 271.325µg/m^3, with a mean value of 136.689± 54.873 µg/m^3,80% of the monitored data exceeded the National Ambient Air Quality Standards (NAAQS) for PM_{10} in the ambient atmosphere. The concentration of SO_X over the site is found to lie between 14.219µg/m^3 to 390.041µg/m^3, with a mean value of 104.601±103.860 µg/m^3 and 45 % of the total data exceeded the NAAQS for the concentration of SO_X in the ambient air. The recorded concentration of NO_X lies between 32.50 µg/m^3- 112.79 µg/m^3, with a mean value of 66.99± 21.63 µg/m^3 and 20% of the monitored data is found to exceed the NAAQS for NO_X in the atmosphere. Record of eight hour (08:00:00 – 16:00:00 h, Indian Standard Time) ground level ozone concentration shows that O_3 concentration gradually increases after sunrise (08:00:00 h) and reaches a high value during the noon (14:00:00 h – 15:00:00h). Detailed study shows that ozone has high positive correlation with temperature and high negative correlation with humidity. Atmospheric concentration of selected heavy metals including Lead (Pb), Copper (Cu), Manganese(Mn) and Cadmium (Cd) were also measured followed by the analysis of their probable sources. Wind rose has been constructed using WindRose PRO (Version 3.1.x). Industrial emission (Sponge Iron industries, Steel industries etc.), vehicular exhausts, open biomass burning, mining etc have been identified as the probable sources of the pollutants in the ambient atmosphere of Gopalpur.*

Keywords:*Air pollution, Heavy metals, Meteorological parameters, Oxides of Nitrogen, Oxides of Sulphur, Ozone, Particulate Matters*

I. Introduction

Air pollution has gained the attention of researchers all over the world. The epidemiological studies of effects of air pollution have demonstrated that the PM exposure and gaseous pollutants are associated with the occurrence of acute respiratory infections, lung cancer and chronic respiratory and cardiovascular diseases ([1] – [4]).Rapid industrialization and urbanization are the major causes of day to day increase in environmental pollution.Concern about air pollution in urban regions is receiving increasing importance world-wide, especially pollution by gaseous and particulate trace metals ([5] –[8]).Gaseous air pollutants like oxides of nitrogen (NO_x), oxides of sulphur (SO_x), tropospheric ozone (O_3) etc. pose serious risk to human health and environment due to their detrimental effects.

In recent years, in Asian countries like India and China, aerosol problems have received considerable attention because of rapid increase in vehicular emission and increasing energy demands for industrial and domestic use ([9]- [11]). Today, India is one of the first ten industrial countries of the world ([12]).Air pollution in India is mainly caused from three sources namely vehicles, industries and domestic sources. Worldwide systematic monitoring and analysis of the causes and effects of air pollution are being carried out on air pollution at different spatio- temporal scales ([13]). In India, various research works have been carried out at different spatio- temporal scale in urban and industrial areas like Burdwan, Kolkata, Delhi, Lucknow, Haryana, Chennai, Mumbai, Dhanbad-Jharia, Raniganj- Asansol etc. ([14]-22]). Elminir ([23]) focused on the dependence of urban air pollutants on meteorology by performing intensive measurements of particulate matter (PM_{10}) and gaseous materials (e.g., CO, NO_2, SO_2, and O_3) at 14 measurement sites distributed over the whole territory of Great Cairo.

Durgapur (Burdwan District) of West Bengal is one of the important industrial areas of the country. Durgapur is the 7th polluted city in India. Along with otherindustries, a cluster of sponge iron industries are situated in Gopalpur of Durgapur area. Air pollution is one of the biggest hazards of sponge iron plants which include particulate matters and gaseous pollutants (SO_X , NO_X etc) as pollutants. This affects the health of the people residing in the nearby areas. It also affects the livestock and forests which in turn affect the livelihood of the people dependent on these forests, agricultural yield, etc. The quality and quantity of agricultural produce has also been affected. The chosen site is 1 km away from the cluster of sponge iron industries and 1.5 km away from National Highway 34. Therefore, systematic monitoring and analysis of different air pollutants (PM including heavy metals, gaseous pollutants) and meteorological parameters might provide important insights into the atmospheric environment of the chosen area. Such a composite study has not yet taken place over this area.

The aim of the present study is to focus on the temporal variation of different pollutants (both particulate matters and gaseous pollutants) followed by the determination of the levels of heavy metals (Pd, Cu Mn & Cd) in the ambient environment of Gopalpur .This work attempts to explore the relationship among different meteorological parameters (temperature, humidity, wind speed and wind direction) and air pollutants (PM, SO_x, NO_x and Ozone).

II. Data and Methods

2.1. Study area

The sampling site, Gopalpur village in Durgapur, West Bengal is situated at 23°29′52.67″ N latitude and 87°23′46.08″E longitude as shown in Figure 1.It has an average elevation of 77m. This area is 60km away from Burdwan town and its distance is 1.5 km from the National Highway (NH-2). The chosen site is a rural location which approximately 1.5 km away from the cluster of sponge iron industries. This area is covered with Red and Yellow Ultisols soil, so industrialization is the prime objective in the region. The topography of this area is undulating. Excessive industrial work in this area has made the soil blackish, infertile and barren.

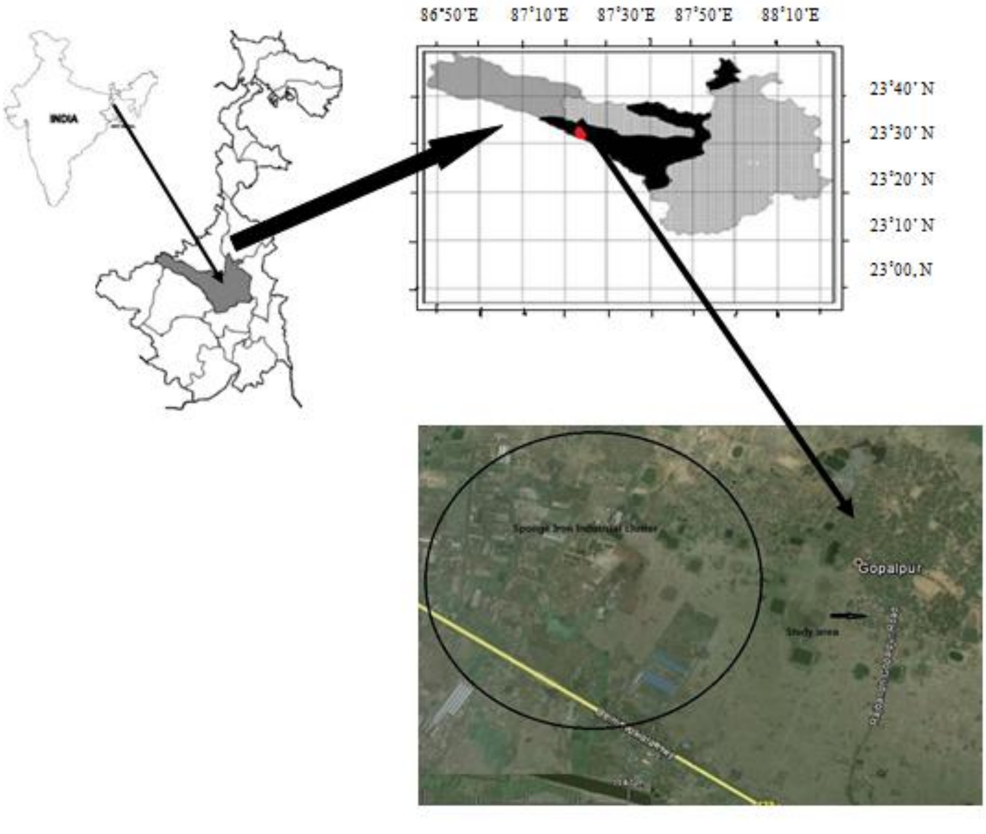


Fig. 1.location of sampling site

2.2. Meteorological background

Generally, Gopalpur (a part of Durgapur) experiences a somewhat transitional climate between the tropical wet and dry climate of Kolkata and the more humid subtropical climate further north. Summers are extremely hot, lasting from March to the middle of June followed by the monsoon season with heavy precipitation and somewhat lower temperatures. The monsoon is followed by a mild, dry winter from November to January. There is a short autumn at the end of October and a short spring in February, both of which have relatively moderate temperatures.

2.3. Measurement techniques

The concentration of Particulate Matters (PM_{10}) and gaseous pollutants (NO_x, $SO_x$and O_3) were measured (thrice a week) at the sampling site from February, 2013 to May, 2013. Meteorological parameters (temperature, humidity, wind speed and wind direction) were simultaneously recorded. The duration of sampling was from 08:00:00 h to 16:00:00h. The data was collected on the roof of a single stored building (about 11 feet height).

The concentration of PM_{10} was obtained with the aid of High Volume Sampler (Envirotech APM 460BL) from Enviriotech. Air is drawn through a size-selective inlet and through a 20.3×25.4cm filter at a flow rate which is typically 1132L/min. Particles with aerodynamic diameters less than a cut-point of the inlet is collected by the filter. The mass of these particles is determined by the difference in filter weights prior to and after sampling. The concentration of suspended particulate matter in the designated size range is calculated by dividing the weight gain of the filter by the volume of air sampled.

The digestion of the exposed filter papers was done in laboratory by using the chemical method proposed by Gharaibeh et al. ([24]).The levels of different heavy metals have been found by using Atomic Absorption Spectroscopy (AAS).In fact, AAS is the maintechnique used for the analysis of heavy metals in air samples, because of its selectivity, sensitivity, reproducibility, wide dynamic concentration range, and its low cost ([25]-[31]).

Oxides of Sulphur (SO_x) were measured by the High Volume Sampler (Envirotech APM 460BL). Ambient air was continuously drawn into 25ml of potassium tetrachloromercurate (TCM) solution at a flow rate of 1 lpm and estimation was done in the laboratory ([32]).

Oxides of Nitrogen (NO_x) were measured using the same High Volume Sampler (Envirotech APM 460BL). Ambient air was continuously drawn into 25ml of sodium hydroxide solution. The average flow rate of ambient air was 1 lpm and estimation was done in the laboratory ([33])

The concentration of O_3 was monitored with the help of an analyzer from aeroQUAL Series200. The measurement unit of this instrument is ppb/ppm. The low concentration ozone head 0.008 to 0.500ppm and high concentration ozone head 0.20 to 20.00ppm.The sampling interval of O_3 is 30 minutes.

Humidity and temperature were measured by a portable hygrometer (Model-HTC-1), wind speed was measured by a digital anemometer (Model-Lutron-AM-4201) and wind direction was recorded by a wind vane. The sampling interval for all the meteorological parameters is 30 minutes.

Windrose has been constructed with the monitored data (wind direction and wind speed) for the study period using software WindRose PRO (Version 3.1.x). The obtained data have been processed and analyzed by different statistical tools.

The data obtained from the sampling site were compared with the secondary data set collected from Central Pollution Control Board (CPCB, Durgapur Station).

2.4. Statistical Analysis

The primary data set was processed and analyzed by using different statistical tools for obtaining their range, mean etc.

Pearson Correlation Coefficient

Pearson Correlation Coefficient among different parameters was done using the formula

$$r = \frac{\sum_{i-1}^{x}(Xi - \bar{X})(Yi - \bar{Y})}{(n-1)SxSy}$$

where X and Y are the two variables with means $\bar{X}$ and $\bar{Y}$ respectively with standard deviation S_x and S_y.

III. Results and Discussion

3.1. Levels of PM_{10}, SO_x, NO_x and Ozone

The concentrations of PM_{10}, SO_X, NO_X and O_3 were monitored during the study period (February 2013-May 2013) over the site. The temporal variations of PM_{10}, SO_X and NO_X have been shown in Fig. 2. 80% of the monitored data exceeded the NAAQS for Particulate Matter PM_{10} [100 μg/m^3 for 8 hours monitoring]. The range of concentration of PM_{10} is found to be 53.803 - 271.325μg/m^3. Observation reveals 45 % of the total data exceeded the NAAQS for the concentration of SO_X in the ambient air and the range of concentration of SO_X

over the site is found to be 14.219µg/m^3 to 390.041µg/m^3. The concentration of NO_X lies between 32.50 µg/m^3-112.79 µg/m^3 and 20% of the observed data have exceeded the standard concentration of NO_X in the ambient air given by NAAQS.

Suspended particulate matter (SPM), respirable particulate matter (RPM), Oxides of sulphur and nitrogen and hydrocarbons, heavy metals, e.g., cadmium, lead, zinc, mercury, manganese, nickel and chromium are the major pollutants of Sponge iron industries ([34]). The chosen sampling site is present within 1 km distance from the cluster of sponge iron industries. The high value of PM_{10} over the site is likely to be associated with the nearby sponge iron industries. Besides the stationary sources (sponge iron industries), the mobile sources (vehicles) in nearby highway might have some contribution in the elevated PM_{10} concentration over the site. High values of NO_x and SO_x might be also associated with gaseous pollutants of the nearby coal based sponge iron industries. In addition to that, the occasional high concentration of SO_x might be also associated with local fossil fuel and biomass burning.

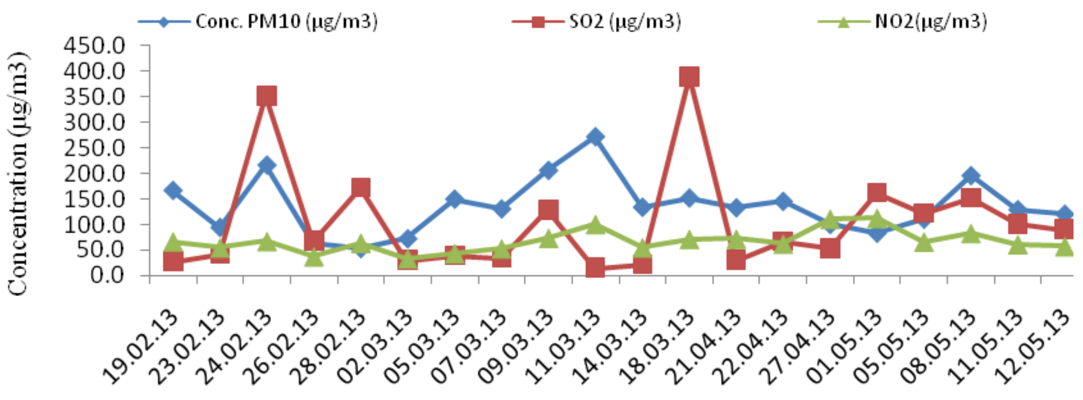


Fig. 2. temporal variation of concentration of PM_{10}, SO_x and NO_x over the site during the study period.

The gradual daytime increase of O_3 is mainly due to the photo-oxidation of industrial and anthropogenic hydrocarbons, carbon monoxide and methane in presence of sufficient amount of NO_x ([35-37]). The gradual increase of O_3 concentration with the onset of sunshine is due to its photochemical formation through the photolysis of NO_2 via the following set of reactions:

$$NO_2 + h\nu\ (\lambda < 420\ nm) \rightarrow NO + O \quad (1)$$

$$O + O_2 + M \rightarrow O_3 + M \quad (2)$$

where M is a third body like nitrogen or oxygen molecule that absorbs the excess amount of vibrational energy and eventually stabilizes the O_3 molecule thus formed which helps in this reaction.

The low concentration of ozone during the nighttime is due to the absence of photolysis of NO_2 and loss of O_3 by NO through the following titration reaction and surface deposition [(38]).

$$O_3 + NO \rightarrow NO_2 + O_2 \quad (3)$$

Minimum concentration of ozone at the onset of sunshine is also due to dry and wet deposition. Reactions (1), (2) and (3) show that NO_x can not only form but also consume ozone. Excessive amount of NO_x in the urban atmosphere is not beneficial for the accumulation of ground level ozone ([38]).

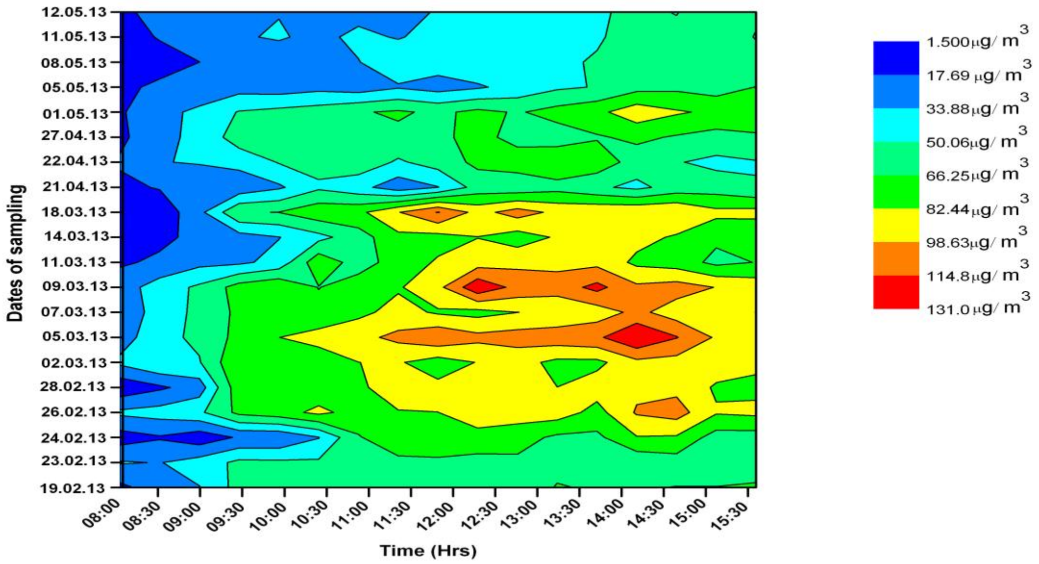


Fig. 3. Variation 0f Ozone concentration over the chosen site during the study period

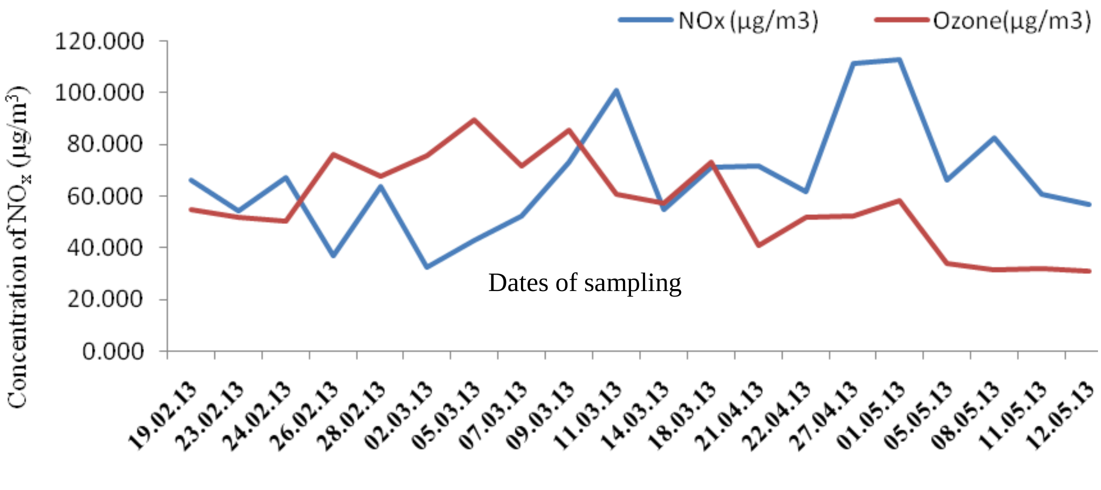


Fig. 4.variation of concentration of Ozone with NO_x over the site during the study period

3.2. Analysis of heavy metal concentration in PM_{10}

The temporal variation of four heavy metals (Pb, Cu, Mn and Cd) has been studied over the site during February 2013 to May 2013.Ambient concentration of selected heavy metals in the atmosphere of the sampling site has been shown in Fig. 5. Except Pb, all other heavy metals (Cu, Mn & Cd) have highest concentration in the month of May.Dry atmospheric conditions of the summer (May) can produce more particulate matters from soil and roads.

During the formation of coal, it incorporates impurities including sulphur and heavy metals from the surrounding soil and sediments. Pb, Mn and Cd are some of the hazardous air pollutants (heavy metals) emitted by coal- fueled industries ([39]).The impacts of these heavy metals are greatest near the source but can also influence the environment and the health far away from the source.Some of these impurities consists of Lead, Nickel, Mercury, Arsenic, Cadmium, Manganese etc. ([39]). Pb has residence time of up to 10 days in the atmosphere and can be transported at local as well as some regional scale. Mn influences the environmental quality at local and regional scale and has a residence time of several days in the atmosphere. Cd is likely to be transported to local, regional and global scale and residence time of 1 to 10 days in the atmosphere ([39]).The nearby sponge iron industries are coal-based, therefore they might have contribution in the increased concentration of heavy metals over the site. The presence of Cd over the site may be associated with industrial emission especially steel production units as large amount of Cd- plated steel scrap is recycled in these industries. Therefore, Steel plants in the Durgapur region might be one of the contributors of Cd which is eventually transported over the chosen site. In addition to this, open burning of municipal wastes containing Ni-Cd batteries and plastic containing Cd, vehicular emission etc may be the other sources of ambient Cd ([40]). The probable source of Pb over the site is the vehicular emission from the National Highway which is approximately 1.5 km away from the site.Cu is emitted in the environment from both natural (like wind-blown dust, decaying vegetation, forest fires and sea spray) and anthropogenic sources (mining, metal production, wood production and phosphate fertilizer production). Copper is often found near mines, industrial settings, landfills and waste disposals. So the nearby coal-mine belt of Raniganj and industrial setups of Durgapur region might be the probable sources of Cu in the atmosphere of Gopalpur.

The field data have been compared with the secondary data obtained from CPCB (Durgapur Station). The comparison of the concentration of PM_{10} has been shown in Fig**.** 10. Slightly higher values of PM_{10} concentration have been observed in field work in some occasions. The underlying cause might be the presence of the cluster of Sponge Iron industries in the vicinity of the site as pariculate matters (PM_{10}) are one of the major air pollutants of Sponge Iron industries ([34]). Infact, it is evident from the Windrose (Fig. 9) that wind direction is favourable for the transport of particulate matters (PM_{10}) from the source to the observational site. Apart from stationary sources, the mobile sources (vehicles) are also major contributors of PM ([41]). Mobile sources in the nearby National Highway and other surrounding roads might be the contributor for the occational elevated values of concentration of PM_{10} over the chosen site.

Table 2 shows the comparision of the concentration of SO_x and NO_x obtained from CPCB and field work. In most of the cases, it has been found that value of data obtained from field work is higher from that of CPCB data. Higher values of NO_x and SO_x over the observational site than that of data obtained from CPCB might be because of the presence of the Sponge Iron industries as they are the major emitters of Oxides of Sulphur and Oxides of Nitrogen ([34] and [42]).

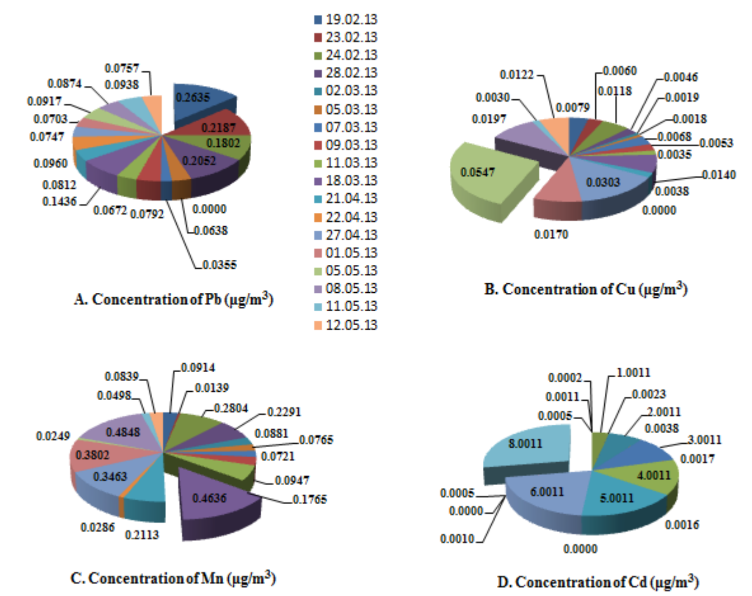


Fig. 5. Concentration of Pb, Cu, Mn and Cd during the study period over the chosen site

Role of meteorology

The importance of meteorological factors in the transport and diffusion stage of air pollution is well recognized. Meteorological factors such as wind speed, precipitation and mixing height, play important roles in determining the pollutant levels for a given rate of pollutant emission ([43] and [44]). It is observed that the concentration of PM_{10} is affected by the wind speed. Air turbulence is created partly by airflow near the ground and it affects the dispersion of pollutants near the ground. The variation of the concentration of PM_{10} with temperature and humidity is shown in Fig. 6.There is no significant correlation between temperature and concentration of PM_{10}. It is evident from the Fig. 6 that concentration of PM_{10} is inversely related to humidity. This inverse relationship might be due to the effect of humidity on coalescence and settling of suspended particles, where the atmospheric moisture helps the fine suspended particles to stick to each other and gradually settle down. Low level of humidity increases the lifetime of the particulate matter in the ambient air thereby resulting in higher concentration of PM_{10} in the atmosphere. Fig.7 shows the variation of concentration of PM_{10} with wind speed. It is found that wind speed has inverse relationship with concentration of PM_{10} in the ambient air. The greater the wind speed, the greater the turbulence and greater the dispersion of the pollutants near the ground ([45]).From the Windrose (Fig.9), it is seen that wind coming from the North-west is almost counter-balanced by the wind coming from the South- east direction. The wind coming from the south-west direction has the potential to transport the pollutants towards the study area. Therefore, high concentration of PM_{10} over the site might be associated with the transport of particulate matters from the nearby sponge iron industries which are located in the south-west direction of the study area. The vehicular emission from the National highway (which is only 1.5 km away from the site) might have some contribution in the elevated concentration of PM_{10} over the study area.

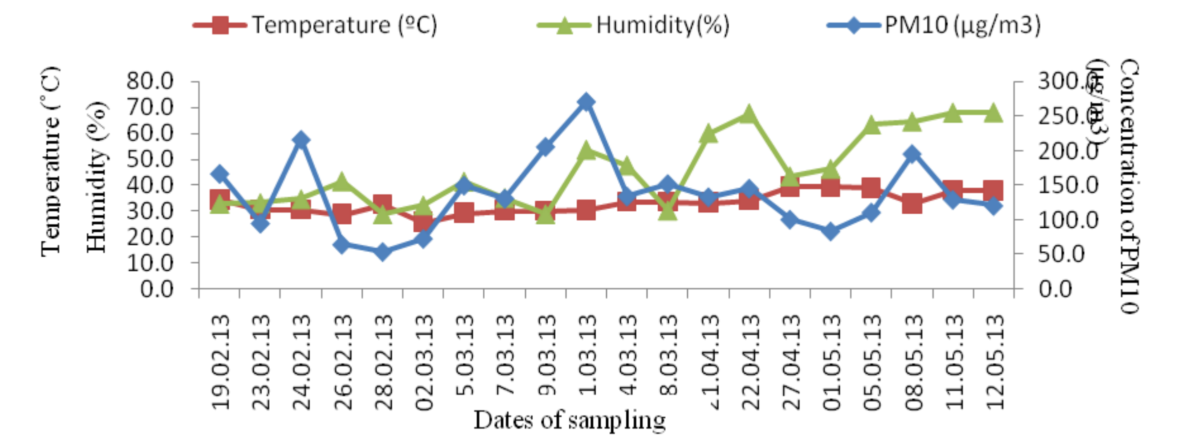


Fig. 6. variation of concentration of PM_{10} with temperature and humidity during the study period over the site.

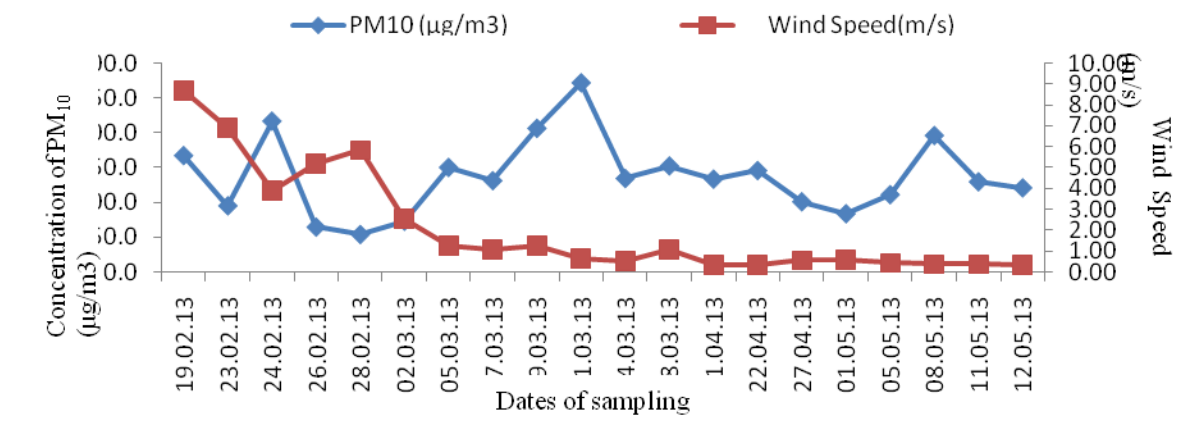


Fig. 7. variation of concentration of PM_{10} with wind speed during the study period over the site.

The influence of meteorological parameters like temperature and humidity on ozone has been studied during the study period (19.02.13 to 12.05.13). Fig.8 elucidates the variation of Ozone with temperature and humidity. The correlation coefficient between ozone and humidity is found to be highly negative and that of ozone and temperature is found to be highly positive. The values of this correlation coefficient are shown in Table 1. It is evident that O_3 concentration is directly correlated to temperature and is inversely proportional to humidity. Thus, in presence of high humidity and low temperature, O_3 production is kept minimum. The positive correlation between temperature and O_3 is due to the fact that radiation controls the temperature which in turn increases the photolysis efficiency. In presence of high humidity, the major photochemical paths for removal of O_3 are enhanced. As higher humidity levels are associated with large cloud cover and atmospheric instability, the photochemical process slows down and the surface O_3 is depleted by deposition on water droplets. Therefore, O_3 concentration has a strong dependence on humidity.

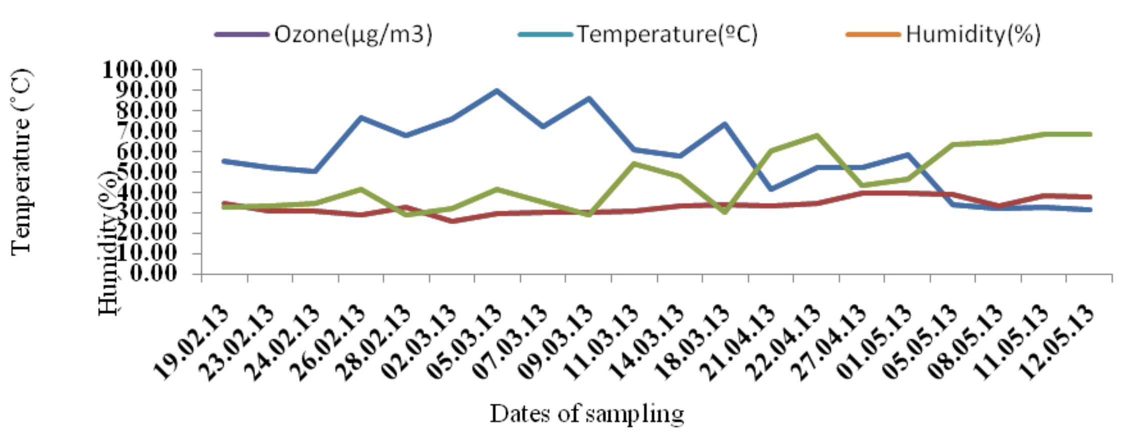


Fig. 8. variation of concentration of Ozone with temperature & humidity during the study period over the site

Table 1. Correlation of concentration of ozone with temperature and humidity.

Sl.No.	Date	Temperature & Ozone	Humidity & Ozone
01.	19.02.13	0.677	-0.939
02.	23.02.13	0.427	-0.810
03.	24.02.13	0.800	-0.951
04.	26.02.13	0.733	-0.823
05.	28.02.13	0.796	-0.895
06.	02.03.13	0.706	-0.682
07.	05.03.13	0.824	-0.738
08.	07.03.13	0.867	-0.850
09.	09.03.13	0.925	-0.925
10.	11.03.13	0.802	-0.713
11.	14.03.13	0.956	-0.877
12.	18.03.13	0.899	-0.813
13.	21.04.13	0.786	-0.811
14.	22.04.13	0.828	-0.790
15.	27.04.13	0.802	-0.935
16.	01.05.13	0.923	-0.929
17.	05.05.13	0.858	-0.885
18.	08.05.13	0.853	-0.674
19.	11.05.13	0.894	-0.933
20.	12.05.13	0.779	-0.877

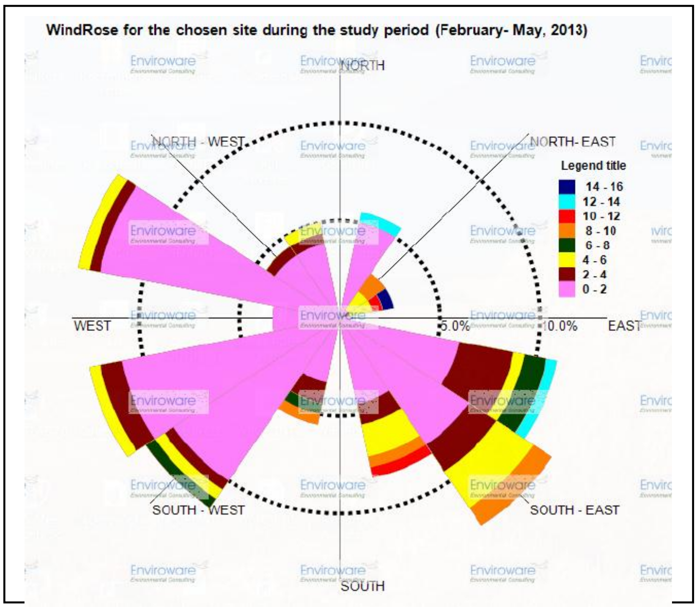


Fig. 9.windrose over the sampling site during the study period

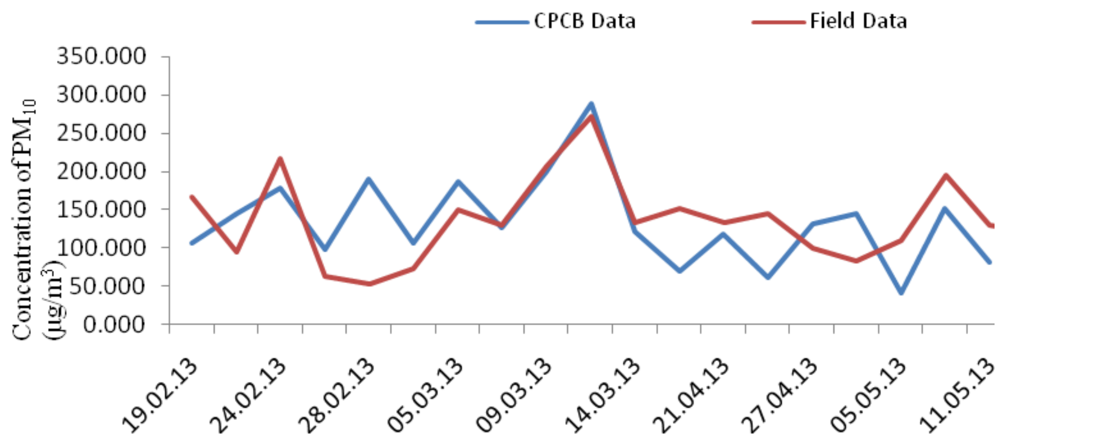
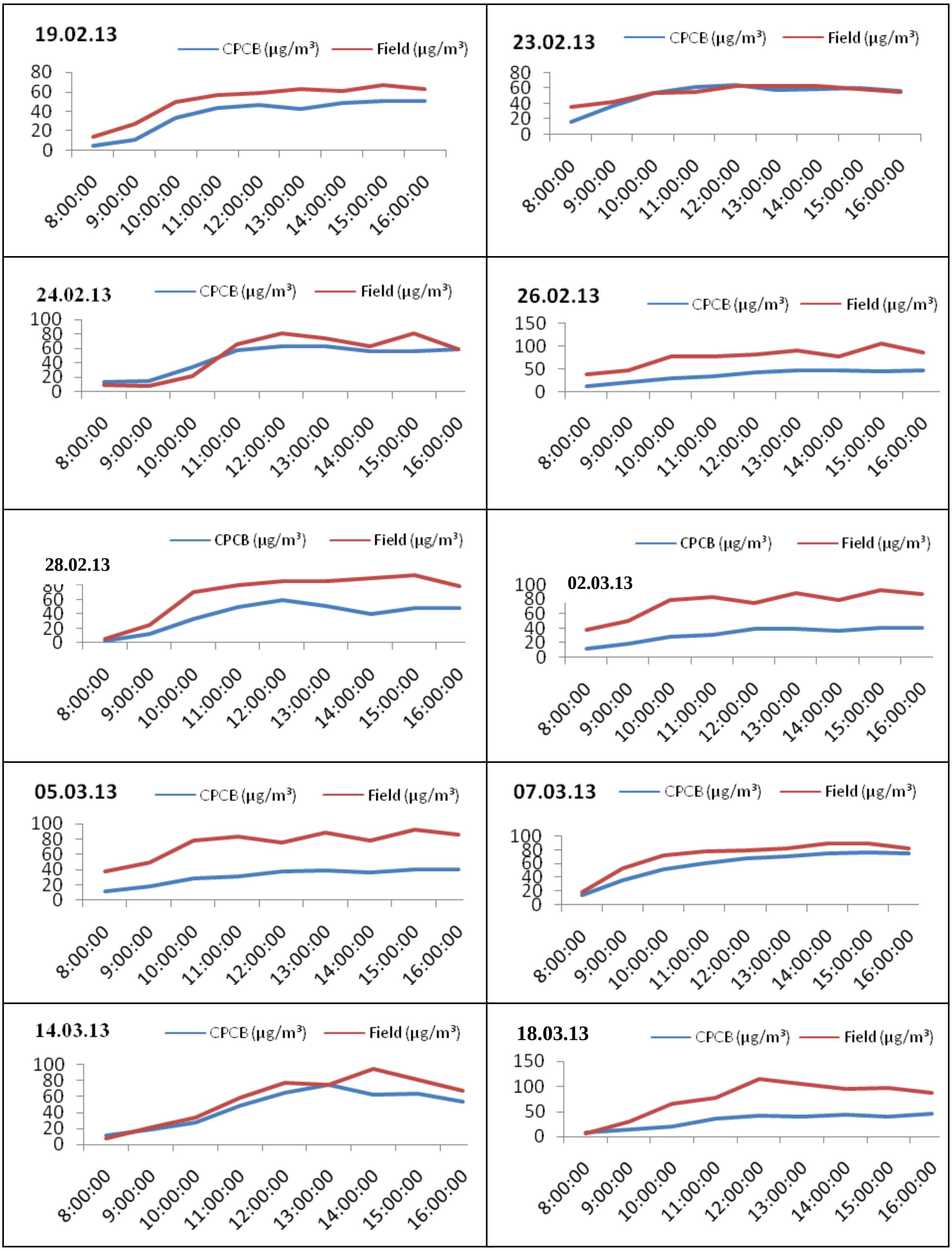


Fig. 10. Comparison of concentration of PM_{10} data obtained from CPCB (Durgapur Station) and field work.

Table 2.comparison of concentration of $SO_x$and NO_x

Date	Concentration of SO_x ($\mu g/m^3$)		Concentration of NO_x ($\mu g/m^3$)	
	CPCB Data	Field data	CPCB Data	Field Data
19.02.13	16.064	27.375	61.844	66.359
23.02.13	20.358	40.703	49.299	54.173
24.02.13	43.934	352.346	59.983	67.030
26.02.13	24.168	67.819	61.382	36.838
28.02.13	36.856	171.661	166.074	63.563
02.03.13	14.113	30.085	186.399	32.504
05.03.13	30.238	38.933	123.668	43.146
07.03.13	27.471	34.009	90.578	52.391
09.03.13	56.123	128.362	92.632	73.169
11.03.13	64.213	14.219	85.358	100.673
14.03.13	52.109	20.990	47.552	54.592
18.03.13	44.743	390.041	34.596	71.286
21.04.13	22.510	29.731	20.438	71.626
22.04.13	43.263	66.718	28.050	61.748
27.04.13	46.137	53.091	12.792	111.230
01.05.13	24.746	161.396	17.849	112.793
05.05.13	12.280	122.109	13.757	65.959
08.05.13	43.287	151.309	15.677	82.710
11.05.13	61.259	100.873	141.956	60.962
12.05.13	33.880	90.255	183.850	56.964


19.02.13
CPCB (µg/m³)
Field (µg/m³)
23.02.13
CPCB (µg/m³)
Field (µg/m³)
24.02.13
CPCB (µg/m³)
Field (µg/m³)
26.02.13
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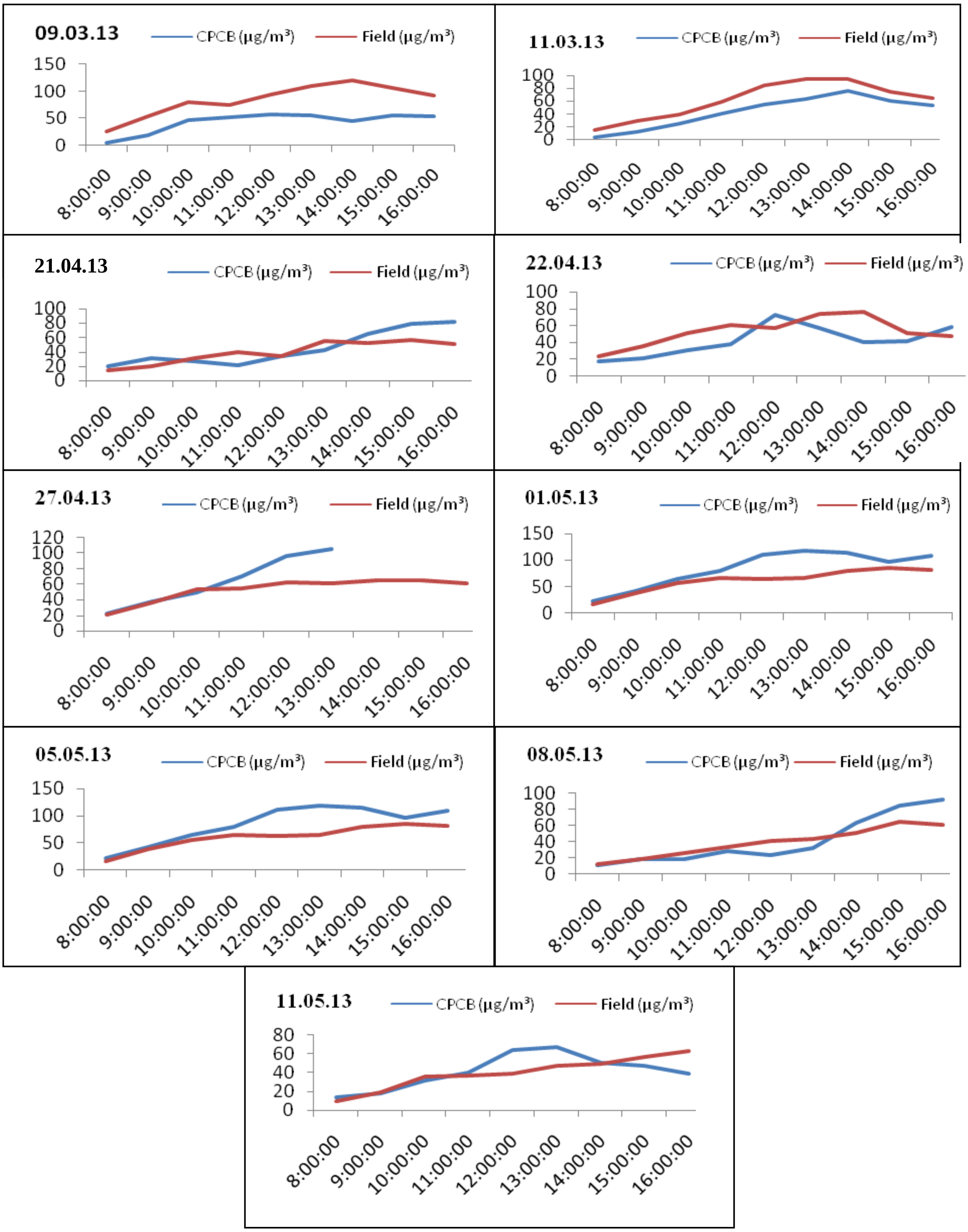

Fig.11. Comparison of concentration of hourly ozone concentration (08:00:00 hr – 16:00:00 hr) obtained from CPCB (Durgapur Station) and field work at the chosen site.

IV. Conclusion

The present study describes the temporal variation of the concentration of PM_{10}, gaseous pollutants (Ozone, Oxides of sulphur and Oxides of nitrogen) and different meteorological parameters (temperature, humidity, wind direction and wind speed). Following conclusions can be drawn from this observation:

- Elevated levels of PM_{10} has been recorded over the study area, where about 80% of the total data exceeded the concentration of PM_{10} in the ambient atmosphere by NAAQS [100 μg/m^3 for 8 hours monitoring].Temporal variation ofselected heavy metals including lead(Pb), copper (Cu), manganese(Mn) and cadmium (Cd) have been studied .
- Day to day variation of SO_X over the site has shown that 45 % of the total data exceeded the NAAQS for the concentration of SO_X in the ambient air. Observation of the concentration of NO_X over the study area has shown occasional high levels (20% of the observed data have exceeded the standard concentration of NO_X in the ambient air given by NAAQS).
- Measurement of eight hour averaged (08:00:00 – 16:00:00 h, Indian Standard Time) ground level ozone concentration has revealed that ozone levels are high in the month of March & April.
- The meteorological parameters like temperature, humidity, wind speed and wind direction show significant influence on the concentration of PM_{10}, SO_X , NO_X and O_3.
- Comparison of the data obtained from field work with the secondary data obtained from CPCB has shown that values of Field data are higher than CPCB data in most of the cases.
- The probable sources of the elevated concentrations of PM_{10}, SOx, NOx, Ozone are Industrial emission (Sponge Iron industries, Steel industries etc.), vehicular exhausts, open biomass burning, mining etc.

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