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Chemical Characterization and Particulate Distribution of PM_{10} and $PM_{2.5}$ at Critically Polluted Area of Dhanbad/Jharia Coalfield

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Abstract:
This paper deals with chemical characterization of PM_{10} and $PM_{2.5}$ mass concentrations estimated at different receptors of critically polluted area of Dhanbad/Jharia coalfield during post-monsoon, winter and summer seasons. Eighteen monitoring stations were selected considering sources of pollution covering mining, industrial, commercial and residential areas apart from siting criteria as per IS: 5182 Part XIV**.** Air quality monitoring has been carried out following standard methodologies and protocols as per Central Pollution Control Board (CPCB)/ National Ambient Air Quality Standard (NAAQS) norms using Respirable Dust Samplers (RDS) and Fine particulate sampler (Envirotech APM 550MFC) for $PM_{2.5}$. The 24-h averages of PM_{10} and $PM_{2.5}$ mass concentrations, showed higher concentrations during the winter season (PM_{10} - 534 μg/m^3; $PM_{2.5}$ - 217 μg/m^3) followed by the summer (PM_{10} -549 μg/m^3; $PM_{2.5}$ -232 μg/m^3) and post-monsoon (PM_{10} - 509 μg/m^3; $PM_{2.5}$ - 205 μg/m^3 seasons. The assessment of 24-h average PM_{10} and $PM_{2.5}$concentrations was indicated as violation of the world health organization (WHO standard for PM_{10} - 50 μg/m^3 and $PM_{2.5}$ - 25 μg/m^3) and Indian national ambient air quality standards (NAAQS for PM_{10} - 100 μg/m^3 and $PM_{2.5}$ - 60 μg/m^3). Particle size distribution and Chemicals characterization of PM_{10} at different monitoring stations indicates direct association of sources nearby receptors. Acid assimilate solution of PM_{10} and $PM_{2.5}$ samples (32 samples) for each season were analyzed by Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) instrument to get the concentration of trace metals which follows the following trends Fe> Al> Cd> Cu> Zn> Mn> Cr> Pb> Ni> As for PM_{10} and Fe> Al> Zn> Mn> Cu> Cr> Pb> Ni> Cd for $PM_{2.5}$ throughout the year. Small size particulate matter is caring very large amount of Fe, Al, Cd, Cr, Pb and Cu.
Keywords: Chemical Characterization, PM_{10}, $PM_{2.5}$, Trace Metal. Particle Size Distribution, National Ambient Air Quality Standard (NAAQS).

I. Introduction:

Jharia coalfield (JCF) occupies an important place in Indian's industrial and energy scenario by virtue of being the only storehouse of primary coking coal and important source of various activities. This coalfield is subjected to intensive mining activities and accounts for 30% of the total Indian coal production (Ghose and Majee 2001). This huge amount of coal production, processing, transportation and other associated activities emit particulate matter in the atmosphere. Over the past few years, with the introduction of mechanized mining techniques and heavy earth moving machines (HEMM), this problem has been further aggravated. Considerable amount of particulate matter (PM_{10} and $PM_{2.5}$) are contributed to the atmosphere due to industrial as well as vehicular emission (Paved/Un-paved) in the urban area (Chaloulakou et al. 2003; Chan and Yao 2008; Deshmukh et al. 2010a,b; Katiyar et al. 2002; Vega et al. 2010; Wang et al. 2010). Trace metals which are present in the air borne particulate matter, are coming in to the food chain and can causes illness for the people and as well as animals. Some trace metals are also acts like a figure print elements to identify the possible sources (Ho et al. 2003; Karar and Gupta 2006; Khan et al. 2010; Singh et al. 2009; Spindler et al. 2004; Tiwari et al. 2009; Tasi and Cheng 2004; Vassilakos et al. 2007; Wang et al. 2003; Wojas and Almquist 2007; Wang et al. 2005).

Jharia Coalfield is one of the most important coalfields in India, located in Dhanbad district, between latitude 23^0 39' to 23^0 48' N and longitude 86^0 11' to 86^0 27' E, about 260 kms north-west of Kolkata, in the heart of Damodar Valley, mainly along the north of the river. The field is roughly elliptical, or sickle shaped, its longer axis running northwest to southwest, covering the area of over 460 sq km and extending for a maximum of about 38 km east-west and 19 km north-south. This is the most exploited coalfield because of available metallurgical grade coal reserves.

II. Study Area:

Study area, within Jharia Coalfield is depicted in Fig. 1. It includes different polluting sources like opencast coal mines, coal washeries, coke oven plants, thermal power stations, mine fire areas, commercial and residential areas. Eighteen (18) ambient air quality monitoring stations were selected for this study as per the siting criteria (IS: 5182 Part XIV) with special consideration of meteorological data and sources of pollution, apart from security, accessibility and availability of electricity. One reference ambient air quality monitoring stations also established at ISM, Dhanbad which is relatively cleaner area providing background particulate levels in the study area.

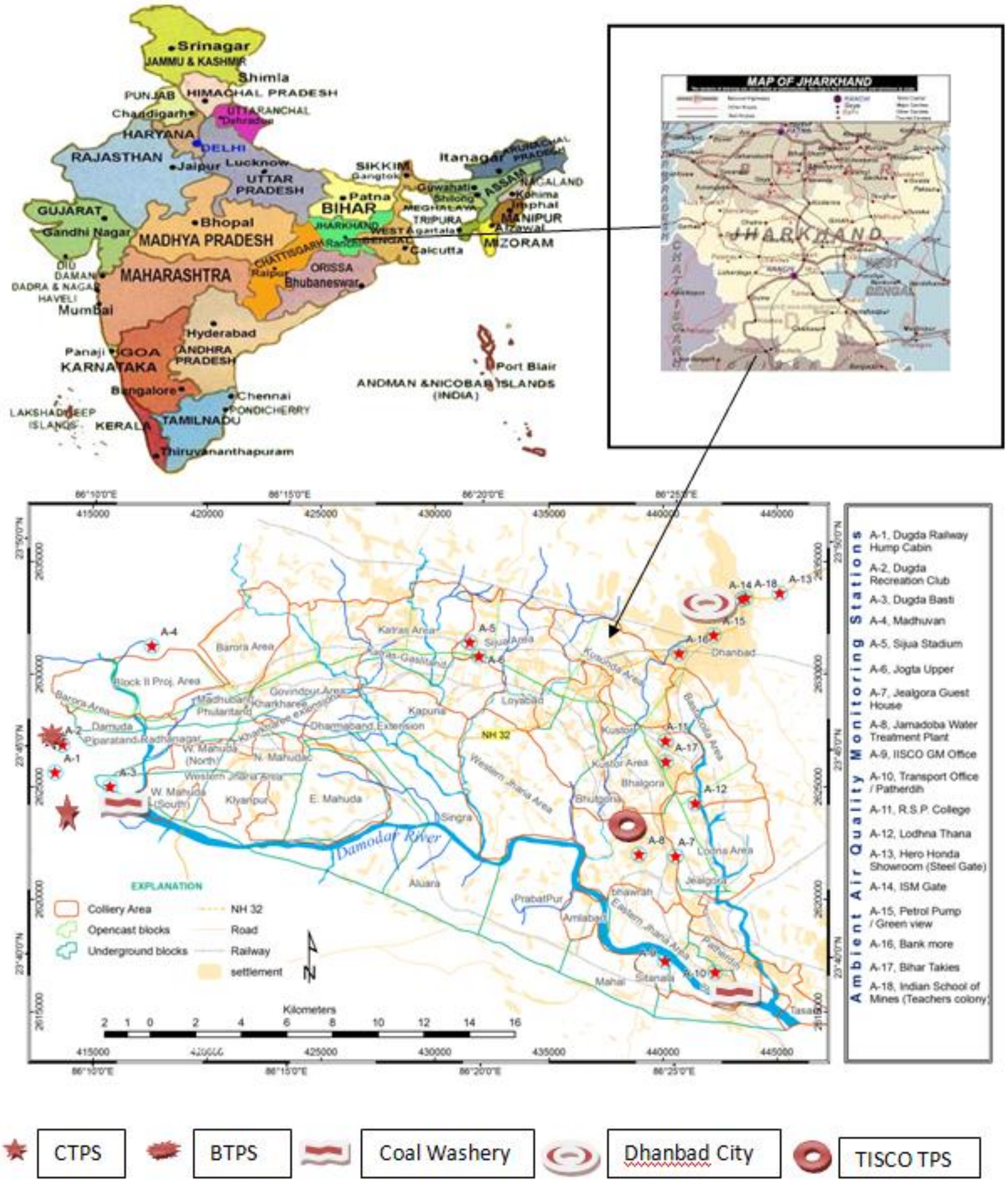

Fig. 1: Location Map of the Study Area

Salient Features of these 18 ambient air quality monitoring stations as sited in the study area are present in Table given below.

Table 1: Salient Features of Ambient Air Quality Monitoring Stations of Study Area

Code	Locations	Geographical Positioning System Reading	Remarks
A-1	Dugda Railway Hump Cabin	Lat- $23^0$44'21.85" N Lon- $86^0$08'59.22"E Elevation (SL) - 679 ft	Existing Dugdha Washery is situated 1 km from station A-3 in N Direction. Railway Track is passing at a distance of <10m from station A-3 in N Direction DVC Plant is situated 2 km from station A-3 in NW Direction. BTPS is situated 6 km from station A-3 in SSW Direction. CTPS is situated 4 km from station A-3 in SW Direction
A-2	Dugda Recreation Club	Lat- $23^0$45'02.09"N Lon- $86^0$09'10.65"E Elevation (SL) - 748 ft	Madhuban Washery is situated 1.5 km from station A-4 in NE Direction. Unpaved Road is passing at a distance of <25m from Station A-4 in NW Direction. CTPS is situated 4 km from station A-4 in E Direction
A-3	Dugda Basti	Lat- $23^0$45'25.74"N Lon- $86^0$09'01.76"E Elevation (SL) - 725 ft	Existing Dugdha Washery is located 1.7 km from Station A-7 in SW Direction Railway Track is passing at a distance of 1 km from Station A-7 in S Direction Proposed Washery is situated at a distance of 2km from the Station A-7 in S Direction
A-4	Madhuban	Lat- $23^0$47'30"N Lon- $86^0$11'30"E Elevation (SL) - 630 ft	0.5 km from Madhuwan Coal washery at S direction. 2.5 km from Muridih (OC) in W direction. 2.3 km from Block-II (OC) in NW direction. 1.3 km from Jamunia (OC) at NNE direction.
A-5	Sijua Stadium	Lat- $23^0$47'32.9"N Lon- $86^0$19'41.2"E Elevation (SL)- 877 ft	3.9 km from Rajhans Coak Oven plant at SE direction. 2 km from Sandra Bansjora (OC) at W Direction 3 km from Nichit pur (OC) in SW direction
A-6	Jogta 14 pit	Lat- $23^0$47'13.1"N Lon- $86^0$19'56.2"E Elevation (SL)- 651 ft	0.5 km from Jogta (OC)
A-7	Jealgora Guest House	Lat - $23^0$42'25.5"N Lon - $86^0$24'59.6"E Elevation(SL)- 715 ft	Existing coal Washery is situated at a distance of 2 km from Station A-6 in SE Direction.
A-8	Water Treatment Plant/ Jamadoba	Lat - $23^0$42'27.89"N Lon - $86^0$24'02.57"E Elevation- 577 ft	Station A-7 is situated <2.5 km from Jamadoba Washery W Direction Patherdih coal Washery is located at a distance of < 5 km in NNW Direction
A-9	IISCO GM Office	Lat - $23^0$39'53.0"N Lon - $86^0$26'44.8" E Elevation (SL) - 512 ft	Station A-3 is situated 2 km from Patherdih Washery in S Direction. Surrounded by coal Washeries in W ,S and N Direction by IISCO/SAIL, Bhojudih Coal Washery and Patherdih existing coal Washery respectively
A-10	Transport Office/Patherdih	Lat - $23^0$40'37.8" N Lon-$86^0$26'03.28"E Elevation (SL) - 555 ft	Existing Washery. is located at a distance of <50 m from Staion A-1 in W Direction Railway track was passing at a distance of <20 m from station A-1 in SW Direction

A-11	R.S.P. College	Lat - $23^0$45’11.6” N Lon-$86^0$24’44.4”E Elevation- 710 ft	1.33 km away from South Jharia (OC) in NWW direction. 2.34 km away from Sudamdih Coal Washery in NW direction. 2.44 km from Goluckdih (OC) in NNW direction
A-12	Lodna Thana	Lat - $23^0$43’41.8” N Lon-$86^0$25’30.6”E Elevation (SL) - 570 ft	1.6 km from Goluckdih (OC) in SSW direction. 1.8 km from Sudamdih Coal Washery in SW direction.
A-13	Hero Honda Showroom/ Steel Gate	Lat - $23^0$48’54.86” N Lon-$86^0$27’51.05”E Elevation (SL) - 770 ft	Near main road. At Dhanbad City.
A-14	ISM Gate	Lat - $23^0$48’32.7” N Lon-$86^0$26’33.3”E Elevation (SL) - 842 ft	Near main road. At Dhanbad City.
A-15	Petrol Pump/ Green View	Lat - $23^0$47’46.7” N Lon-$86^0$25’51.4”E Elevation (SL) - 770 ft	Near main road. At Dhanbad City.
A-16	Bank More	Lat - $23^0$47’16.9” N Lon-$86^0$25’07.2”E Elevation (SL) - 775 ft	Near main road. At Dhanbad City.
A-17	Bihar Talkies	Lat - $23^0$44’42.05” N Lon-$86^0$24’45.79”E Elevation (SL) - 580 ft	Near main road. 1.3 km from South Jharia (OC) at SW direction. 2.1 km from Sudamdih Washery at W direction. 2 km from Goluckdih (OC) in NNW.
A-18	ISM, Dhanbad Teaches Colony	Lat-$23^0$48’45.3”N Lon-$86^0$26’23.5” E Elevation (SL) - 822 ft	Used as a reference station as isolated from the industrial activities

III. Methodology of Ambient Air Quality Monitoring:

Summarized Methodologies and Measuring Instruments for Ambient Air Quality Monitoring are given in Table 2.

Table 2: Summarized Methodology and Measuring Instruments for Ambient Air Quality Monitoring

Pollutants	Measuring Instruments	Standard Methodology
Respirable Particulate Matter (PM_{10})	Envirotech (APM460) Respirable Dust Sampler	Instruments were operated at an average flow rate of 1.1-1.2m^3/min. as per IS: 5182-Part XXIII: 2006 for sampling/collection of SPM and PM_{10} levels. They were computed as per standard methods after determining the weights of GF/A or EPM 2000 filter paper before and after sampling in Electronic Balance.
Fine particulate matter (size less than 2.5 µm)	Envirotech APM 550MFC	Gravimetric PTFE 47 mm diameter filter paper, TOEM Beta attenuation
Lead (Pb) µg/m3	ICP-OES	ICP-OES after sampling on EPM 2000 equivalent filter paper
Arsenic (As)	ICP-OES	ICP-OES after sampling on EPM 2000 equivalent filter paper
Nickel (Ni)	ICP-OES	ICP-OES after sampling on EPM 2000 equivalent filter paper

Note: Same methodology has been followed fort the determination of other trace metals.

IV. Meteorological Status of the Study Area:

Weather Monitor station (WM-231) was installed at roof top of Centre of Mining Environment (CME)/ Env. Sc. & Engg. (ESE) Department, ISM, Dhanbad. The location was free from obstruction for free flow of air from all the directions. Continuous measurements of maximum and minimum temperature, relative humidity, and wind speed and wind direction were recorded. Details of the wind speed, frequency distribution and wind direction for the period of air quality monitoring during Winter, Summer, Monsoon and Post- monsoon season during, 2011-2012 are given in Table 3.

Table 3: Meteorological Status during the Study Period (2011-2012)

Seasons	Temperature (^{0}C)		Relative Humidity (%)		Mixing Depth (m)		Rainfall (mm)	Dominant Wind direction (From)
Winter	30.0	4.6	97.0	23.0	900	32	Nil	NW,NNE & NNW
Summer	47.0	19.8	98.0	18.0	1356	45	86.0	S, SE & SW
Monsoon	41.4	24.5	98.0	35.0	1290	30	792.8	S
Post-monsoon	38.0	24.0	98.0	35.8	1020	28	83.0	WSW

Details of the wind speed, frequency distribution, wind direction for the study for all seasons i.e., Winter (December 2011- February 2012), Summer (March 2012-May 2012) Monsoon (June 2011-September 2011) and Post Monsoon (October 2011- November 2011) are given in Table 8 to Table 10 and accordingly wind rose diagram were developed which are presented in Fig. 2 to Fig. 5 respectively.

During winter the predominant wind direction was NW, NNE and NNW for 7.78% and 7.65% of the time respectively. The predominant wind speed of 0.5-1.5 m/sec was observed for 48.63% of total time. During summer the predominant wind direction was South for 9.57% of the total time respectively. The predominant wind speed of 5.0-8.0 m/sec was observed for 28.07% of total time. During Monsoon the predominant wind direction was South for 11.66% of the total time respectively. The predominant wind speed of 5-8 m/sec was observed for 3.29% of total time. During Post monsoon the predominant wind direction was WSW for 1.29% of the total time. The predominant wind speed of 3.0-5.0 m/sec was observed for 4.6% of total time. Atmospheric parameters like, Wind speed, wind direction, rain fall, mixing height, temperature, etc. are playing an important role in distribution of particulate matters (Hien et al. 2002).

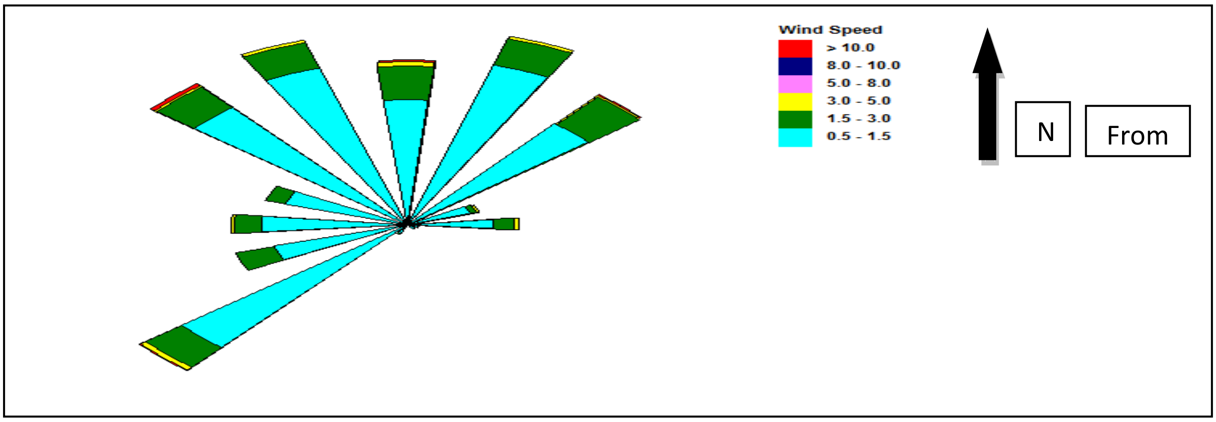

Fig. 2: Wind Rose Diagram of Study Area during Winter Season (2011-2012)

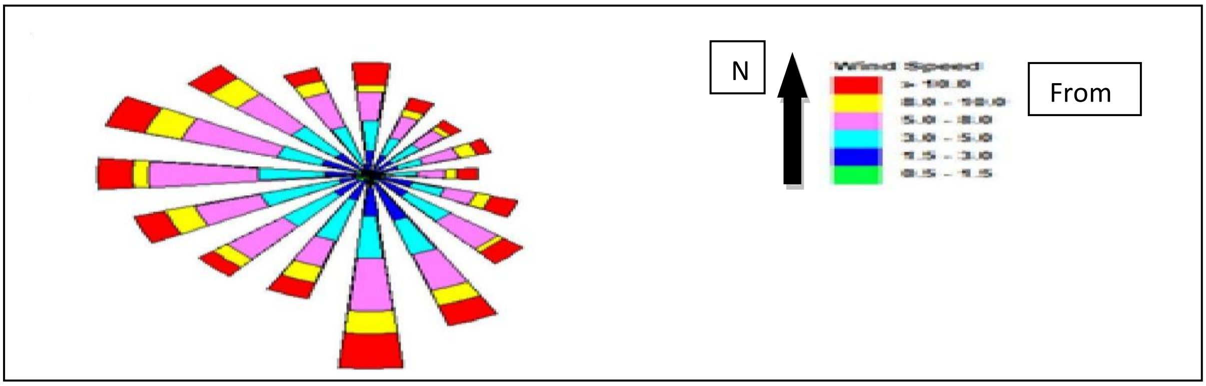

Fig. 3: Wind Rose Diagram of Study Area during Summer Season (2012)

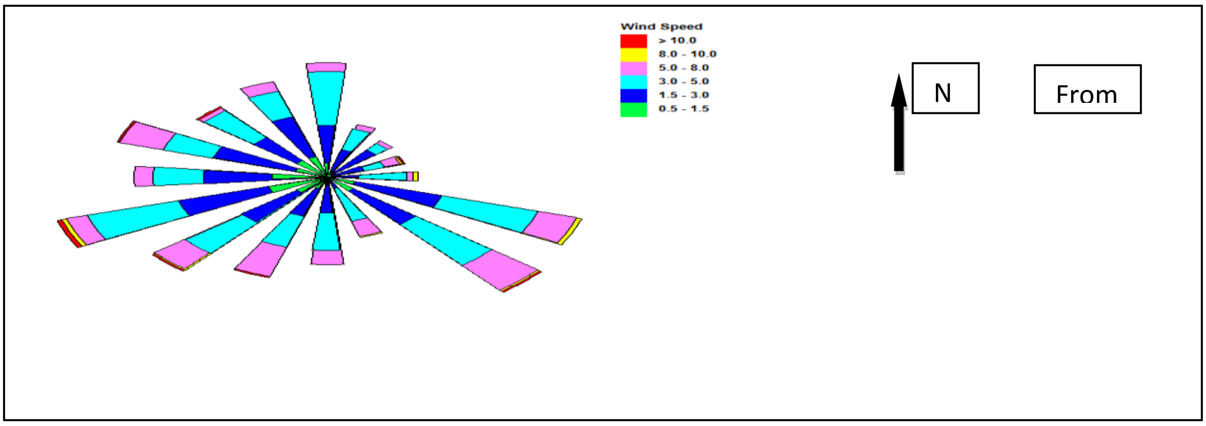

Fig. 5: Wind Rose Diagram of StudyAarea during Post- Monsoon Season (2011)

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V. Results and Discussion:

Seasonal Variation of Particulate Matter:

Ambient Air Quality Monitoring at 18 monitoring locations with observance of maximum concentration levels of PM_{10} & $PM_{2.5}$ during winter followed by post monsoon and summer. Although the wind speed varied between the seasons, other meteorological parameters such as temperature and relative humidity, pointed to poor mixing during winter season. Moreover, winter received much less rainfall in comparison to other seasons. As a result, removal of atmospheric aerosol particles by wet scavenging is much reduced in winter. Specifically, during summer the prevailing winds, which are due to thermal circulations, are stronger and the mixing height is deeper (Hien et al., 2002). All the monitoring stations except ISM, teacher's colony excites the permissible limit given by NAAQS-2009.

Bank More (A-16), is badly affected by vehicle lode for that reason maximum fine particulates (PM_{10} & $PM_{2.5}$) concentration observed during all Seasons (post-monsoon- PM_{10} 534 ± 21 µg/m3& $PM_{2.5}$ -189± 12 µg/m3; summer- PM_{10} 509 ± 19 µg/m3& $PM_{2.5}$ -185± 11 µg/m3; winter- PM_{10} 549 ± 23 µg/m3& $PM_{2.5}$ -219± 15 µg/m3). Sijua Stadium (A-5) and Transport Office (A-10) were recorded higher fine particulates level. Minimum concentration level of air borne particulate matter observed at ISM, teachers colony (A-18) (post-monsoon- PM_{10} 77 ± 06 µg/m3& $PM_{2.5}$ -49± 09 µg/m3; summer- PM_{10} 68 ± 10 µg/m3& $PM_{2.5}$ -37± 05 µg/m3; winter- PM_{10} 85 ± 13 µg/m3& $PM_{2.5}$ -56± 06 µg/m3) due to distance from source and greenbelt surrounding the campus. Variations of the observed data of particulates are given below (Fig. 6 to Fig. 8).

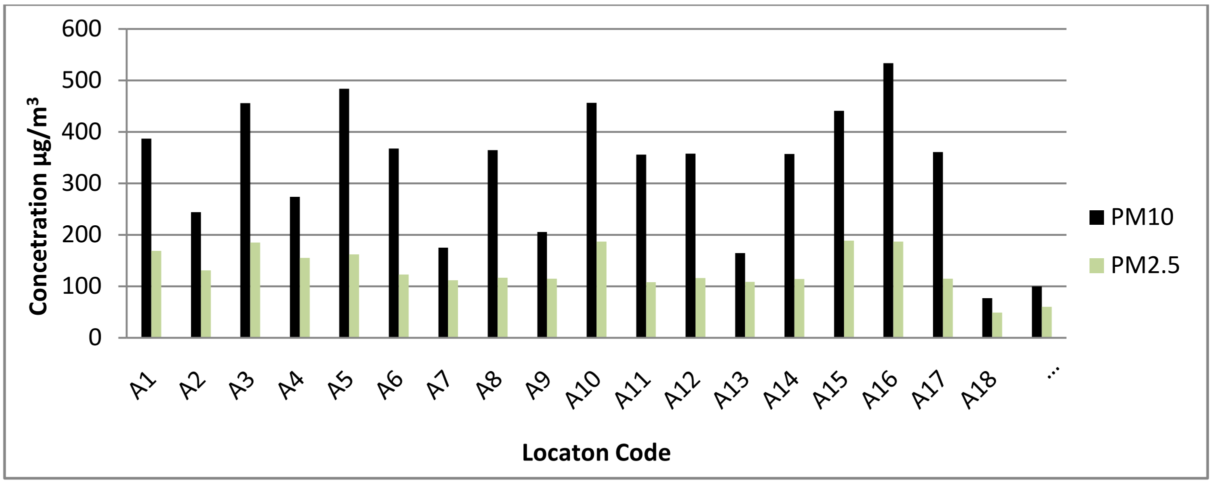

Fig. 6: Showing Concentration of PM_{10} and $PM_{2.5}$ during Post-Monsoon Season

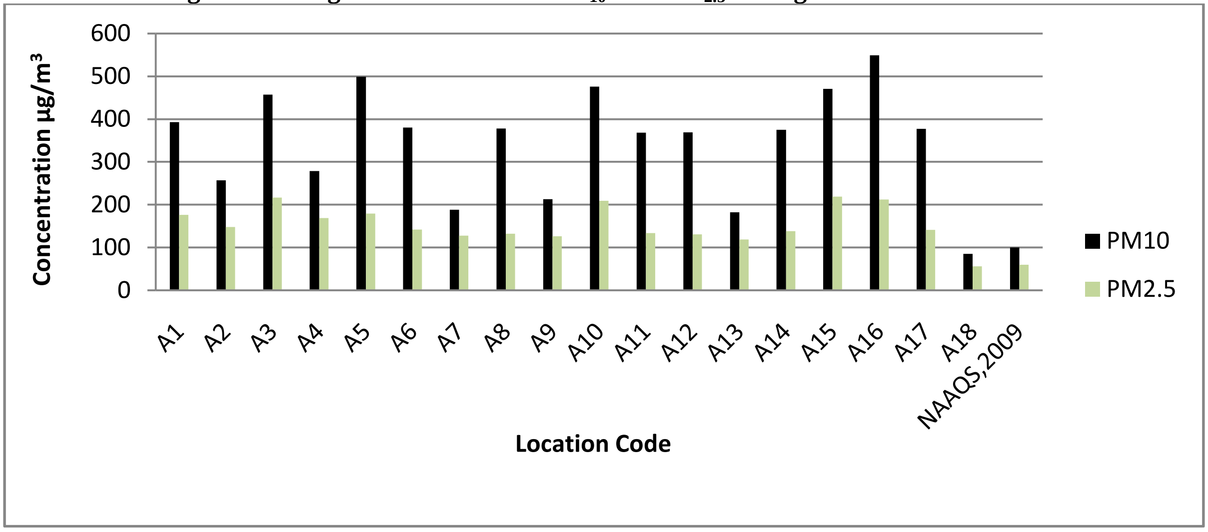

Fig. 7: Showing Concentration of PM_{10} and $PM_{2.5}$ during Winter Season

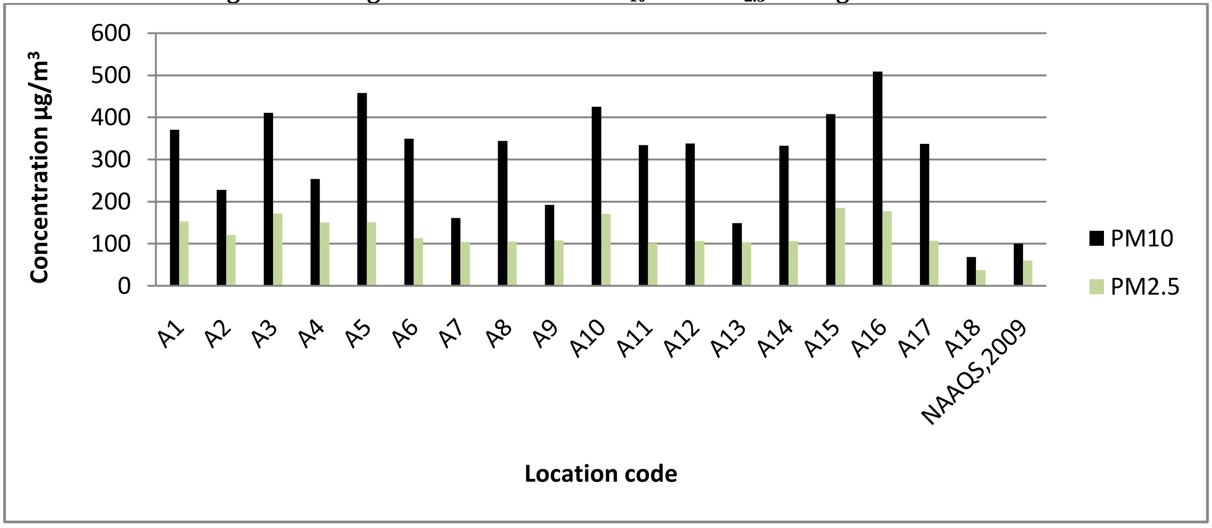

Fig. 8: Showing Concentration of PM_{10} and $PM_{2.5}$ during Summer Season

Dust has been collected from EPM, 2000 filter paper and analyzed through FRITSCH PARTICLE SIZER ANALYSETTE 22 for particle size analysis. A-3, A-8, A-13, A-15, A-16 and A-18 have been observed maximum percentage fine particulate Matter (>4 µm) and A-4, A-5, A-6, A-9 and A-10 caontains maximum quantity of particulate matter more than 4 µm. Size distribution of particulates (PM_{10}) at different monitoring stations is shown in Fig. 9.

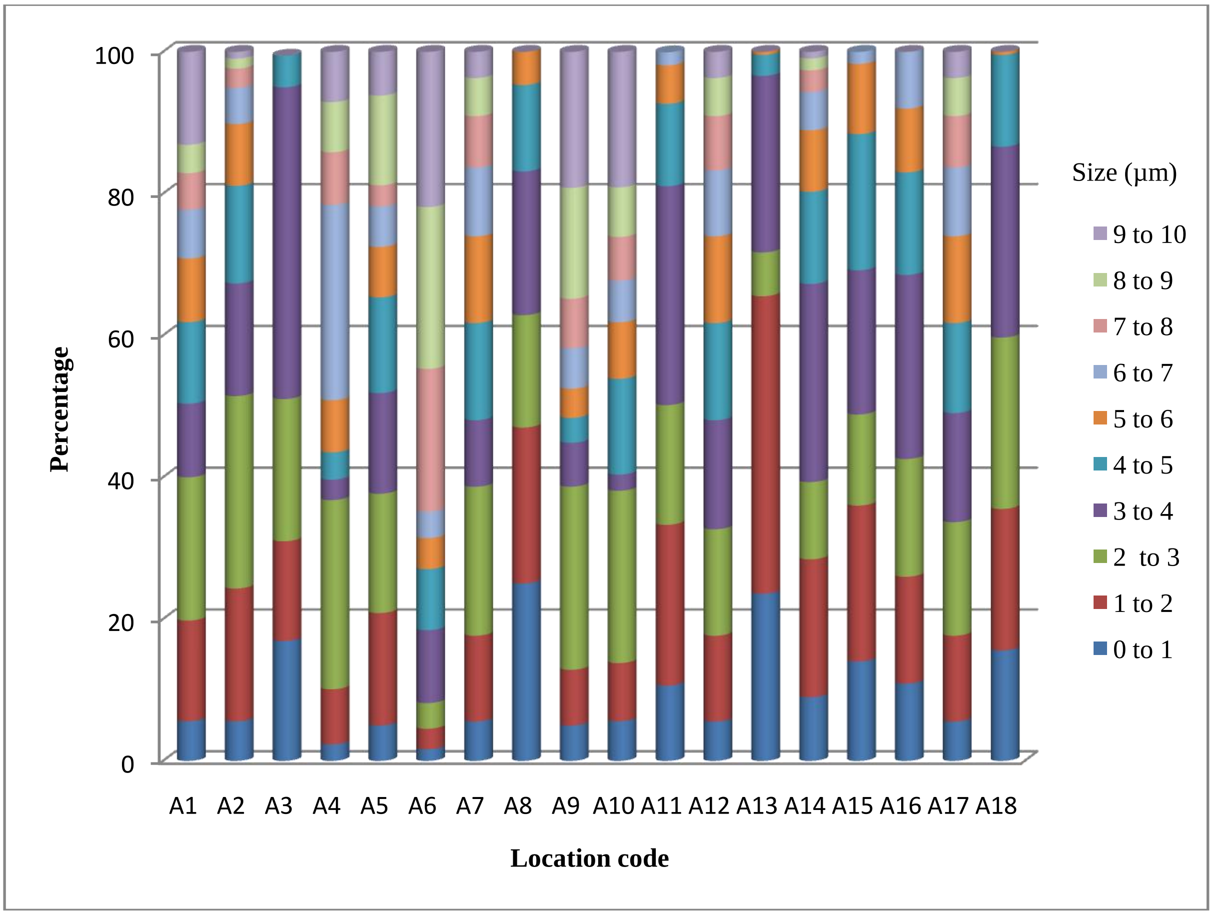

Figure 9: Size Distribution of Particulate Matter PM_{10} at Monitoring Mtations

VI. Concentration of Trace Elements:

Fe, Al, Ni, Cu, Mn, Cd, Pb, Zn, and As are the most commonly found trace element in coalfield region as revealed from literature review. Concentrations of trace elements present in dust sample of less than 10 micron at different seasons are given below.

Acid assimilate solution of PM_{10} and $PM_{2.5}$ samples (32 samples) for each season were analyzed by Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) instrument to get the concentration of trace metals which follows the following trends Fe> Al>> Cd> Cu> Zn> Mn> Cr> Pb> Ni> As for PM_{10} and Fe> Al>> Zn> Mn> Cu> Cr> Pb> Ni> Cd> for $PM_{2.5}$ throughout the year. Maximum concentration of trace metals recorded at winter followed by post-monsoon and summer. PM_{10} bound Iron (Fe) Concentration observed maximum at A-16 (34.45±0.45 µg/m^3) subsequently A-11 (30.38±0.25 µg/m3), A-8 (23.66±0.27 µg/m^3) and A-3 (17.526±0.003 µg/m^3). In case of $PM_{2.5}$ Fe concentration at A-16 (11.25±0.03 µg/m^3) maximum followed by A-3, A-5, A-2 and A-8. Maximum concentration of PM_{10} bound Aluminium (Al) noted at A-16 afterwards A-17, A-7, A-5, A-6 and A-9. But this scenario is different for $PM_{2.5}$ bound Al. Trend was A-5> A-9> A-8>A-13> A-12> A-15 and A-6. Fe and Al are showing remarkable concentration in PM_{10} and $PM_{2.5}$ samples throughout the monitoring period. In case of PM_{10}, apart from Fe and Al, concentration of Cadmium (Cd) found higher at A-16 (13.40±0.01 µg/m3) next A-17 (6.75±1.621 µg/m3) and A11 (6.049±0.01 µg/m3). Concentration trend of Cupper (Cu) is A-16 (6.317±0.17 µg/m3)> A-11 (3.11±0.02 µg/m3)> A-5 (2.98±0.145 µg/m3)>A-17 (2.967±0.095 µg/m3). $PM_{2.5}$ contains remarkable concentration of Chromium (Cr) (A-9 (1.037±0.02 µg/m3)> A-16 (0.995±0.045 µg/m3) > A-17 (0.950±0.17 µg/m^3) and Cupper (Cu) (A-16> A-13> A-14> A-17> A-15 respectively). Average annual trace metal concentration of PM_{10} and $PM_{2.5}$ samples showing on Fig. 10 and Fig. 11.

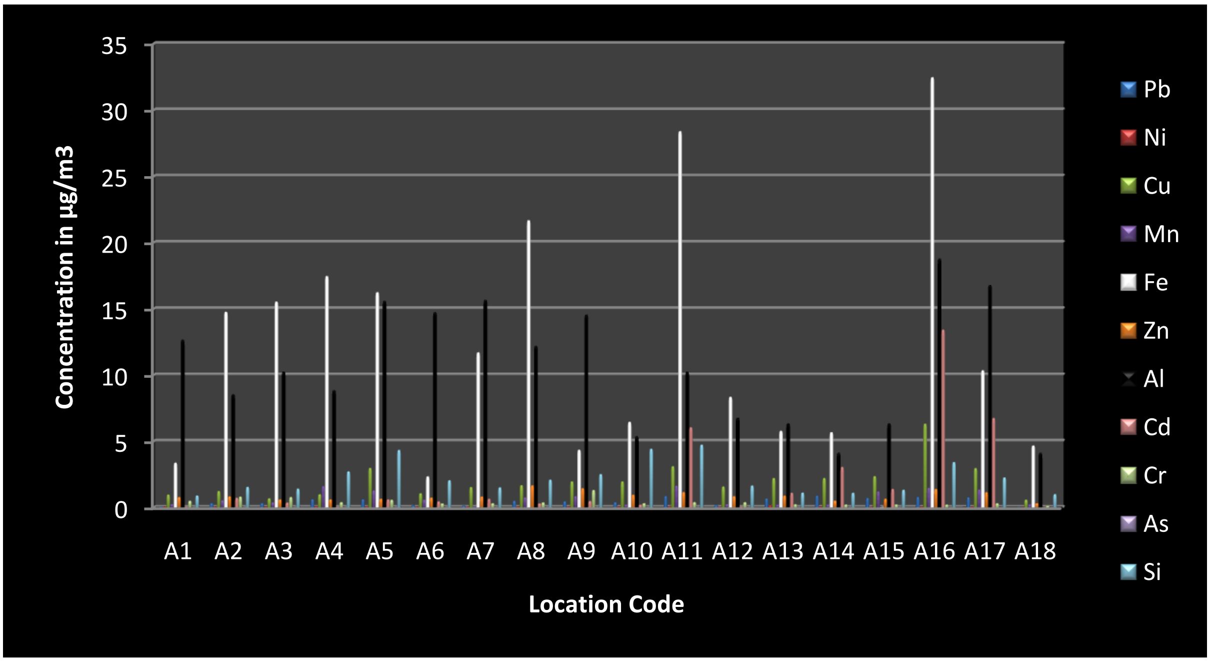

Fig. 10: Showing Annual Average Concentration of Trace Metals of PM_{10} at different locations

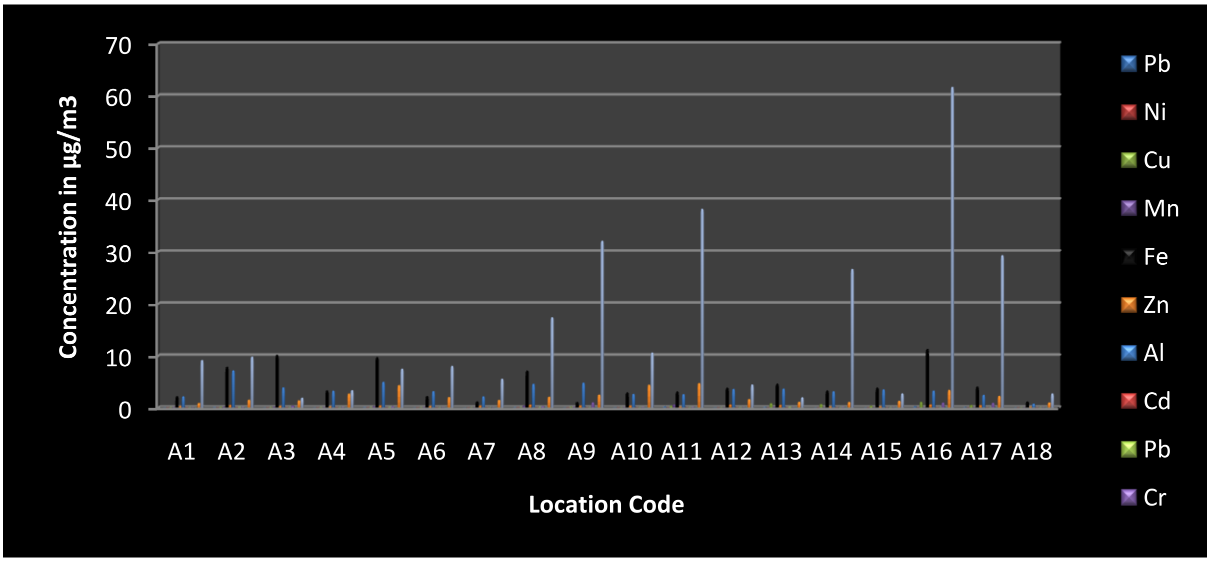

Fig. 11: Showing Annual Average Concentration of Trace Metals of $PM_{2.5}$ at different locations

VII. Conclusions:

Dhanbad/Jharia Coalfield (JCF) is very critically polluted with respect to fine particulate matter (PM_{10} and $PM_{2.5}$) and particulate bound trace metals. All monitoring stations except ISM, teacher's colony crossed permissible limit of PM_{10}, $PM_{2.5}$ and trace metals as per NAAQS-2009. Minimum concentration level of air borne particulate matter observed at ISM, teachers colony due to distance from source and greenbelt surrounding the campus. Monitoring stations contains (A-16, A-17, A-3, A-11 and A-8) high percentage of small size particulate matter is caring very large amount of Fe, Al, Cd, Cr, Pb and Cu. Mainly vehicular exhausts, tyre erosion, unauthorized coal burning, domestic fuel burning and very fine particulate matter travelling from industries. Study area nearby mining and other associated activities (A-4 and A-6) were found high percentage of larger size particulate matter and monitoring station (A-5,A-10, A-11 and A-17) containing both sizes of particulate matter are affected by of mining as well as transportation activities.

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