# Dispersion of Respirable Particles Emitted from Surface Mining Operations

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**Abstract**

Earlier studies on particulate matter (PM) emission from surface mining operations are mainly focussed on estimation of PM emission from different mining activities and quantificaion of the workers' exposure. Another set of studies measured PM around the mine to quantify the exposure level of people residing around the mine. However, these studies did not quantify the the contribution of mining to it. A study has been conducted to quantify the contribution of an active surface mine to the ambient PM level at locations up to a distance of 500 m from the mine. Mass concentrations of $PM_{10}$, $PM_{2.5}$ and $PM_1$ are measured at pit boundary, 100m, 200m, 300m, 400m and 500m from the pit boundary, using an aerosol spectrometer. Simultaneously the mining activity taking place inside the mine is recorded. Very high concentrations above 3500 μg $m^{-3}$ are observed when the mine was in full operation thatincludes coal cutting by surface miners and transport by tippers. Coarse fractions, which are primarily produced due to mining activities, were higher than the background level at a distance of 500m from the mine, which indicates a mine can contribute to enhance the ambient PM level even beyond 500m away from it. Significant positive correlations and linear relationships with moderate to good coefficient of determination ($R^2$) were obtained using Pearson's correlation coefficient and regression analysis respectively between concentrations of different particle sizes.

**Keywords:** $PM_{10}$, $PM_{2.5}$, $PM_1$, Pit boundary

## 1. Introduction

Air pollution from surface mines is mainly due to the fugitive emission of particulate matter (PM) and gases, including methane, sulphur dioxide and oxides of nitrogen. In comparison to underground mines, opencast mines give higher production due to the large-scale operations and use of high capacity and heavy machines. These machines sometimes generate huge quantities of PM leading to enhanced pollution levels in and around surface mines. This PM includes the raw materials mined and particles in the nearby haul road that is carried by the wind and some transportation movement in the working mine environment. In a surface mine, unit operations such as drilling, blasting, loading, transport and unloading emit PM in diverse size ranges directly to the atmosphere worsening human health and surrounding environment (Chaulya *et al*., 2003; Zhengfu *et al*., 2010; Heal *et al*., 2012; Zhang *et al*., 2013; Kumar *et al*., 2014; Patra *et al*., 2016). Studies in mining locality involved assessment of PM level around the mine that gives the exposure level of people residing around the mine (Pandey *et al*., 2014; Aneja *et al*., 2012; Kakosimos *et al*, 2011; Tecer *et al*. 2008; Ghose&Majee, 2001). While assessing the PM status around the mining locality it has not been clearly identified the contribution of mining and non-mining activities to it. For example, some studies have measured the PM level at the pit boundary which is expected to be predominantly contributed by mining activities (Gautam *et al*., 2015). However, very limited studies are available which have followed through the measurement to ascertain the change in PM level as we travel away from the pit boundary (Trivedi *et al*., 2009). These studies concentrated on coarse fraction ($PM_{10}$, TSPM) which are of little interest from health point. It is therefore important to know how far from the mine the respirable PM from mining activities can travel and thus the distance from the mine until which the mine is responsible for the deterioration of air quality. The PM level at different locations as we travel away from the pit boundary needs to be measured to understand how different sizes of respirable particles emitted from the mine get diminished in the air.

## 2. Methodology

### *2.1 Study Site*

The study was conducted at Kulda opencast project (OCP), located in the eastern part of India. It is situated between

latitudes 22° 01' 02" and 22° 03' 03" North and longitudes 83°43'28" and 83°45'35" East.Lease hold area of Kulda OCP is 536 ha. The pit size of Kulda OCP is 1600 × 550 m. Layout of Kulda OCP is shown in Figure 1.

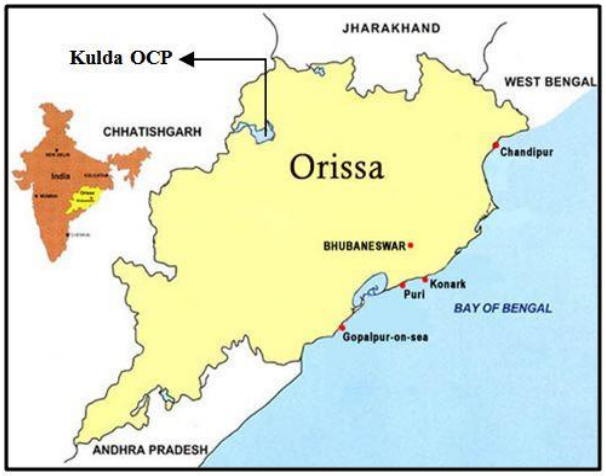



**Figure 1.** Layout of Kulda OCP

The project is designed to produce 10 million tonnes of coal at an overall stripping ratio of 0.97. At Kulda OCP, surface RL (RL stands for "Reduced Level") is 273.41 m. It has 3 overburden and 4 coal benches. Bench height and width for overburden are 10 m and 15 m respectively. Bench height and width for coal are 10 m and 50-70 m respectively. The pit bottom RL is 189.24 m. Mining is carried out using 5 surface miners each of which has cutting width and cutting depth of 3.8 m and 20 cm respectively, 12 pay loaders of 3 $m^3$ capacity each, 14 $m^3$ and 11 $m^3$ capacity tipper for overburden and coal respectively.

*2.2 Sampling Location and Duration*

In Kulda OCP, measurements were taken at 7 locations. The sampling locations are located on the surface at 100 m, 200 m, 300 m, 400 m and 500 m away from the pit boundary respectively. The sampling was carried out along the predominant downwind direction (i.e. towards SW). The study was carried out during the first shift during 24 November-13 December 2016. The duration of first shift is from 6:30 to 13:30. Starting time of sampling varied depending on the logistics of transport.

*2.2 Instruments*

*2.2.1. Grimm Aerosol Spectrometer*

Particulate matter concentration was measured using aerosol spectrometer (Model 1.108, Grimm, GRIMM Aerosol Technik GmbH & Co. KG, Germany) (Figure 2). Grimm aerosol spectrometer is a portable instrument which provides continuous measurement of aerosols in mass and number concentration. The instrument samples the air at 1.21 l $min^{-1}$. The instrument uses light scattering technology to measure particle concentration in 15 channels with size varying from 0.3 to 20 µm size. The measurement range is 0.1 – 100,000 µg/$m^3$ with an accuracy of ±3%. The time interval for sampling of this instrument ranges from 6s to 60 min. Data were retrieved through software (Windows Software model 1.177). During the present study data were recorded at 1 min interval.


**Figure 2.** Grimm aerosol spectrometer

## 3. Results and Discussion

*3.1 Spatio-temporal variation of PM concentrations*

The spatial and temporal variation of PM concentration levels at pit boundary and at five other locations away from the mine are shown in Figures 3-5. PM concentrations attained their highest values between 8 AM and 10 AM at every location though production statred before 8 AM. The possible reasons are: (1) PM started escapingthe pit due to gradual increase of temperature, decrease in RH when sun came out, (2) peak production and (3) transport of PMs with gradual increase in wind speed. Good dispersion of PMs occurred after 10 AM due to rapid decrease in RH and increase in wind flow. The maximum and average PM concentrations usually decreased with increasing distance from the mine. At a distance of 400-500 m from the mine, the PM level approached the local background level. Background PM concentrations are shown in Figure 6.

*3.2 Descriptive Statistics*

Descriptive statistics of PM concentrations is given in Table 1. The highest concentrations of $PM_{10}$, $PM_{2.5}$, $PM_1$ recorded at pit boundary were 3905.2, 493 and 187.3 µg $m^{-3}$ respectively. The corresponding average values are 521.72, 141.5 and 92.68 µg $m^{-3}$ which shows that the coarse particles dominate the PM that escapes from the mine. The mean $PM_{10}$ concentration continuously decreased from the pit boundary suggesting mining generated coarse particles settle fast. Up to 200 m the mean $PM_{2.5}$ and $PM_1$ concentrations were higher than the concentrations at pit boundary. In addition to the PM emitted from the mine travelling close to the surface, it was observed during the study that the often PM plume from the mine rises to a height of about 20 m. With wind the plume travelled in downwind direction and PM continuously settles from this plume with increasing distance until the visible plum completely disappeared. The higher $PM_{2.5}$ and $PM_1$ concentrations at 100 and 200 can be attributed to this combined action of PM transport near and above the surface. It has been observed that at a distance of 500m, the mean $PM_{2.5}$ and $PM_1$ concentrations

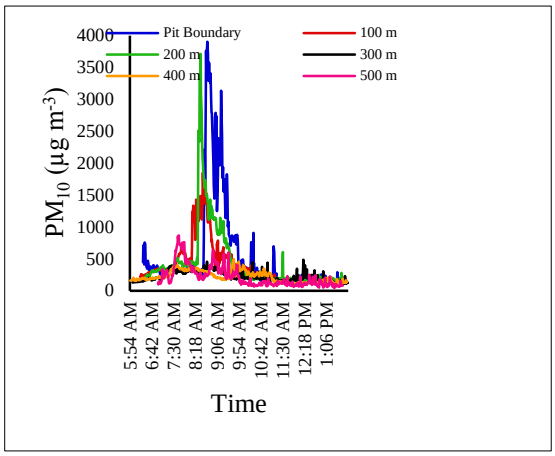



**Figure 3:** $PM_{10}$concentrations up to 500 m from pit boundary

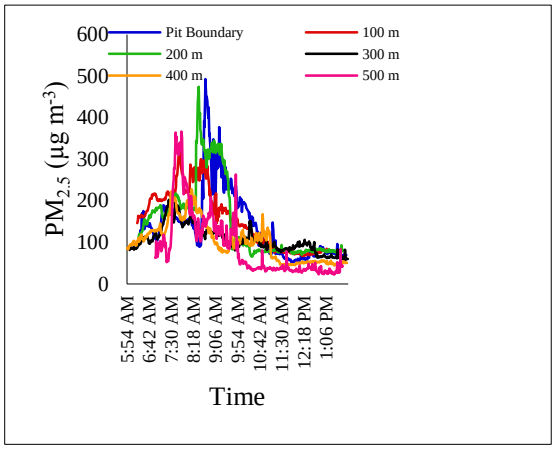



**Figure 4**: $PM_{2.5}$concentrations up to 500m from pit boundary

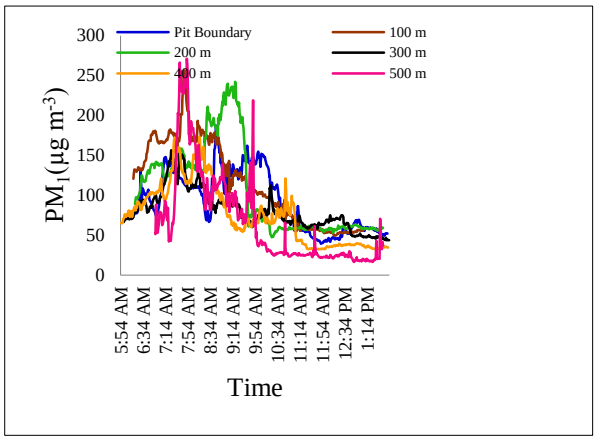



**Figure 5:** $PM_1$concentrations up to 500 m from pit boundary

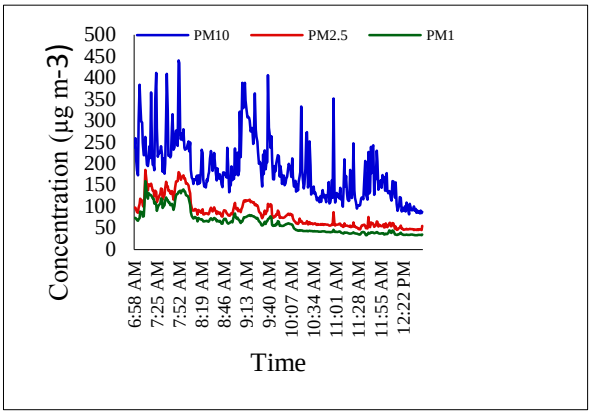



**Figure 6:** Background PM concentrations

have reached the background level while the PM10 level is higher than the background level. The coarse particles are primarily formed due to mining operations. This indicates that at a distance of 500 m from the mine, the contribution of surface mine to the local PM level still persists.

*3.3 Correlation and Regression Analysis*

The Pearson correlation coefficients between concentrations of different paticle sizes at each location were estimated with the aid of SPSS package (IBM SPPS Statistics 20) and presented in Table2. Significant positive correlations ($p = 0.000$) were obtained between $PM_{2.5}$ and $PM_{10}$, $PM_1$ and $PM_{10}$, $PM_1$ and $PM_{2.5}$ (Table 2). Linear relationships with $R^2 = 0.63$-$0.89$ between $PM_{2.5}$ and $PM_{10}$ (Srimuruganandam and Nagendra, 2010; Gupta et al., 2006**;** Chalouakou et al., 2003; Lu and Fang, 2002), $R^2 = 0.33$-$0.84$ between $PM_1$ and $PM_{10}$ (Srimuruganandam and Nagendra, 2010) were found at several monitoring locations starting from pit boundary up to 500 m (Figure 7). Linear relationships with $R^2 = 0.76$-$0.99$ were also obtained between $PM_1$ and $PM_{2.5}$ **(**Srimuruganandam and Nagendra, 2010) at each location (Figure 7). The relationships of coarse ($PM_{10}$) with fine ($PM_{2.5}$ and $PM_1$) particulates showed moderate to good coefficient of determination since $PM_{10}$ comprises of a large fraction of $PM_{2.5}$ and $PM_1$ which further reveals that the sources of these PMs are same i.e. mining operations.

## 4. Conclusion

From this study it has been found that the concentration of $PM_{10}$ continuously decreases from the pit boundary while the concentrations of $PM_{2.5}$ and $PM_1$ remain higher than the concentrations at pit boundary up to a distance of ~200 m from the mine. Combined action of PM transport near and above the surface is proposed to be reason behind this. At a distance of 500 m from the mine, the contribution of the mine to the local PM level still persists, especially in terms of coarse fractions. Significant positive correlations were obtained between $PM_{2.5}$ and $PM_{10}$, $PM_1$ and $PM_{10}$, $PM_1$ and $PM_{2.5}$ at each location. Linear relationships of coarse ($PM_{10}$) with fine ($PM_{2.5}$ and $PM_1$) particulates with moderate to good coefficient of determinations indicate that the sources of these PMs are same i.e. mining operations.

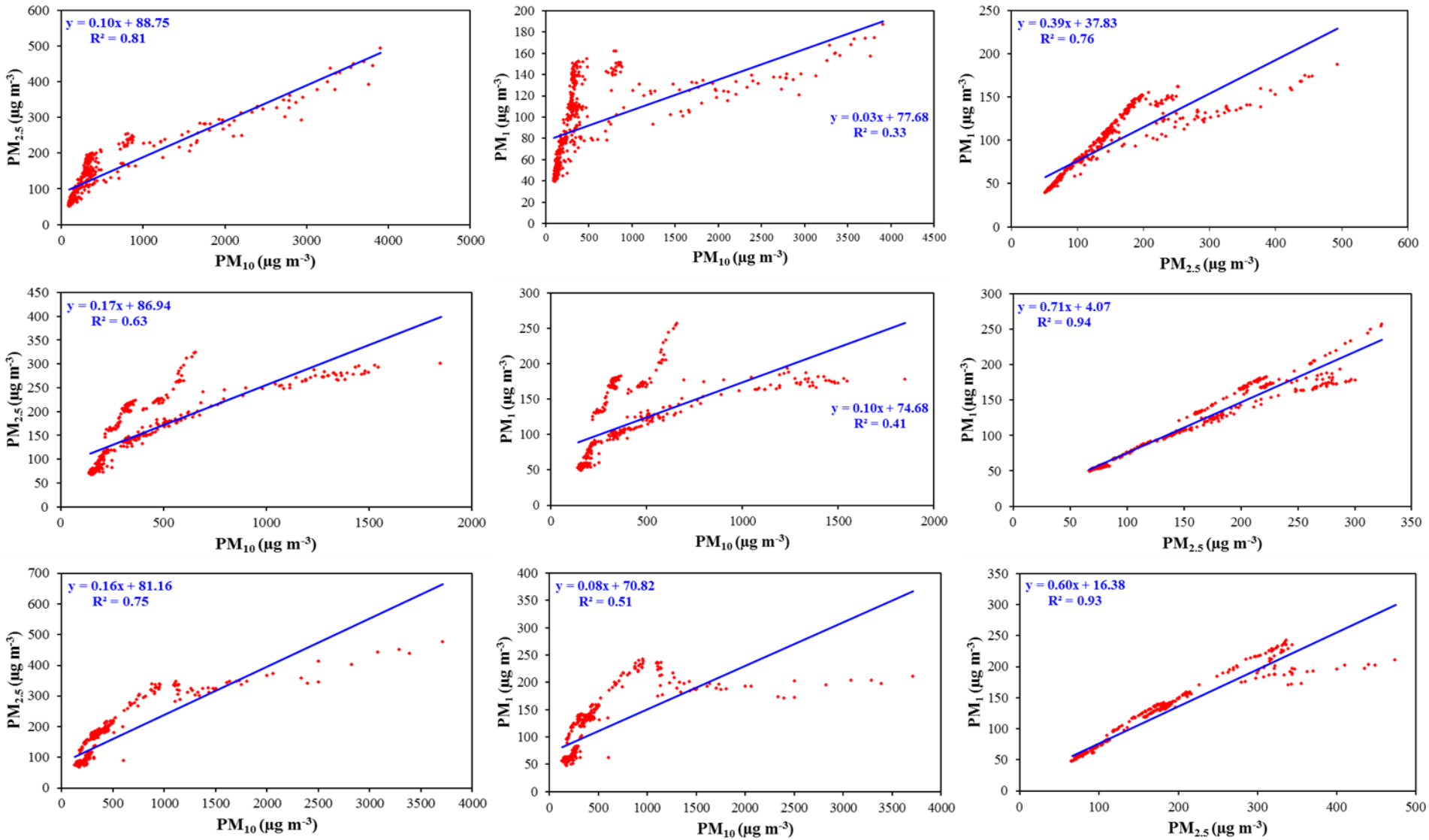
**Table 2:** Correlation matrix for PM concentrations

| Monitoring Location | | $PM_{10}$ | $PM_{2.5}$ | $PM_1$ |
|---|---|---|---|---|
| Pit Boundary | $PM_{10}$ | 1 | | |
| | $PM_{2.5}$ | 0.900** | 1 | |
| | $PM_1$ | 0.575** | 0.869** | 1 |
| 100 m | $PM_{10}$ | 1 | | |
| | $PM_{2.5}$ | 0.796** | 1 | |
| | $PM_1$ | 0.637** | 0.972** | 1 |
| 200 m | $PM_{10}$ | 1 | | |
| | $PM_{2.5}$ | 0.867** | 1 | |
| | $PM_1$ | 0.712** | 0.966** | 1 |
| 300 m | $PM_{10}$ | 1 | | |
| | $PM_{2.5}$ | 0.793** | 1 | |
| | $PM_1$ | 0.716** | 0.987** | 1 |
| 400 m | $PM_{10}$ | 1 | | |
| | $PM_{2.5}$ | 0.843** | 1 | |
| | $PM_1$ | 0.768** | 0.993** | 1 |
| 500 m | $PM_{10}$ | 1 | | |
| | $PM_{2.5}$ | 0.941** | 1 | |
| | $PM_1$ | 0.918** | 0.997** | 1 |

** Correlation is significant at the 0.01 level (2-tailed).

**Table 1:** Descriptive statistics of PM concentrations

| Location | PM ( $\mu g\ m^{-3}$) | N | Mean | Standard Deviation | Minimum | Maximum | Percentiles | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | 25 | 50 | 75 |
| Pit Boundary | $PM_{10}$ | 449 | 521.72 | 741.59 | 92.3 | 3905.2 | 144.1 | 295.2 | 380.5 |
| | $PM_{2.5}$ | 449 | 141.25 | 82.96 | 51.1 | 493 | 73.6 | 125.9 | 177.15 |
| | $PM_1$ | 449 | 92.68 | 37..07 | 39.3 | 187.3 | 56.5 | 91.9 | 125.35 |
| 100 m | $PM_{10}$ | 412 | 409.57 | 331.62 | 142.90 | 1850.2 | 183.9 | 319.95 | 482.25 |
| | $PM_{2.5}$ | 412 | 155.89 | 70.14 | 66.9 | 323.7 | 80 | 150.9 | 212.25 |
| | $PM_1$ | 412 | 115.12 | 51.4 | 49.3 | 256.6 | 57.875 | 107.8 | 167.175 |
| 200 m | $PM_{10}$ | 444 | 429.08 | 496.98 | 130.5 | 3713 | 182.28 | 244.8 | 420.98 |
| | $PM_{2.5}$ | 444 | 148.69 | 90.03 | 65.8 | 474.4 | 79.3 | 103.05 | 185.5 |
| | $PM_1$ | 444 | 105.04 | 55.57 | 47.4 | 242 | 58.53 | 73.95 | 138.18 |
| 300 m | $PM_{10}$ | 475 | 221.83 | 79.32 | 110.2 | 487.1 | 160.8 | 194.7 | 292.8 |
| | $PM_{2.5}$ | 475 | 106 | 31.60 | 57.8 | 202.6 | 85 | 98.6 | 123 |
| | $PM_1$ | 475 | 80.28 | 25.10 | 43.5 | 156.4 | 64.4 | 73.9 | 92.5 |
| 400 m | $PM_{10}$ | 478 | 216.69 | 87.75 | 98.3 | 492.4 | 135.28 | 197.15 | 287.43 |
| | $PM_{2.5}$ | 478 | 101.56 | 47.47 | 44.5 | 227.5 | 53.25 | 99.25 | 128.1 |
| | $PM_1$ | 478 | 75.34 | 37.5 | 32.1 | 173.3 | 37.8 | 71 | 101.1 |
| 500 m | $PM_{10}$ | 408 | 212.67 | 168.76 | 43.2 | 866.2 | 96.05 | 141.25 | 270.23 |
| | $PM_{2.5}$ | 408 | 89.53 | 77.62 | 22.9 | 366.8 | 34.73 | 47.9 | 127.70 |
| | $PM_1$ | 408 | 66.32 | 58.02 | 16.4 | 271 | 24.50 | 37 | 94.65 |
| Background | $PM_{10}$ | 348 | 185.47 | 70.84 | 81.5 | 440 | 131.78 | 171.7 | 224.58 |
| | $PM_{2.5}$ | 348 | 83.68 | 33.12 | 44.8 | 184.9 | 57.03 | 78.3 | 99.18 |
| | $PM_1$ | 348 | 62.98 | 28.67 | 32.9 | 158.9 | 39.73 | 58.35 | 74.03 |


y = 0.10x + 88.75
R² = 0.81
PM2.5 (μg m-3)
PM10 (μg m-3)
y = 0.03x + 77.68
R² = 0.33
PM1 (μg m-3)
PM10 (μg m-3)
y = 0.39x + 37.83
R² = 0.76
PM1 (μg m-3)
PM2.5 (μg m-3)
(A)
y = 0.17x + 86.94
R² = 0.63
PM2.5 (μg m-3)
PM10 (μg m-3)
y = 0.10x + 74.68
R² = 0.41
PM1 (μg m-3)
PM10 (μg m-3)
y = 0.71x + 4.07
R² = 0.94
PM1 (μg m-3)
PM2.5 (μg m-3)
(B)
y = 0.16x + 81.16
R² = 0.75
PM2.5 (μg m-3)
PM10 (μg m-3)
y = 0.08x + 70.82
R² = 0.51
PM1 (μg m-3)
PM10 (μg m-3)
y = 0.60x + 16.38
R² = 0.93
PM1 (μg m-3)
PM2.5 (μg m-3)
(C)

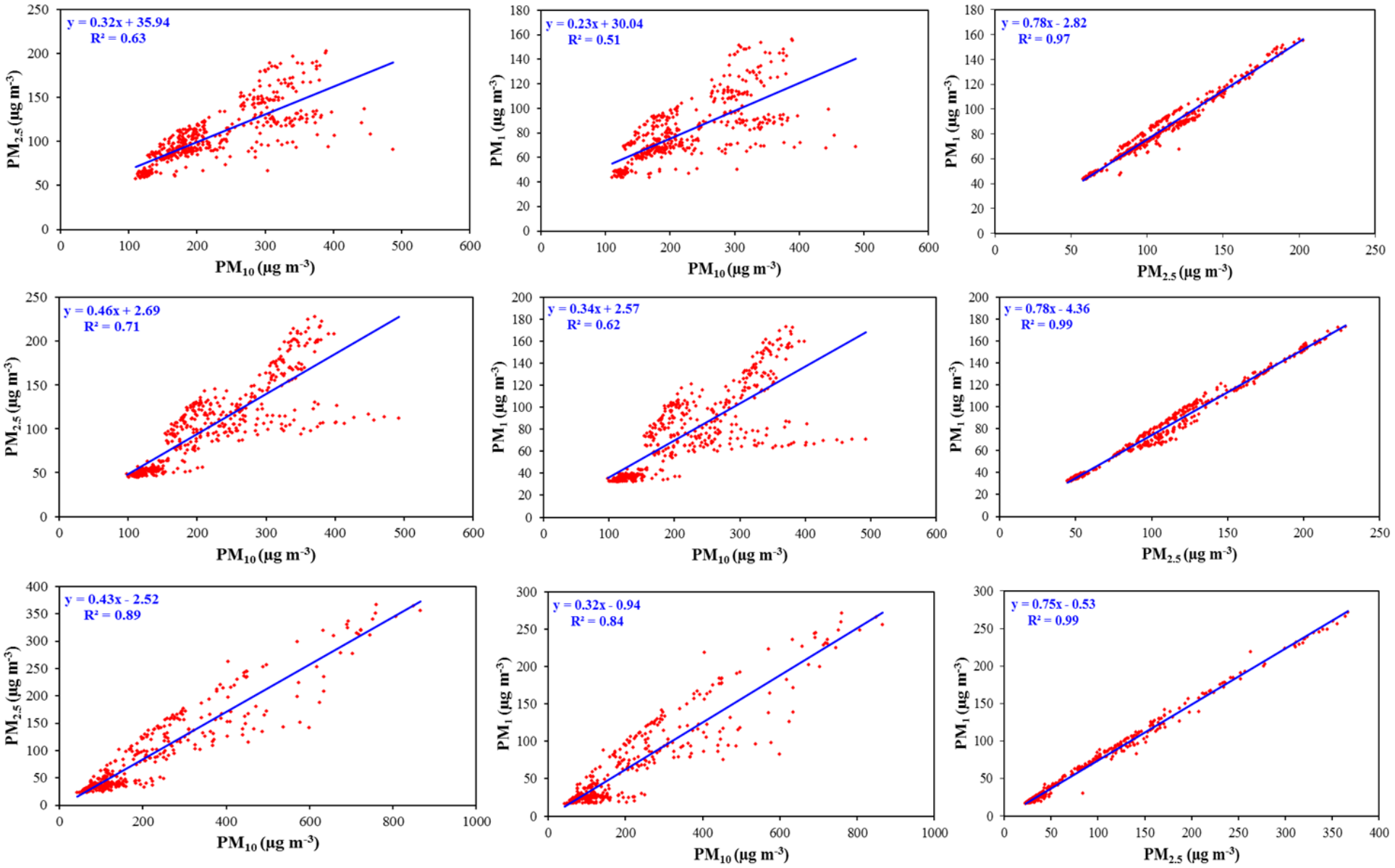



**Figure 7:** Scatter plots between concentrations of diffrent particle sizes at; (A) pit boundary, (B) 100 m, (C) 200 m, (D) 300 m, (E) 400 m and (F) 500 m

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