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AMBIENT AIR QUALITY IN AND AROUND SPONGE IRON INDUSTRIAL CLUSTERS IN SUNDARGARH DISTRICT OF ODISHA, INDIA

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ABSTRACT

The ambient air quality of sponge iron industries located in four distinct clusters in Sundargarh district of Odisha, India (i.e., Kuarmunda, Kalunga, Rajgangpur and Bonaigarh clusters having 12, 13, 7 and 12 numbers of industries and a cumulative capacity of sponge iron production of 2075, 2450, 1500 and 1700 TPD respectively) were assessed in the present work to judge the impact of various sponge iron plants operating in the area. For the purpose, monitoring of stack and ambient air quality inside the five industries in each industrial cluster and ambient air quality within a radius of 2.0 kms around the four industrial clusters (in East, West, North and South directions) was carried out every week with a frequency of two samples per week in three seasons (i.e. during rainy, winter and summer) during 2010 – 11 for a year following the guidelines of Central Pollution Control Board. The results suggest that all the industrial clusters have exceeded the permissible limit with respect to the particulate matter and NO_2 emission from the stacks (PM: ≥ 106.07 and NO_2: ≥96.47 against standard of 100 µg/Nm^3 and 80 µg/m^3 respectively). The particulate pollutants (SPM and RPM) inside and outside the plants in all the clusters were also found to be exceeded their respective standards (SPM: ≥ 891.23 and RPM: ≥284.40 and SPM: ≥ 322.77 and RPM: ≥138.31 against standard of 360 and 120 µg/m^3 and 140 and 60 µg/m^3 inside and outside the plants respectively), but the gaseous pollutants (SO_2 and NO_2) were marginally under the permissible standards. Also evident from the Air Pollution Index (API), all the clusters both inside (API: ≥148.14) and outside (API: ≥ 128.65) the plants suffered from Severe Air Pollution (SAP) situation. Hence, immediate implementation of corrective measures along with massive plantation in and around the sponge iron industrial clusters is the urgent need of the hour.

KEY WORDS : Ambient air quality, Particulate matter, Gaseous pollutant, Stack monitoring, sponge iron plants

INTRODUCTION

Air, being a basic amenity of life has been under severe stress over the decades due to rapid growth of industrialization, urbanization, motorization and above all population (Chauhan and Pawar, 2010). Among the various agents responsible for the pollution of the air, industries are by far most conspicuous (Panda and Panda, 2012). Industrial activities discharge a variety of particulate and gaseous pollutants (both primary and secondary) from various operating units, depending on the nature of the industry and raw materials concerned. Further, the nature of wastes is contingent upon the industrial processes in which these originate (Mahajan, 1985).

The extent of the air pollution problem and the impact that industrial activities creates in the developing countries, are far higher than those in the developed countries. The developing nations in their pursuit of better economic growth and competitiveness in the global market tend to set up industries that employ cheaper technologies and are not stringently adhered to emission norms even at the cost of human health and well being, surrounding natural resources as well as environment (Hegerl *et al.,* 2007).

Air pollutants, when released to the surroundings, pose serious threats to the different life forms and other segments of the environment (Hippeli and Elstner, 1993). The particulate and gaseous pollutants are not only responsible directly or indirectly for altering the primary composition of the atmosphere (Singh and Agarwal, 2005), but also recognized as one of the major threats to human health in the modern times (Pascal *et al.*. 2013). According to estimates of the World Health Organization (WHO, 2016), ninety two percent of the world's population lives in areas exposed to air quality that exceeds WHO standards, leading to considerable morbidity and mortality.

Today, India occupies the seventh place in industrialization among the developing countries of the world and iron and steel industries are one among the several rapid growing industrial sectors in India (Alvi *et al.,* 2013). The modern method of iron extraction is either through blast furnace route or though sponge route. Steel production through blast furnace route involves huge investment and large scale operation (Collins, 2014). Therefore production of steel through sponge iron or directly reduced iron (DRI) route is nowadays gaining importance in India. India is the largest producer of sponge iron in the world and 30% of the world's sponge iron comes from India (Swar, 2009). Of the total sponge iron plants in India, about 80% are coal based (CPCB, 2007) and therefore air pollution due to these industries has become a common feature in the country (CSE, 2011).

In India, Odisha has vast reserves of coal and iron ore (Ghose and Majee, 2007). Therefore, there are approximately 115 sponge iron plants operating at present in Odisha out of which forty-six are in Sundargarh districts (Patra *et al.,* 2012). Sundargarh district has become a favorite destination due to its strategic location, available infrastructure like railways and highways, existing steel business network, location-wise equidistant from raw material source of coal and iron ore. The sponge iron plants operating in the district of Sundargarh are mostly installed in four clusters. Establishment of sponge iron plants in clusters has added the pollution problem in the area to many folds.

Sponge iron manufacturing process is considered as resource intensive unit and basically involves in reduction of iron ore in a rotary kiln, where iron ore (especially hematite), coal (non-coking) and dolomite (of very small fraction) are used as raw materials (CPCB, 2007). The process involved for the production of sponge iron is the removal of oxygen from iron ore. During this process, the oxygen exits from the ore body and create micro-pores which resemble a honeycomb structure looking spongy in texture, hence the name sponge iron. Coal plays a dual role in the process by acting as a reductant as well as a fuel for providing heat to maintain the requisite temperature inside the kiln (Swar, 2009).

The sponge iron manufacturing process is potentially air polluting in nature. Emission of flue gas from the rotary kiln is the prime source of air pollution, where particulate matter (i.e. dust) is predominant pollutant. Besides the above, dust pollution is generated in fugitive form at various intermediate stages of the process. As a consequence, these industries releases particulate pollutants (like SPM, RPM) and gaseous pollutants (like SO_2, NO_2, O_3, CO, VOCs, dioxins, certain toxic air pollutants, some gaseous forms of metals) to the atmosphere at thick and large (Sasi, 2013; Pathak, 2020) and pose high burden of diseases in human beings particularly affecting the respiratory system and showing acute and chronic symptoms like dyspnoea, cough, phlegm, wheezing, bronchitis asthma etc (Pascal *et al.,* 2013; Kumar, 2014; Chattopadhyay *et al.,* 2015).

For the above reasons, there is a statutory norm that involves the source reduction of pollutants emission into the atmosphere by the industries through adoption of various methods and installation of different devices. Even so, a periodic analysis remains an important aspect to understand the operational defects and get an insight into the ambient air quality of the area (Tiwari *et al.,* 2016).

Based on the above backdrop, a work was envisaged to study the ambient air quality in and around the four sponge iron industrial clusters in Sundargarh district of Odisha, India through the measurements of stack emission and gaseous pollutants inside the sponge iron plants and ambient air quality around the sponge iron industrial clusters.

MATERIALS AND METHODS

Study site

The study site is located in the sponge iron industrial setup of Sundargarh district in Odisha, India. It encompasses 46 sponge iron industries. These industries are situated in 4 clusters namely Kuarmunda, Kalunga, Rajgangpur and Bonaigarh having 12, 13, 7 and 12 numbers of industries respectively. Two industries are however positioned outside these clusters. The cumulative capacity of sponge iron production is 2075, 2450, 1500 and 1700 TPD in Kuarmunda, Kalunga, Rajgangpur and Bonaigarh clusters respectively. The Kuarmunda cluster is located within the coordinates 22^0 16′ N and 84^0 46′ E, whereas Kalunga Rajgangpur and Bonaigarh clusters are located within the coordinates 22^0 12′ N and 84^0 44′ E, 22^0 11′ N and 84^0 35′ E, and 21^0 49′ N and 84^0 57′ E respectively.

Sampling Stations and Sampling Frequency

Air quality assessment was carried out through stack monitoring inside the five industries in each industrial cluster. In addition to stack monitoring, the ambient air quality was analyzed inside these five industries in each industrial cluster. Besides the inside plants, the ambient air quality analysis was also carried out within a radius of 2.0kms around the four industrial clusters in all directions (East, West, North and South). The air quality monitoring stations around the clusters (but outside the plants) were fixed following the guidelines of Central Pollution Control Board (CPCB, 2011). The stack as well as ambient air quality analysis was carried out every week with a frequency of two samples per week in three seasons (i.e. during rainy, winter and summer) during 2010 – 11 for a year.

Analysis of Air Quality Parameters and Air Quality Index

Stack Monitoring: The stack monitoring was conducted using the Vayubodhan Stack Sampling kit for particulate matter and gaseous concentration in the flue gas under an isokinetic condition after initial calculation for nozzle size, temperature, pressure. The thimble was kept in the filter holder followed by the respective absorbing reagents of gases in gas holder. The sampling was carried out for one hour following the insertion of the assembled sampling train in the pre-identified sampling duct. After an hour, the thimble was oven dried and the collected particulate was determined gravimetrically and expressed in µg/Nm^3, whereas the gaseous concentrations (SO_2 and NO_2) were determined spectrophotometrically as per the standard procedure of Vayubodhan manual and both the values were expressed in µg/m^3

Ambient Air Quality (AAQ): The ambient air quality inside and outside the plants of industrial clusters in respect of particulate matter and gaseous pollutants were carried out using a high volume sampler for 24 hours (8 hours x 3 no. of samples). The particulate pollutants (SPM and RPM) were determined gravimetrically taking the initial and final weights of the filter papers and beakers respectively (CPCB, 2001) and the values were expressed in µg/m^3. SO_2 and NO_2 were determined by West and Gaeke technique and Modified Jacob and Hoechhiser method respectively and the values were expressed in µg/m^3.

Air Pollution Index (API): The Air Pollution Index (API) of the ambient air quality inside and outside the plants of the four clusters in Sundargarh district during the period under report was calculated as per the formula of Ziauddin and Siddiqui (2006) given below:

$$\text{Air Pollution Index (API)} = \frac{1}{4}\left(\frac{IPM10}{SPM10} + \frac{IPM2.5}{SPM2.5} + \frac{ISO2}{SSO2} + \frac{INO2}{SNO2}\right) \times 100$$

Where,

IPM_{10}, $IPM_{2.5}$, ISO_2 and INO_2 = Individual values of PM_{10}, $PM_{2.5}$, SO_2 and NO_2 obtained after sampling and analysis,

SPM_{10}, $SPM_{2.5}$, SSO_2 and SNO_2 = Standards as AAQ as prescribed by CPCB

RESULTS

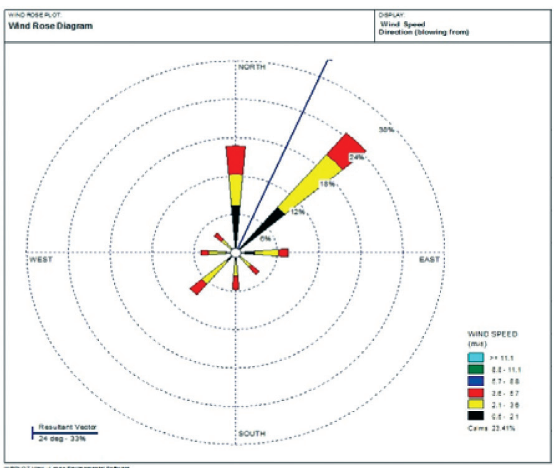
Ambient air quality of an area is largely dependent on the wind speed direction since the wind properties direct the pollutant dispersal. Figure 1 (a – d) presents the seasonal and annual windrose of the industrial clusters in Sundargarh district during 2010 – 11. It is clearly visible from the windrose that, on most occasions the wind blew either from North-East or the South-West direction. Hence, it was presumed that the areas located to the opposite direction (i.e. north and south) were more likely to be affected due to the pollutant concentration.

Stack Monitoring

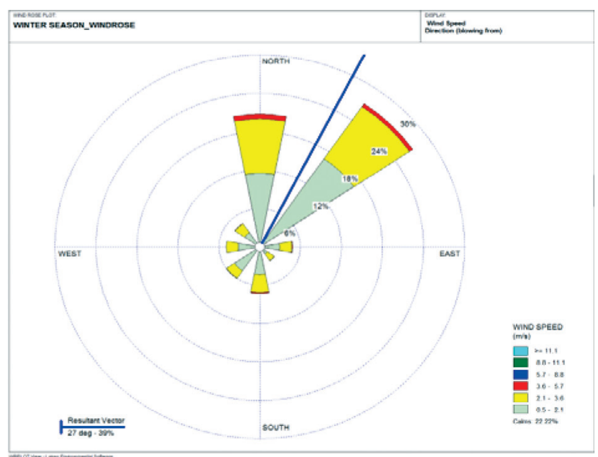
The stack monitoring results for various pollutants inside the plants of four sponge iron industrial clusters of Sundargarh district during 2010 - 11 have been presented in Table 1. It is evident from the table that the values of particulate matter in Kuarmunda cluster ranged from 82 – 115 µg/Nm^3 in rainy season, whereas in the winter and summer season, it ranged from 117 – 162 and 100 – 139 µg/Nm^3, respectively. Similarly, the gaseous pollutants (SO_2 and NO_2) in this cluster respectively ranged from 58 – 72 and 84 – 91 µg/m^3 in the rainy season, 79 – 94 and 99 – 112 µg/m^3 in the winter season and 65 – 83 and 91 – 102 µg/m^3 in the summer season. However, irrespective of the seasons, the concentrations of particulate matter, SO_2 and NO_2 were found to be 118.27 µg/Nm^3, 75.13 µg/m^3 and 96.47 µg/m^3 respectively (Table 1).

In the Kalunga cluster, the particulate matter, SO_2 and NO_2 ranged from 90 – 129 µg/Nm^3, 62 - 71 µg/m^3 and 82 - 93 µg/m^3 in the rainy season respectively, while that in the winter season, the same ranged from 122 – 178 µg/Nm^3, 78 - 99 µg/m^3 and 101 – 119 µg/m^3 respectively. The summer season witnessed the values of particulate matter, SO_2 and NO_2 in the range of 105 – 142 µg/Nm^3, 71 - 86 µg/m^3 and 90 – 109 µg/m^3 respectively. The concentrations of particulate matter, SO_2 and NO_2, irrespective of seasons came to be 127.33 µg/Nm^3, 79.80 µg/m^3 and 100 µg/m^3, respectively (Table 1).

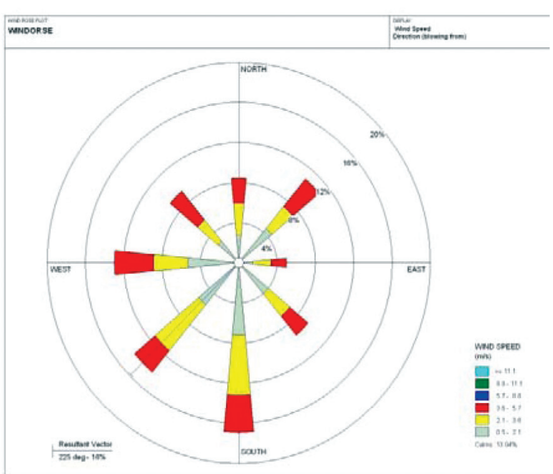
In the Rajgangpur cluster, the particulate matter ranged from 83 - 193 µg/Nm^3 in the rainy season, 119 – 265 µg/Nm^3 in the winter season and 98 – 223 µg/Nm^3 in the summer season. While the SO_2 concentration in the same cluster varied from 62 - 71, 88 - 97 and 76 – 83 µg/m^3 and NO_2 concentration varied from 80 - 94, 93 - 116 and 83 – 106 µg/m^3 in the rainy, winter and summer seasons respectively. However, irrespective of the seasons, the concentrations of particulate matter, SO_2 and NO_2 were found to be 145.40 µg/Nm^3, 79.40 µg/m^3 and 96.53 µg/m^3, respectively (Table 1).



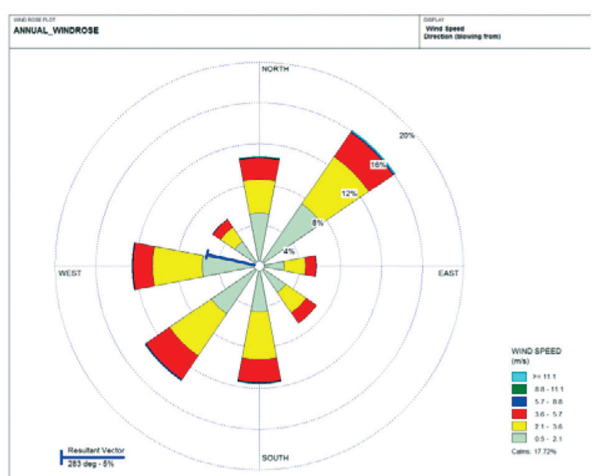
a. Monsoon



b. Winter



c. Post-monsoon



d. Annual

Fig. 1 (a – d). Seasonal and annual Windrose of Sundargarh district during 2010 - 11

The Bonaigarh cluster similarly witnessed the particulate matter concentration in the range of 71 - 98, 114 - 142 and 100 – 121 µg/Nm³ in rainy, winter and summer seasons respectively, while that of the SO_2 and NO_2 concentrations ranged from 62 - 72 and 80 – 99 µg/m³ in rainy, 79 – 98 and 103 – 124 µg/m³ in winter and 69 – 90 and 95 – 111 µg/m³ in the summer seasons respectively. However, irrespective

Table 1. Stack monitoring results for various pollutants inside the plants of four sponge iron industrial clusters of Sundargarh district during 2010 - 11

Seasons	PM (µg/Nm³)		SO_2 (µg/m³)		NO_2 (µg/m³)	
	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD
			Kuarmunda			
Rainy	82 - 115	99.0 ± 14.64	58 - 72	64.8 ± 5.40	84 - 91	87.6 ± 2.70
Winter	117 - 162	138.4 ± 21.31	79 - 94	86.2 ± 6.38	99 - 112	105.8 ± 5.54
Summer	100 - 139	117.4 ± 17.50	65 - 83	74.4 ± 6.91	91 - 102	96.0 ± 4.0
Average	82 - 162	118.27 ± 19.71	58 – 94	75.13 ± 10.72	84 - 112	96.47 ± 9.11
			Kalunga			
Rainy	90 - 129	107.6 ± 15.47	62 - 71	67.0 ± 3.67	83 - 93	89.4 ± 4.62
Winter	122 - 178	148.8 ± 21.44	78 - 99	92.6 ± 8.73	101 -119	111.6 ± 7.44
Summer	105 - 142	125.6 ± 14.17	71 - 86	79.8 ± 5.50	90 - 109	99.0 ± 8.15
Average	90 - 178	127.33 ± 20.65	62 - 99	79.80 ± 12.80	83 - 119	100.00 ± 11.13
			Rajgangpur			
Rainy	83 - 193	122.6 ± 52.45	62 - 71	65.8 ± 3.35	80 - 94	86.8 ± 5.89
Winter	119 - 265	169.6 ± 62.78	88 - 97	92.8 ± 3.42	93 - 116	105.4 ± 9.07
Summer	98 - 223	144.0 ± 56.95	76 - 83	79.6 ± 3.05	83 - 106	97.4 ± 10.11
Average	83 - 265	145.40 ± 23.53	62 - 97	79.40 ± 13.50	80 - 116	96.53 ± 9.33
			Bonaigarh			
Rainy	71 - 98	85.2 ± 9.73	62 - 72	66.8 ± 3.56	80 - 99	92.2 ± 7.60
Winter	114 - 142	126.8 ± 12.07	79 - 98	88.2 ± 6.98	103 - 124	111.6 ± 8.17
Summer	100 - 121	106.2 ± 8.47	69 - 90	77.6 ± 8.62	95 - 111	102.2 ± 5.72
Average	71 - 142	106.07 ± 20.80	62 - 98	77.53 ± 10.70	80 - 124	102.00 ± 9.70

Table 2. AAQ results of various air pollutants inside the plants of different industrial clusters of Sundargarh district during 2010 -11 (all values are presented in µg/m³)

Seasons	SPM		RPM		SO_2		NO_2	
	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD
				Kuarmunda				
Rainy	806 - 1121	993.4 ± 123.20	287 - 396	329.2 ± 41.48	55 - 63	59.0 ± 3.39	73 - 81	77.2 ± 3.56
Winter	867 - 1352	1141.4 ± 186.84	297 - 409	346.8 ± 44.49	59 - 71	64.4 ± 4.77	72 - 83	79.2 ± 4.55
Summer	814 - 1192	1046.0 ± 153.19	291 - 461	364.4 ± 61.12	54 - 69	62.4 ± 5.55	69 - 85	80.6 ± 6.58
Average	806 - 1352	1060.27 ± 75.62	287 - 461	346.80 ± 17.60	54 - 71	61.93 ± 2.73	69 - 85	79.00 ± 1.71
				Kalunga				
Rainy	654 - 1035	921.4 ± 151.9	245 - 354	310.0 ± 39.84	56 - 67	61.2 ± 5.36	70 - 89	80.2 ± 7.05
Winter	764 - 1467	1130.8 ± 249.51	301 - 425	370.2 ± 52.46	61 - 73	66.2 ± 4.38	75 - 91	85.0 ± 6.44
Summer	693 - 1198	1016.2 ± 189.86	298 - 376	345.8 ± 33.04	54 - 71	64.0 ± 6.44	69 -93	82.8 ± 9.18
Average	654 – 1467	1022.80 ± 104.86	245 – 425	342.00 ± 30.28	54 – 73	63.80 ± 2.51	69 - 93	82.67 ± 2.40
				Rajgangpur				
Rainy	605 - 987	824.6 ± 139.92	176 - 305	265.2 ± 53.89	31 - 57	47.6 ± 9.94	46 - 73	66.4 ± 11.44
Winter	688 - 1162	959.6 ± 172.05	212 - 354	299.2 ± 52.64	41 - 60	52.6 ± 7.23	53 - 83	72.2 ± 11.43
Summer	672 - 1092	889.2 ± 149.25	201 - 341	288.8 ± 53.78	38 - 63	52.4 ± 9.45	55 - 78	71.2 ± 9.42
Average	605 – 1162	891.13 ± 67.52	176 – 354	284.40 ± 17.42	31 – 63	50.81 ± 2.83	46 - 83	69.93 ± 3.10
				Bonaigarh				
Rainy	591 - 1154	840.2 ± 237.07	179 - 415	290.6 ± 109.87	34 - 65	48.0 ± 15.18	51 - 89	67.6 ± 18.89
Winter	774 - 1551	1149.4 ± 365.41	215 - 513	353.2 ± 146.38	40 - 75	54.0 ± 18.28	63 - 83	71.8 ± 9.20
Summer	715 - 1083	915.6 ± 167.66	214 - 451	328.2 ± 111.35	41 - 69	52.6 ± 14.10	52 - 83	68.8 ± 12.72
Average	591 - 1551	1149.40 ± 365.41	179 – 513	353.20 ± 146.38	34 – 75	54.00 ± 18.28	51 - 89	71.80 ± 9.20

Table 3. Seasonal variation of Suspended Particulate Matter (SPM) in µg/m³ outside the plants of different industrial clusters of Sundargarh district during 2010 -11

Seasons	East		West		North		South	
	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD
				Kuarmunda				
Rainy	340.66 - 487.32	405.56 ± 61.71	399.62 - 504.77	451.65 ± 49.12	310.14 - 433.22	372.30 ± 50.82	411.21 - 524.35	470.69 ± 49.37
Winter	402.15 - 543.27	469.63 ± 61.60	506.78 - 617.18	563.65 ± 48.85	440.16 - 522.89	481.09 ± 36.52	560.12 - 643.56	597.40 ± 35.55
Summer	412.23 - 505.24	468.96 ± 40.96	451.89 - 542.18	499.24 ± 38.67	440.12 - 500.19	470.33 ± 25.55	483.22 - 578.16	523.82 ± 41.47
Average	340.66 – 543.27	448.05 ± 36.80	399.62 – 617.18	504.85 ± 56.21	310.14 – 522.89	441.24 ± 59.94	411.21 – 643.56	530.64 ± 63.63
				Kalunga				
Rainy	322.76 - 432.55	385.80 ± 47.95	364.22 - 463.87	417.99 ± 43.56	307.22 - 401.23	361.68 ± 40.71	404.22 - 480.98	441.98 ± 34.58
Winter	398.66 - 487.63	439.07 ± 39.20	398.12 - 500.12	445.57 ± 45.30	362.11 - 441.35	399.07 ± 33.71	477.27 - 532.17	503.20 ± 23.98
Summer	364.10 - 455.68	401.94 ± 39.41	320.03 - 430.22	377.69 ± 47.52	382.23 - 476.33	422.95 ± 41.10	300.22 - 397.34	349.05 ± 43.24
Average	322.76 – 487.63	408.94 ± 27.31	320.23 – 500.12	413.75 ± 34.14	307.22 – 476.33	394.57 ± 30.88	300.22 – 532.17	431.41 ± 77.62
				Rajgangpur				
Rainy	276.41 - 344.26	306.34 ± 28.28	299.12 - 363.27	324.27 ± 29.71	254.22 - 311.18	283.15 ± 24.00	303.18 - 387.23	342.50 ± 35.65
Winter	301.24 - 376.89	337.37 ± 34.46	310.67 - 408.12	357.73 ± 44.10	270.18 - 340.28	306.37 ± 29.61	349.28 - 428.74	389.97 ± 33.67
Summer	243.21 - 356.24	299.57 ± 47.51	270.84 - 340.49	306.22 ± 30.19	320.05 - 392.02	362.52 ± 34.01	259.46 - 331.13	291.84 ± 31.18
Average	243.21 – 376.89	314.43 ± 20.16	270.84 – 408.12	329.41 ± 26.14	254.22 – 392.02	317.35 ± 40.81	259.46 – 428.74	341.44 ± 49.07
				Bonaigarh				
Rainy	220.12 - 311.12	265.92 ± 38.42	279.99 - 338.75	309.24 ± 25.01	243.22 - 305.12	277.64 ± 26.72	302.22 - 357.27	330.03 ± 24.02
Winter	292.87 - 369.56	325.96 ± 33.25	330.22 - 398.55	361.92 ± 29.39	319.67 - 406.22	369.57 ± 37.91	239.43 - 308.65	276.13 ± 29.86
Summer	306.35 - 387.29	349.00 ± 34.65	295.44 - 362.11	324.25 ± 28.68	316.89 - 400.23	362.43 ± 35.31	295.13 - 354.67	321.14 ± 26.72
Average	220.12 – 387.29	313.62 ± 42.89	279.99 – 398.55	331.80 ± 27.14	243.22 – 406.22	336.55 ± 51.14	239.43 – 357.27	309.10 ± 28.90

of the seasons, the concentrations of particulate matter, SO_2 and NO_2 were found to be 106.07 µg/Nm³, 77.53 µg/m³ and 102 µg/m³, respectively (Table 1).

AAQ inside the Plant

The ambient air quality inside the plants of four clusters has been studied and the data is presented in Table 2. It is evident from the table that the concentration of all the pollutants was higher in the winter season followed by the summer season and rainy season on most occasions. The concentration of particulate matters (SPM and RPM) in the Kuarmunda cluster was found to be in the range of 806 - 1121 and 287 - 396 µg/m³ in the rainy season, while the concentrations of the same during the winter season was 867 - 1352 and 297 - 409 µg/m³ and during the summer season was 814 - 1192 and 291 - 461 µg/m³. Similarly, the concentrations of the gaseous pollutants (SO_2 and NO_2) were found to be in the range of 55 - 63 and 73 - 81 µg/m³ during the rainy season, 59 - 71 and 72 - 83 µg/m³ during the winter season and 54 - 69 and 69 - 85 µg/m³ during the summer season. Irrespective of seasons, the concentrations of SPM, RPM, SO_2 and NO_2 were found to be 1060.27, 346.80, 61.93 and 79 µg/m³ respectively (Table 2).

The concentration of particulate matters (SPM and RPM) in the Kalunga cluster was found to be in the range of 654 - 1035 and 245 - 354 µg/m³ in the rainy season, 764 - 1467 and 301 - 425 µg/m³ in the winter season, and 693 - 1198 and 298 - 376 µg/m³ in the summer season. Similarly, the concentration of gaseous pollutants (SO_2 and NO_2) was found to be in the range of 56 - 67 and 70 - 89 µg/m³ during the rainy season, 61 - 73 and 75 - 91 µg/m³ during the winter season, and 54 - 71 and 69 - 93 µg/m³during the summer season. Irrespective of seasons, the concentrations of SPM, RPM, SO_2 and NO_2 were found to be 1022.80, 342, 63.80 and 82.67 µg/m³ respectively (Table 2).

Similarly, the Rajgangpur cluster witnessed a particulate concentration

Table 4. Seasonal variation of Respirable Particulate Matter (RPM) in μg/m³ outside the plants of different industrial clusters of Sundargarh district during 2010 -11

Seasons	East		West		North		South	
	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD
Kuarmunda								
Rainy	120.43 - 148.22	133.95 ± 11.86	124.64 - 154.76	140.08 ± 12.22	112.03 - 137.82	125.07 ± 11.04	140.14 - 160.17	149.20 ± 8.83
Winter	153.34 - 182.66	167.89 ± 12.39	165.39 - 188.23	176.02 ± 10.04	148.67 - 179.23	163.13 ± 13.46	169.99 - 192.13	180.86 ± 9.33
Summer	140.63 - 169.31	154.06 ± 12.50	146.17 - 173.27	160.25 ± 12.43	137.41 - 163.64	149.11 ± 11.44	153.59 - 179.22	167.34 ± 10.89
Average	120.43 – 182.66	151.97 ± 17.07	124.64 – 188.23	158.78 ± 18.02	112.03 – 179.23	145.77 ± 19.25	140.14 – 192.13	165.80 ± 15.88
Kalunga								
Rainy	117.23 - 140.66	129.35 ± 10.27	133.73 - 146.82	135.75 ± 10.68	105.23 - 134.23	121.61 ± 12.39	138.84 - 156.23	146.23 ± 8.06
Winter	146.67 - 169.77	156.84 ± 10.05	154.63 - 179.45	167.86 ± 10.51	140.76 - 158.56	149.53 ± 7.46	165.33 - 185.32	175.82 ± 8.77
Summer	139.26 - 163.63	149.63 ± 10.75	144.99 - 168.89	156.68 ± 11.37	137.81 - 152.65	145.38 ± 6.34	150.71 - 174.81	162.68 ± 10.60
Average	117.23 – 169.77	145.27 ± 14.25	133.73 – 179.45	153.43 ± 16.30	105.23 – 158.56	138.84 ± 15.06	138.84 – 185.32	161.58 ± 14.83
Rajgangpur								
Rainy	113.15 - 138.72	126.27 ± 10.87	119.77 - 143.27	132.67 ± 10.17	101.23 - 130.22	117.17 ± 12.51	132.45 - 153.82	142.87 ± 9.43
Winter	139.47 - 153.61	146.54 ± 6.32	142.66 - 160.34	150.50 ± 8.10	132.55 - 146.66	139.70 ± 5.98	147.22 - 171.46	158.78 ± 11.64
Summer	130.11 - 148.87	139.04 ± 7.91	141.96 - 156.29	149.29 ± 6.13	122.11 - 142.87	132.83 ± 8.88	147.41 - 165.24	156.76 ± 7.67
Average	113.15 – 153.61	137.28 ± 10.25	119.77 – 160.34	144.15 ± 9.96	101.23 – 146.66	129.90 ± 11.54	132.45 – 171.46	152.80 ± 8.67
Bonaigarh								
Rainy	113.01 - 137.28	125.02 ± 10.58	118.65 - 141.98	131.18 ± 9.92	100.43 - 128.09	114.96 ± 11.89	131.38 - 150.56	141.32 ± 8.73
Winter	138.23 - 147.43	142.36 ± 3.87	140.39 - 154.38	147.63 ± 6.55	130.43 - 145.22	138.01 ± 6.24	144.92 - 164.23	154.19 ± 9.77
Summer	128.49 - 144.65	137.13 ± 6.92	138.33 - 151.91	144.59 ± 6.02	120.07 - 140.11	130.90 ± 8.73	146.41 - 158.22	152.47 ± 4.87
Average	113.01 – 147.43	134.84 ± 8.89	118.65 – 154.38	141.13 ± 8.75	100.43 – 145.22	127.95 ± 11.80	131.38 – 164.23	149.33 ± 6.99

(SPM and RPM) ranging from 605 - 987 and 176 - 305 μg/m³ during the rainy season, 688 - 1162 and 212 - 354 μg/m³ during the winter season and 672 - 1092 and 201 - 341 μg/m³ during the summer season respectively. The gaseous pollutants (SO_2 and NO_2) in the same cluster varied from 31 - 57 and 46 - 73 μg/m³ during the rainy, 41 - 60 and 53 - 83 μg/m³ during the winter and 38 - 63 and 55 - 78 μg/m³ during the summer season respectively. Irrespective of seasons, the concentrations of SPM, RPM, SO_2 and NO_2 were found to be 891.13, 284.4, 50.81 and 69.93 μg/m³ respectively (Table 2).

The Bonaigarh cluster on the other hand, experienced a pollutant concentration (SPM and RPM) ranging from 591 - 1154 and 179 - 415 μg/m³ in the rainy season, 774 - 1551 and 215 - 513 in the winter season and 715 - 1083 and 214 - 451 μg/m³ in the summer season respectively. While that of the gaseous pollutants (SO_2 and NO_2) ranged from 34 - 65 and 51 - 89 μg/m³ in the rainy season, 40 - 75 and 63 - 83 μg/m³ in the winter season and 41 - 69 and 52 - 83 μg/m³ in the summer season respectively. Irrespective of seasons, the concentrations of SPM, RPM, SO_2 and NO_2 were found to be 1149.40, 353.2, 54 and 71.80 μg/m³ respectively (Table 2).

AAQ outside the Plant

The ambient air quality in the four clusters, but outside the plant premises were studied in four directions and the data is presented in Table 3 for SPM, in Table for RPM, in Table 5 for SO_2 and in Table 6 for NO_2.

From the Table 3 it is evident that, irrespective of directions the SPM concentration ranged from 310.14 - 524.35 μg/m³ during the rainy season in the Kuarmunda cluster, while that of the SPM concentration in the same cluster during the winter and summer seasons ranged from 402.15 - 643.56 μg/m³ and 412.23 - 578.16 μg/m³, respectively. Similarly, in the Kalunga cluster, the SPM ranged from 307.22 - 480.98 μg/m³ during the rainy, 362.11 - 532.17 μg/m³ during the winter

Table 5. Seasonal variation of Sulphur Dioxide (SO_2) in µg/m^3 outside the plants of different industrial clusters of Sundargarh district during 2010 -11

Seasons	East		West		North		South	
	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD
			Kuarmunda					
Rainy	10.51 - 17.67	13.94 ± 3.06	10.16 - 18.43	14.37 ± 3.44	10.12 - 16.16	13.04 ± 2.62	11.32 - 20.87	16.23 ± 4.03
Winter	19.01 - 26.32	22.34 ± 3.15	19.93 - 28.31	23.81 ± 3.77	18.79 - 24.48	21.24 ± 2.49	20.66 - 32.41	25.82 ± 5.37
Summer	14.83 - 24.78	20.33 ± 4.17	15.32 - 25.41	20.87 ± 4.20	14.19 - 21.67	18.70 ± 3.26	16.31 - 27.41	22.13 ± 4.58
Average	10.51 – 26.32	18.87 ± 4.39	10.16 – 28.31	19.68 ± 4.83	10.12 – 24.48	17.66 ± 4.20	11.32 – 32.41	21.39 ± 4.84
			Kalunga					
Rainy	14.23 - 17.79	15.50 ± 1.57	14.05 - 18.01	15.79 ± 1.68	14.02 - 16.66	15.02 ± 1.17	14.22 - 18.18	16.13 ± 1.63
Winter	17.23 - 20.56	19.13 ± 1.42	17.97 - 21.09	19.62 ± 1.30	17.16 - 19.77	18.72 ± 1.11	18.21 - 21.67	20.18 ± 1.45
Summer	15.66 - 17.89	16.84 ± 0.93	16.02 - 18.19	17.37 ± 0.99	15.12 - 17.17	16.33 ± 0.90	16.21 - 18.99	17.74 ± 1.20
Average	14.23 – 20.56	17.16 ± 1.84	14.05 – 21.09	17.59 ± 1.93	14.02 – 19.77	16.69 ± 1.88	14.22 – 21.67	17.98 ± 1.99
			Rajgangpur					
Rainy	14.89 - 15.78	15.22 ± 0.40	15.15 - 15.96	15.58 ± 0.36	14.78 - 15.15	14.97 ± 0.16	15.71 - 16.43	16.05 ± 0.30
Winter	16.29 - 17.98	17.12 ± 0.74	17.08 - 18.12	17.72 ± 0.47	15.47 - 17.22	16.46 ± 0.80	17.98 - 19.26	18.65 ± 0.57
Summer	15.74 - 17.22	16.40 ± 0.65	16.22 - 17.55	16.92 ± 0.55	15.01 - 16.56	15.83 ± 0.66	16.45 - 17.88	17.12 ± 0.60
Average	14.89 – 17.98	16.25 ± 0.96	15.15 – 18.12	16.74 ± 1.08	14.78 – 17.22	15.75 ± 0.75	15.71 – 19.26	17.27 ± 1.31
			Bonaigarh					
Rainy	14.68 - 15.54	15.09 ± 0.37	15.03 - 15.73	15.42 ± 0.30	14.02 - 15.01	14.53 ± 0.44	15.69 - 16.29	15.97 ± 0.25
Winter	16.22 - 17.93	17.06 ± 0.76	16.88 - 17.79	17.34 ± 0.39	16.16 - 16.87	16.50 ± 0.32	17.79 - 18.87	18.28 ± 0.47
Summer	15.65 - 16.78	16.14 ± 0.51	16.07 - 17.15	16.74 ± 0.48	14.86 - 15.89	15.41 ± 0.47	16.27 - 17.27	16.88 ± 0.43
Average	14.68 – 17.93	16.09 ± 0.98	15.03 – 17.79	16.50 ± 0.99	14.02 – 16.87	15.48 ± 0.99	15.69 – 18.87	17.04 ± 1.16

and 300.22 - 476.33 µg/m^3 during the summer seasons. The Rajgangpur cluster on the other hand witnessed a SPM concentration in the range of 254.22 - 387.23 µg/m^3 during rainy, 270.18 - 428.74 µg/m^3 during winter and 243.21 - 392.02 µg/m^3 during summer seasons respectively. Also, the Bonaigarh cluster had a SPM concentration in between 220.12 and 357.27 µg/m^3 during the rainy, 239.43 and 406.22 µg/m^3 during the winter and 295.13 and 400.23 µg/m^3 during the summer seasons respectively. The average value of SPM irrespective of seasons and directions however ranged from 441.24 – 530.64, 394.57 – 431.41, 314.43 – 341.44 and 309.10 – 336.55 µg/m^3 in Kuarmunda, Kalunga, Rajgangpur and Bonaigarh clusters respectively (Table 3).

The RPM concentration in the Kuarmunda cluster was found to be in the range of 112.03 - 160.17 µg/m^{3}during the rainy season irrespective of directions. Likewise, the winter and summer seasons witnessed the RPM concentration in the range of 148.67 - 192.13 µg/m^3 and 137.41 - 179.22 µg/m^3 respectively in the same cluster. Similarly, the Kalunga, Rajgangpur and Bonaigarh clusters had a RPM concentration in the range of 105.23 - 156.23, 101.23 - 153.82 and 100.43 -150.56 µg/m^3 during the rainy season, 140.76 - 185.32, 132.55 - 171.46 and 122.11 - 165.24 µg/m^3 during the winter season and 137.81 - 174.81, 122.11 - 165.24 and 120.07 - 158.22 µg/m^3 during the summer season respectively. The average value of RPM, irrespective or seasons and directions, ranged from 145.77 – 165.80, 138.84 – 161.58, 129.90 – 152.80 and 127.95 – 149.33 µg/m^3 in Kuarmunda, Kalunga, Rajgangpur and Bonaigarh clusters respectively (Table 4).

Similarly, the SO_2 concentration in the Kuarmunda cluster irrespective of directions varied from 10.12 - 20.87 µg/m^{3}during the rainy season, 18.79 - 32.41 µg/m^3 during the winter season and 14.19 - 27.41 µg/m^3 during the summer season. Similarly, the Kalunga, Rajgangpur and Bonaigarh clusters were

Table 6. Seasonal variation of Nitrogen Dioxide (NO_2) in µg/m^3 outside the plants of different industrial clusters of Sundargarh district during 2010 -11

Seasons	East		West		North		South	
	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD
				Kuarmunda				
Rainy	42.22 - 43.96	43.15 ± 0.75	43.55 - 44.76	44.12 ± 0.52	38.26 - 43.22	40.93 ± 2.20	44.33 - 45.63	44.95 ± 0.54
Winter	48.62 - 51.67	49.91 ± 1.34	50.99 - 52.54	51.70 ± 0.69	47.56 - 49.27	48.67 ± 0.77	51.75 - 52.98	52.32 ± 0.54
Summer	46.68 - 48.33	47.46 ± 0.75	48.87 - 50.17	49.56 ± 0.56	42.98 - 44.65	43.83 ± 0.72	49.38 - 50.96	50.11 ± 0.68
Average	42.22 – 51.67	46.84 ± 3.42	43.55 – 52.54	48.46 ± 3.91	38.26 – 49.27	44.48 ± 3.91	44.33 – 52.98	49.12 ± 3.78
				Kalunga				
Rainy	39.22 - 40.41	39.87 ± 0.50	40.52 - 41.76	41.06 ± 0.53	37.65 - 39.87	38.85 ± 0.94	42.44 - 43.35	42.90 ± 0.39
Winter	44.93 - 46.17	45.59 ± 0.56	47.41 - 48.96	48.14 ± 0.68	42.91 - 44.53	43.81 ± 0.69	49.19 - 50.96	50.08 ± 0.77
Summer	41.83 - 43.36	42.63 ± 0.65	44.02 - 45.22	44.69 ± 0.52	40.17 - 41.63	40.96 ± 0.62	46.39 - 47.63	47.02 ± 0.53
Average	39.22 – 46.17	42.69 ± 2.86	40.52 – 48.96	44.63 ± 3.54	37.65 – 44.53	41.20 ± 2.49	42.44 – 50.96	46.67 ± 3.61
				Rajgangpur				
Rainy	38.43 - 39.26	38.86 ± 0.36	39.51 - 40.76	40.08 ± 0.54	32.11 - 37.33	33.75 ± 2.41	41.04 - 42.24	41.69 ± 0.52
Winter	42.85 - 43.92	43.34 ± 0.48	45.52 - 46.77	46.12 ± 0.54	41.36 - 42.86	42.05 ± 0.64	47.91 - 49.36	48.62 ± 0.64
Summer	40.55 - 41.66	41.04 ± 0.48	41.55 - 42.43	41.96 ± 0.38	39.02 - 40.12	39.58 ± 0.49	42.29 - 43.63	42.93 ± 0.56
Average	38.43 – 43.92	41.08 ± 2.24	39.51 – 46.77	42.72 ± 3.09	32.11 – 42.86	38.46 ± 4.26	41.04 – 49.36	44.41 ± 3.69
				Bonaigarh				
Rainy	37.49 - 38.59	38.01 ± 0.47	38.87 - 39.91	39.34 ± 0.45	35.88 - 36.87	36.31 ± 0.43	40.31 - 41.78	40.97 ± 0.64
Winter	41.29 - 42.38	41.84 ± 0.45	43.14 - 44.32	43.74 ± 0.52	40.39 - 41.63	40.97 ± 0.53	46.49 - 47.34	46.91 ± 0.36
Summer	38.74 - 39.91	39.27 ± 0.51	40.53 - 41.44	40.96 ± 0.39	37.79 - 38.88	38.31 ± 0.48	42.01 - 43.06	42.57 ± 0.46
Average	37.49 – 42.38	39.70 ± 1.95	38.87 – 44.32	41.34 ± 2.22	35.88 – 41.63	38.53 ± 2.34	40.31 – 47.34	43.48 ± 3.07

found to have SO_2 in the range of 14.02 - 18.18, 14.78 - 16.43 and 14.02 - 16.29 µg/m^3 during the rainy season, 17.16 - 21.67, 15.47 - 19.26 and 16.16 - 18.87 µg/m^3 during the winter season and 15.12 - 18.99, 15.01 - 17.88 and 14.86 17.27 µg/m^3 during the summer season respectively. The average value of SO_2, irrespective or seasons and directions, ranged from 17.66 – 21.39, 16.69 – 17.98, 16.25 – 17.27 and 15.48 – 17.04 µg/m^3 in Kuarmunda, Kalunga, Rajgangpur and Bonaigarh clusters respectively (Table 5).

The NO_2 concentration in the Kuarmunda cluster ranged from 38.26 - 45.63 µg/m^{3}during the rainy season irrespective of directions. Likewise, in the same cluster during winter and summer seasons the NO_2 concentration ranged from 47.56 - 52.98 and 42.98 - 50.96 µg/m^3 respectively. Correspondingly, the Kalunga, Rajgangpur and Bonaigarh clusters were found to have NO_2 in the range of 37.65 - 43.35, 32.11 - 42.24 and 35.88 - 41.78 µg/m^3 during the rainy season, 42.91 - 50.96, 41.36 - 49.36 and 40.97 - 47.34 µg/m^3 during the winter season and 40.17 - 47.63, 39.02 - 43.63 and 38.31 - 43.06 µg/m^3 during the summer season respectively. The average value of NO_2, irrespective or seasons and directions, ranged from 44.48 – 49.12, 41.20 – 46.67, 38.46 – 44.41 and 38.53 – 43.48 µg/m^3 in Kuarmunda, Kalunga, Rajgangpur and Bonaigarh clusters respectively (Table 6).

Comparison of stack emission and ambient air quality parameters with standards

Table 7 shows a comparison between the average values of various air quality parameters against the permissible standard of stack emissions, whereas the comparison of ambient air quality against their respective standards inside and outside the plants are shown in Tables 8 and 9. It is evident from the tables that all the industrial clusters have exceeded the permissible limit with respect to the particulate matter and NO_2 emission from the stacks, while SO_2 was marginally

Table 7. Comparison of the stack monitoring results of various clusters with the permissible standards (CPCB, 2009)

Clusters	PM(µg/Nm^3)		SO_2(µg/m^3)		NO_2(µg/m^3)	
	Mean ± SD	Standard	Mean ± SD	Standard	Mean ± SD	Standard
Kuarmunda	118.27 ± 23.58	100	75.13 ± 10.76	80	96.47 ± 8.64	80
Kalunga	127.33 ± 23.70		79.80 ± 12.30		100.00 ± 11.38	
Rajgangpur	145.40 ± 56.87		79.40 ± 11.81		96.53 ± 11.17	
Bonaigarh	106.07 ± 19.96		77.53 ± 10.98		102.00 ± 10.59	

under the permissible standards and is very likely to exceed the permissible limit in near future if no management strategy is implemented. Similarly, the ambient air quality tested in respect of particulate pollutants (SPM and RPM) inside and outside the plants in all the clusters were found to be exceeded their respective standards, but the gaseous pollutants (SO_2 and NO_2) were within their respective standards, both inside and outside the plant premises (except NO_2 in Kalunga cluster).

API of the AAQ inside and outside the plants

Table 10 provides the data of the Air Pollution Index (API) of the ambient air quality inside the plants of the four clusters in Sundargarh district during 2010 – 11, while that of the same index for the four clusters outside the plants have been presented in Table 11. It is evident from the tables that, in general the ambient air quality in all the clusters both inside and outside the plants suffered from Severe Air Pollution (SAP) condition. The API values inside the plants ranged from 180.13 – 196.39 with an average value of 189.32 in Kuarmunda cluster, while that in the Kalunga cluster, it ranged from 172.76 – 202.90 with an average value of 188.05. Similarly, the API value in the Rajgangpur and Bonaigarh clusters ranged from 148.14 – 167.97 and 155.01 – 192.72 with an average value of 158.89 and 172.54 respectively.

The API values outside the plants during the study period in Kuarmunda and Kalunga clusters ranged from 157.05 – 196.75 and 150.72 – 175.11 with an average value of 178.51 and 161.49 respectively. Similarly, the Rajgangpur and Bonaigarh clusters witnessed an API value in the range of 132.66 – 150.20 and 128.65 – 145.45 with an average value of 141.15 and 139.04, respectively.

DISCUSSION

The particulate matters (SPM and RPM) finds an entry into the industrial environment through many sources that involves ore crushing and handling, operational process, coal burning in power plants, vehicular movements, construction activities etc. (Ghose and Majee, 2007; Schembari *et al.*, 2012). These particulates need to be trapped not only through machineries and equipments (like electrostatic precipitator, bag filters etc) attached to the various operational units, but also be trapped by natural means through plantation or green belt development (Das and Prasad, 2012; Sahu *et al.*, 2020, 2021). On most occasions, a periodical monitoring is helpful for proper control of these pollutants (Mishra *et al.*, 2016; Sahu and Sahu, 2019). The fact that our results' showing high values of these particulate pollutants in all the clusters from the stack, inside and outside the plant premises revealed that all the plants have a huge scope of improvement in the efficiency of the controlling devices attached to different operational units. It is also suggested that there might be a cumulative effect of the industries in a particular cluster and the concentration of the particulate pollutants might have direct relation with the number and capacity of the operating plants in that cluster. This can be marked through the fact that Kuarmunda and Kalunga clusters were found to have the highest concentration of particulates as compared to the other two clusters in their ambient air. Since, in all of the reported cases, the particulate matter concentration was well above the permissible limit, it can be deduced that the cluster areas need immediate attention and ameliorating techniques have to be implemented in order to avoid any catastrophic situation.

The gaseous pollutants (SO_2 and NO_2) find an entry into the industrial air, mainly through the burning of coal in power plants, vehicular movements and industrial process (Calori *et al.*, 2001). The results of the stack monitoring suggest that coal based power plants have emitted large volumes of the particulate and gaseous pollutants and hence their emissions had exceeded the permissible limit or were nearing that limit. These needs to be checked through implementation of corrective measures in the stack release. The ambient air quality analysis inside and outside plants in all

Table 8. Comparison of the AAQ results (all the units are in µg/m³) of various clusters (inside the plants) with the permissible National Ambient Air Quality standard (CPCB, 2009)

Clusters	SPM		RPM		SO_2		NO_2	
	Mean ± SD	Permissible Standard	Mean ± SD	Permissible Standard	Mean ± SD	Permissible Standard	Mean ± SD	Permissible Standard
Kuarmunda	1060.27 ± 158.23	360	346.80 ± 48.43	120	61.93 ± 4.89	80	79.00 ± 4.90	80
Kalunga	1022.80 ± 206.23		342.00 ± 46.97		63.80 ± 5.48		82.67 ± 7.36	
Rajgangpur	891.23 ± 153.85		284.40 ± 51.62		50.87 ± 8.63		69.93 ± 10.34	
Bonaigarh	968.40 ± 284.26		324.00 ± 117.57		51.53 ± 15.00		69.40 ± 13.25	

clusters, no doubt showed that the gaseous pollutant values are well within the permissible limit, but within the plant premises, these gaseous pollutants were on the higher side as compared to the ambient air outside the plants. This might be due to the dilution effect of air driven by temperature related phenomenon (Hogrefe *et al.*, 2006). Similar results have been reported by Shafii *et al.* (2017) in a work at Klang, Selangor – an industrial belt in Malayasia.

The seasonal and weather impact responsible for the pollutants accumulation cannot be ruled out in the industrial clusters. This was marked from the fact that the monsoon witnessed the least particulate and gaseous concentration which could be due to the suppression by rain. The wind direction as described by the windrose diagram earlier might be the possible reason for the greater accumulation of pollutants in the north and south directions. Further, the seasonal fluctuation of the pollutants concentration may be attributed to the air temperature causing dispersal of pollutants (Prati *et al.,* 2015).

Further, the Tables 10 and 11 reveal that, the highest value for API both inside and outside the plants was witnessed during winter season while the lowest value was found during the rainy season. The SAP (Severe Air Pollution) condition of the ambient air quality could be primarily attributed to the particulate matter (SPM and RPM) both inside and outside the plants which was found to be exceeding the prescribed standard value (500 and 360 µg/m³, respectively). The rainy season witnesses a lower concentration of particulate matter owing to the suppression by rain leading to low API value while the winter witnesses foggy and dewy condition leading to high particulate condition resulting in high API value. Since, the API values indicate severe air pollution condition, it may lead to serious health hazards and hence an implementation of a corrective measure is the need of the hour. The present findings of high API in the industrial area, mainly attributed to the particulate matters, is consistent with the previous results reported by Panda and Panda (2012) and Prakash *et al.* (2017) in similar industrial areas.

CONCLUSION

Industries have a massive impact on the ambient air quality of an area. The present study revealed that the cumulative impacts of all the sponge iron plants in the industrial clusters of Sundargarh district have

Table 9. Comparison of the AAQ results (all the units are in μg/m^3) of various clusters (outside the plants) with the permissible National Ambient Air Quality standard (CPCB, 2009)

Clusters	SPM		RPM		SO_2		NO_2	
	Mean ± SD	Permissible Standard	Mean ± SD	Permissible Standard	Mean ± SD	Permissible Standard	Mean ± SD	Permissible Standard
Kuarmunda	481.19 ± 71.80	140	155.58 ± 19.21	60	19.40 ± 5.19	60	47.22 ± 3.69	60
Kalunga	412.16 ± 54.30		149.78 ± 17.49		17.35 ± 2.01		43.80 ± 3.38	
Rajgangpur	325.65 ± 43.45		141.03 ± 14.35		16.50 ± 1.14		41.67 ± 3.66	
Bonaigarh	322.77 ± 43.70		138.31 ± 13.17		16.28 ± 1.10		40.76 ± 2.78	

Table 10. Air Pollution Index (API) of various clusters (inside the plants) of Sundargarh district in different seasons during 2010-11. All values presented (except API) are in μg/m^3

	SPM	RPM	SO_2	NO_2	API	Category
			Kuarmunda			
Rainy	993.4	329.2	59.0	77.2	180.13	SAP
Winter	1141.4	346.8	64.4	79.2	196.39	SAP
Summer	1046.0	364.4	62.4	80.6	193.24	SAP
Average	1060.3	346.8	61.9	79.0	189.92	SAP
			Kalunga			
Rainy	921.4	310.0	61.2	80.2	172.76	SAP
Winter	1130.8	370.2	66.2	85.0	202.90	SAP
Summer	1016.2	345.8	64.0	82.8	188.49	SAP
Average	1022.8	342.0	63.8	82.7	188.05	SAP
			Rajgangpur			
Rainy	824.6	265.2	47.6	66.4	148.14	SAP
Winter	959.6	299.2	52.6	72.2	167.97	SAP
Summer	889.2	288.8	52.4	71.2	160.54	SAP
Average	891.2	284.4	50.9	69.9	158.89	SAP
			Bonaigarh			
Rainy	840.2	290.6	48.0	67.6	155.01	SAP
Winter	1149.4	353.2	54.0	71.8	192.72	SAP
Summer	915.6	328.2	52.6	68.8	169.90	SAP
Average	968.4	324.0	51.5	69.4	172.54	SAP

SAP = Severe Air Pollution

Table 11. Air Pollution Index (API) of various clusters (outside the plants) of Sundargarh district in different seasons during 2010 -11. All values presented (except API) are in μg/m^3

	SPM	RPM	SO_2	NO_2	API	Category
			Kuarmunda			
Rainy	425.05	137.07	14.39	43.29	**157.05**	**SAP**
Winter	527.94	171.98	23.30	50.65	**196.75**	**SAP**
Summer	490.58	157.69	20.51	47.74	**181.74**	**SAP**
Average	481.19	155.58	19.40	47.22	**178.51**	**SAP**
			Kalunga			
Rainy	401.86	133.23	15.61	40.67	**150.72**	**SAP**
Winter	446.73	162.51	19.39	46.91	**175.11**	**SAP**
Summer	387.91	153.59	17.07	43.82	**158.64**	**SAP**
Average	412.16	149.78	17.35	43.80	**161.49**	**SAP**
			Rajgangpur			
Rainy	314.06	129.74	15.45	38.59	**132.66**	**SAP**
Winter	347.86	148.88	17.49	45.03	**150.20**	**SAP**
Summer	315.04	144.48	16.57	41.38	**140.60**	**SAP**
Average	325.65	141.03	16.50	41.67	**141.15**	**SAP**
			Bonaigarh			
Rainy	295.71	128.12	15.25	38.66	**128.65**	**SAP**
Winter	333.39	145.55	17.29	43.36	**145.45**	**SAP**
Summer	339.20	141.27	16.29	40.28	**143.01**	**SAP**
Average	322.77	138.31	16.28	40.76	**139.04**	**SAP**

SAP = Severe Air Pollution

depleted the ambient air quality of the area with respect to particulate pollution. The gaseous pollutants were also main concern, but they are in the near margin with respect to the prescribed permissible standard. Hence, an immediate source correction employing the implementation of management strategies and enhancement of the performance efficiency of the controlling devices is urgently required. Besides the source correction, massive green belt development in and around the industries and their clusters will also be quite helpful for scrubbing the pollutants from the surrounding atmosphere.

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REFERENCES

Alvi, M.S., Ahmed, S. and Chaturvedi, S.K. 2013. Approaching green manufacturing in iron and steel industry. *Internatioanl Journal of Mechanical Engineering and Robotics Research.* 2(3): 108 - 112.

Calori, G., Carmichael, G.R., Street, D., Thongboonchoo, N. and Guttikunda, S.K. 2001. Interannual variability in sulfur deposition in Asia. *Journal of Global Environmental Engineering.* 7: 1 - 16.

Chattopadhyay, K., Chattopadhyay, C. and Kaltenthaler, E. 2015. Respiratory health status and its predictors: a cross-sectional study among coal-based sponge iron plant workers in Barjora, India. *BMJ Open.* 5(3) : 7084-7084.

Chauhan, A. and Pawar, M. 2010. Assessment of ambient air quality status in urbanization, Industrialization and commercial centers of Uttarakhand (India). *New York Science Journal.* 3(7): 85-94.

Collins, A. Cortan, H. Glazer, S. Gorodniuk, S. Delville, J.L. Moin, N. Rodriguez, A. Rogers, J. and Vozza, G. 2014. Iron & Steel Producers Research Brief. Sustainability Accounting Standards Board**. 1 – 33.**

CPCB (Central Pollution Control Board). 2007. Sponge Iron Industry. Comprehensive industry document series. Central Pollution Control Board (Ministry of Environment and Forests, Govt. of India). COINDS/ 66/2006-07, pp:1-2 and pp: 87-98.

CPCB (Central Pollution Control Board). 2011. Guidelines for the measurement of ambient air pollutants (Vol. 1). New Delhi: Central Pollution Control Board, India.

CSE (Centre for Science and Environment). 2011. Sponge iron industry: The regulatory challenge. Centre for Science and Environment, New Delhi, pp.1-3.

Das, S. and Prasad, P. 2012. Particulate matter capturing ability of some plant species: Implication for phytoremediation of particulate pollution around Rourkela Steel Plant, Rourkela, India. *Nature Environment and Pollution Technology.* 11(4): 657-665.

Ghose, M.K. and Majee, S.R. 2007. Characteristics of hazardous airborne dust around an Indian surface coal mining area. *Environmental Monitoring and Assessment.* 130 : 17-25.

Hegerl, G.C., Zwiers, F.W., Braconnot, P., Gillett, N.P., Luo, Y., Marengo Orsini, J.A., Nicholls, N., Penner, J.E. and Stott, P.A. 2007. Understanding and Attributing Climate Change. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S. D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (Eds.) *Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA*. Available from: https://www.ipcc.ch/pdf/assessmentreport/ar4/wg1/ar4-wg1-chapter9-supp-material.pdf

Hippeli, S. and Elstner, E.F. 1993. Effects of air pollutants on man, animals, plants and buildings: mechanisms and dose-response effects. *Stud. Environ. Sci.* 55: 13-22.

Hogrefe, C., Porter, P.S., Gego, E., Gilliland, A., Gilliam, R., Swall, J., Irwin, J. and Rao, S.T. 2006. Temporal features in observed and simulated meteorology and air quality over the Eastern United States. *Atmospheric Environment.* 40 : 5041-5055.

Kumar, M. 2014. An occupational health exposure study in Iron Industry of Mandi Gobindgarh, Punjab, India. *IOSR Journal of Environmental Science, Toxicology and Food Technology.* 8(9): 17-24.

Mahajan, S.P. 1985. *Pollution Contrtol in Process Industries.* Tata McGraw Hill Publ. Co. Ltd., New Delhi, India.

Mishra, S.R., Pradhan, R.P., Prusty, B.A.K. and Sahu, S.K. 2016. Meteorology drives ambient air quality in a valley: A case of Sukinda chromite mine, one among the ten most polluted areas in the world. *Environmental Monitoring and Assessment.* 188 : 1-15.

Panda, B.K. and Panda, C.R. 2012. Estimation of ambient air quality status in Kalinga Nagar industrial complex in the district of Jajpur of Odisha. *International Journal of Environmental Sciences.*

3(2) : 767-775.

Pascal, M., Pascal, L. and Bidondo, M.L. Cochet, A., Sarter, H., Stempfelet, M. and Wagner, V. 2013. A Review of the Epidemiological Methods Used to Investigate the Health Impacts of Air Pollution around Major Industrial Areas. *Journal of Environmental and Public Health.* 1-17.

Pathak, M.J. 2020. Air Pollution Scenario of India: A State-wise analysis. *Our Heritage.* 68 (1) : 2137 - 2146.

Patra, H.S., Sahoo, B. and Mishra, B.K. 2012. Status of sponge iron plants in Orissa. Bhubaneswar, India: *Vasundhara*. Available from: http:// bmjopen.bmj.com/ content/bmjopen/ 5/3/ e007084. full.pdf

Prakash, B.M., Majumder, S., Swamy, M.M. and Mahesh, S. 2017. Assimilative capacity and air quality index studies of the atmosphere in Hebbal industrial area, Mysuru. *International Journal of Innovative Research in Science, Engineering and Technology.* 6(10) : 20651-20662.

Prati, M.V., Costagliola, M.A., Quaranta, F. and Murena, F. 2015. Assessment of ambient air quality in the port of Naples. *Journal of Air & Waste Management Association.* 65(8): 970-979.

Sahu, C. and Sahu, S.K. 2019. Ambient air quality and air pollution index of Sambalpur: a major town in Eastern India. *International Journal of Environmental Science and Technology.* 16(12): 8217-8228.

Sahu, C. Basti, S. and Sahu, S.K. 2020. Air Pollution Tolerance Index (APTI) and Expected Performance Index (EPI) of Trees in Sambalpur Town of India. *SN Applied Sciences.* 2 : 1327, doi.org/10.1007/ s42452-020-3120-6.

Sahu, C., Basti, S. and Sahu, S.K. 2021. Particulate Collection Potential of Trees as a means to improve the air quality in urban areas in India. *Environmental Processes.* 1 - 19. doi.org/10.1007/ s40710-021-00494-3.

Sasi, J.M.B. 2013. Air Pollution Caused by Iron and Steel Plants. *International Journal of Mining, Metallurgy & Mechanical Engineering.* 1(3): 219 - 222.

Schembari, C. Cavalli, F. Cuccia, E. Horth, J. Calzolai, G. Perez, N. Pey, J. Prati, P. and Raes, F. 2012. Impact of a European directive on ship emissions on air quality in Mediterranean harbours. *Atmospheric Environment.* 61 : 661-669.

Shafii, N.Z., Saudi, A.S.M., Mahmud, M. and Rizman, Z.I. 2017. Spatial assessment on ambient air quality status: A case study in Klang, Selangor. *Journal of Fundamental and Applied Sciences.* doi: http:// dx.doi.org/10.4314/jfas.v9i4s.58

Singh, R.K. and Agarwal, M. 2005. Atmospheric deposition around a heavily industrialized area in a seasonally dry tropical .environment of India. *Environ. Pollut.* 138 : 142-152.

Swar, A.K. 2009. Regulatory mechanism adopted to control pollution in DRI steel plants of Orissa for protection of environment. In: *Proceedings of International Convention on Clean Green and Sustainable Technologies in Iron and Steel Making, Bhubaneswar,* pp 25-30.

Tiwari, M.K., Bajpai, S. and Dewangan, U.K. 2016. Air and leaching pollution scenario by iron and steel plants in central India. *Elixir International Journal.* 101: 44011-44017.

WHO 2016. WHO releases country estimates on air pollution exposure and health impact. Geneva, 27th September. Available from: http:// www.who.int/ mediacentre/news/ releases/ 2016/air-pollutionestimates/en/.

Ziauddin, A. and Siddiqui, N.A. 2006. Air quality index (AQI) – a tool to determine ambient air quality. *Pollution Research.* 25: 885-887.