Non-linear Regression Models for PM$_{10}$ and PM$_{2.5}$ Concentrations in Ambient Air due to Burning of Crop Residues

Lippi Chanduka$^1$, Ram Pal Singh$^2*$ and Amit Dhir$^3$

$^1$Department of Civil Engineering, Motilal Nehru National Institute of technology, Allahabad-211004, Uttar Pradesh, India
$^2$Department of Civil Engineering, Motilal Nehru National Institute of technology, Allahabad-211004, Uttar Pradesh, India
$^3$School of Energy and Environment, Thapar University, Patiala-147004, Punjab, India

Abstract

In Mandi-Gobindgarh, Punjab, India, open crop residue burning is one of the major sources of air pollution in the area besides pollutions from industries, vehicles, etc. In this paper, the impact of open crop residue burning on the concentrations of particulate matters (PM$_{10}$ and PM$_{2.5}$) in ambient air for paddy and wheat crop seasons were monitored at five different locations during year 2012-2013. The air quality data for PM$_{10}$ and PM$_{2.5}$ were subjected to non-linear regression analysis for both paddy and wheat crop seasons. The regression models for PM$_{10}$ are best described by the power functions, while for PM$_{2.5}$ by the exponential functions with $R^2$ values higher than 0.99. These models may prove useful tool in estimation of the PM$_{10}$ and PM$_{2.5}$ concentrations in ambient air for the areas where stubble burning is practiced by farmers.

Keywords: Ambient air quality; Crop residue burning; PM$_{10}$; PM$_{2.5}$; Non-linear regression model

Abbreviations: PM$_{10}$: Particulate Matter (Size less than 10 μm); PM$_{2.5}$: Particulate Matter (Size less than 2.5 μm); $R^2$: Coefficient of Determination; $V$: Volume of air sampled; $F$: Measured flow rate before sampling; $F_1$: Measured flow rate after sampling; $T$: Time of sampling; $W$: Final mass of glass fibre filter (47 mm) paper; $W_1$: Initial mass of glass fibre filter (47 mm) paper; $W_f$: Final mass of PTFE filter paper; $W_{f1}$: Initial mass of PTFE filter paper; $y$: PM$_{10}$ concentration; $y_1$: PM$_{2.5}$ concentration; $x$: Sample No. (Time); RMSE: Root Mean Square Error; MPSD: Marquardt’s Percent Standard Deviation; SE: Standard Error; SSE: Sum of Square Error

Introduction

Burning of crop residue has been an agricultural practice, especially in the developing countries like India, as it is one of the cheapest ways of disposal, less time consuming and less laborious to prepare the land for further farming. It deteriorates the ambient air quality by producing large amounts of particulate matters and gases into the atmosphere. The ambient air quality of Mandi-Gobindgarh, Punjab, India has been degraded a lot during the last few years due to extensive industrialization as well as crop residue burning. The Cumulative Environmental Pollution Index (CEPI) for Mandi-Gobindgarh with respect to air was calculated to be 62 [1]. Due to this reason, Mandi-Gobindgarh is declared as critically polluted area [2]. Apart from the industries and vehicular emissions, crop residue burning in agricultural fields is one of the main reasons for the deterioration of the ambient air quality of Mandi-Gobindgarh area.

To prepare the fields for the subsequent crop to be sown, crop residue burning is done by the farmers for clearing the land from stubble and weeds. Biomass burning is one of the major sources of gaseous and particulate emissions in to the atmosphere. Therefore, monitoring of particulate matters especially PM$_{10}$ and PM$_{2.5}$ in the ambient air is necessary as they cause severe adverse health effects on human beings residing in such area.

Limited studies on gaseous and particulate emissions from open burning of crop residue, especially in an industrial area, have been reported. In the survey by Gao et al. [3], on an average, only 6.6% of the crop residue is returned to the soil directly. Ground-based ambient air monitoring at five different locations in and around Patiala city was conducted in order to determine the impact of open burning of rice crop residues on SPM, SO$_2$ and NO$_x$ concentrations in the ambient air. Substantially higher concentrations of PM$_{10}$ and PM$_{2.5}$ were reported by Singh et al. [4] at the commercial areas as compared to the other sampling sites. Gupta et al. [5] studied the type as well as amount of air pollutants in industrial town of Mandi-Gobindgarh as well as surrounding areas and reported that the cause of urban air pollution is mainly due to presence of excessive suspended particulate matters, whereas, in rural areas, air is polluted by particulate matters as well as CO$_2$ and NOx from stubble burning. Demuzere and Lipizig [6] used a multiple linear regression technique combined with the automated Lamb weather classification to make projections for the future air quality levels. Akpinar et al. [7], studied the relationship between monitored air pollutant concentrations and meteorological factors using linear and non-linear regression models and observed that there exist a moderate and weak correlation between the air pollutant concentrations and the meteorological factors. The present study aims to develop non-linear regression models to predict the PM$_{10}$ and PM$_{2.5}$ concentrations in the ambient air due to open biomass burning based on the experimental study conducted in Mandi-Gobindgarh district in Punjab, India.

Materials and Methods

Study area

Mandi-Gobindgarh is a town located in Fatehgarh Sahib District in the state of Punjab, India and is also known as ‘Steel Town of India’

*Corresponding author: R.P. Singh, Professor, Department of Civil Engineering, Motilal Nehru National Institute of technology, Allahabad-211004, Uttar Pradesh, India, Tel: +919450536371; E-mail: rps@mnmit.ac.in

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as various steel manufacturing industries is operating in this town. The
town is located on National Highway-I and spread over an area
of 10.64 Sq. k.ms with population of 55,416 as per 2001 census records.
Geographically, Mandi-Gobindgarh is situated in between north
latitude 30°-37'-30" and 30°-42'-30" and east longitude 76°-15' and 76°-
20'. There are 510 coal/oil based industries (404 in Mandi-Gobindgarh
and 106 in Khanna area) causing air pollution in the area besides
the fugitive emissions [1]. On the basis of land use, demography and
industrial clusters, five sampling sites were selected for the study.
Eight industrial clusters have been identified within the jurisdiction
of critically polluted area of Mandi-Gobindgarh and Khanna area (PPCB,
2010). The site location and its classification are presented below in
Table 1.

Measurement of PM10 and PM2.5

The weather monitoring station used in this study was Watch
Dog of Spectrum Series 2000. The Watch Dog weather station is a
multifunction device to detect as well as to store seven parameters
including wind speed, wind direction, temperature, relative humidity,
dew point, pressure and solar radiations using different sensors for
each parameter. For measurement of PM10 and PM2.5 in ambient air,
Ambient Fine Dust Sampler (Model no. IPMDFS-2.5 μ/10 μ of INSTRUMEX) was used and it conforms to the USEPA,
USA and CPCB, India norms. For sampling of PM10, Whatman 1820-
047 filter paper having 47 mm diameter, while for sampling of PM2.5,
Whatman 7582-004 filter paper having 37 mm diameter and PTFE
filters having diameter 46.2 mm were used [8,9].

Sampling of PM10 and PM2.5 was carried out for rice and wheat
harvesting periods starting from September 2012 to May 2013, at all
the five selected sites. The total time period of monitoring has been
categorized as pre-harvesting (September, 2012 to February-March, 2013 for wheat); harvesting period (October-November, 2012 for rice and April, 2013 for wheat) and post-harvesting period (December, 2012 to January, 2013 for rice and May, 2013 for wheat). Each new blank filter paper was conditioned over dried
silica gel, prior to use, in a desiccator for 24 hrs and weighed at room
temperature (25°C). Pre-inspected and weighed new blank filters were
placed into the sampling device for continuous sampling. After 24 h of
sampling, an exposed filter paper was reweighed; data were retrieved
from the instrument to get initial and final flow rate for each sample
and the concentrations of PM10 and PM2.5 were calculated as follows.
The volume of air sampled was calculated using following equation.

\[ V_a = (F_1 + F_2) \times T/2 \]  

(1)

Where, \( V_a \) is the volume of air sampled in m³, \( F_1 \) and \( F_2 \) are the measured flow rates before and after sampling in LPM and \( T \) is time of
sampling in minutes.

PM10 concentration was calculated by the following expression,

\[ PM_{10} = (W_f - W'f) \times 1000/V_a \]  

(2)

Where, \( PM_{10} \) is total mass concentration of PM10 collected during
the sampling period in μg/m³, \( W_f \) and \( W'f \) are the final and initial mass
of PTFE filter paper in mg, \( V_a \) is the total air volume sampled in m³.

PM2.5 concentration was calculated by:

\[ PM_{2.5} = (W_f - W') \times 1000/V_a \]  

(3)

Where, \( PM_{2.5} \) is total mass concentration of PM2.5, collected during
the sampling period in μg/m³, \( W_f \) and \( W' \) are the final and initial mass
of PTFE filter paper in mg.

Using Eq’s (1), (2) and (3) PM10 and PM2.5 concentrations were
calculated for all the sampling sites during three sampling periods viz.
pre-harvesting, during harvesting and post-harvesting. Tables 2 and 3
shows the experimental concentration of PM10 and PM2.5 for paddy and
wheat crops respectively.

Non-Linear regression analysis

Since high concentrations of particulate matters affect the public
health, much attention is required to be paid towards the improvement
of the accuracy of short-term deterministic and statistical models and
the development of robust long-term air-quality prediction models.

| Site No. | Site classification | Site location | Site description | Percent area covered |
|---------|-------------------|---------------|-----------------|----------------------|
| 1       | Agricultural Site | 20 kms South-East of Mandi-Gobindgarh | It is a broad open area with no side buildings with no industries | 100% agricultural area |
| 2       | Mixed-land use site(i) | 2 kms North of Amloh Chowk | Partially industrialized area, major proportion is covered by agriculture | 30% industrial area and 70% agricultural area |
| 3       | Mixed-land use site(ii) | National highway (NH1) | Broad open area with no side buildings with high vehicular pollution | 60% area covered by highway and 20% agricultural and industrial area |
| 4       | Mixed-land use site(iii) | Guru kinagri, south-east on GT road from Mandi-Gobindgarh | Semi urban site, having mixed land use comprising of industrial, residential and agricultural area | 80% industrial and 20% agricultural area |
| 5       | Industrial site | Industrial focal point, 2 kms South-west from Mandi-Gobindgarh | Area is less populated as land use of the area is totally industrial | 100% Industrial area |

Table 1: Site location and classification.

| Site No. | Sample No. | PM10 experimental conc. for three sampling periods for paddy crop | PM2.5 experimental conc. for three sampling periods for wheat crop |
|----------|------------|---------------------------------------------------------------|---------------------------------------------------------------|
|          |            | Pre-harvesting | During harvesting | Post-harvesting | Pre-harvesting | During harvesting | Post-harvesting |
| 1        | 1          | 228.2          | 376.4           | 336           | 285.1          | 458.5           | 420.5           |
| 2        | 2          | 260.4          | 432.9           | 368.6         | 316.5          | 495.8           | 447.8           |
| 3        | 3          | 328.4          | 490.8           | 396.7         | 355.8          | 530.6           | 473.4           |
| 4        | 4          | 344.2          | 502.9           | 429.2         | 375.2          | 548.7           | 487.1           |
| 5        | 5          | 380.1          | 525.6           | 442.6         | 400.3          | 559.1           | 499.6           |
| 6        | 6          | 400            | 539.7           | 458.9         | 419.1          | 566.2           | 508.8           |
| 7        | 7          | 425.3          | 557.7           | 480.2         | 438.7          | 587.4           | 522.3           |
| 8        | 8          | 439.2          | 569.9           | 492.1         | 449.5          | 595.2           | 528.6           |
| 9        | 9          | 461.5          | 583.9           | 508.2         | 465.5          | 600.1           | 542.2           |
| 10       | 10         | 473.3          | 592.3           | 518.4         | 480.6          | 617.2           | 551.4           |

Table 2: Experimental concentrations of PM10.
Non-linear regression models for PM$_{10}$ and PM$_{2.5}$ concentrations in ambient air due to burning of crop residues.

Results and Discussion

Non-linear regression analysis of PM$_{10}$ in ambient air

The experimental concentrations of PM$_{10}$, as presented in Table 2, are plotted against sample number (Time) for all the three sampling periods. Figures 1a-1c show the variation of PM$_{10}$ concentration for paddy and wheat crops respectively during pre-harvesting, harvesting and post-harvesting periods. From Figures 1a-1c, it is evident that the variation of PM$_{10}$ concentration is well described by a non-linear power function with $R^2$ values more than 0.99 in all the three cases. Thus exponential functions so developed are suitable non-linear

Non-linear regression analysis of PM$_{2.5}$ in ambient air

The experimental concentrations of PM$_{2.5}$, as presented in Table 3, are plotted against sample number (Time) for all the three sampling periods. Figures 2a-2c show the variation of PM$_{2.5}$ concentration for paddy and wheat crops respectively during pre-harvesting, harvesting and post-harvesting periods. From Figures 2a-2c, it is evident that the variation of PM$_{2.5}$ concentration is well described by a non-linear exponential function with $R^2$ values more than 0.99 in all the three cases. Thus exponential functions so developed are suitable non-linear.
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| Site No. | Sample No. | Pre-harvesting | During harvesting | Post-harvesting | Pre-harvesting | During harvesting | Post-harvesting |
|----------|-------------|----------------|------------------|----------------|----------------|------------------|----------------|
|          |             | Experimental conc. | Predicted conc. | % error | Experimental conc. | Predicted conc. | % error | Experimental conc. | Predicted conc. | % error | Experimental conc. | Predicted conc. | % error |
| 1        | 1           | 228.2           | 220.9            | 3.2      | 378.4           | 381.9           | -3.2     | 285.1           | 276.6           | 3.1      | 458.5           | 457.8           | 0.1      |
| 2        | 2           | 260.4           | 278.1            | -6.8     | 432.9           | 437.2           | -1.1     | 316.5           | 325.2           | -2.8     | 495.8           | 499.6           | -0.8     |
| 3        | 3           | 328.4           | 318.1            | 3.1      | 490.8           | 473.1           | 3.6      | 355.8           | 357.5           | -0.5     | 530.6           | 525.8           | 0.9      |
| 4        | 4           | 344.2           | 349.9            | -1.7     | 502.9           | 500.4           | 0.5      | 375.2           | 382.3           | -1.9     | 548.7           | 545.2           | 0.6      |
| 5        | 5           | 380.1           | 376.9            | 0.8      | 525.6           | 522.7           | 0.6      | 442.6           | 447.9           | -1.2     | 559.1           | 560.7           | -0.3     |
| 6        | 6           | 400             | 400.4            | 0.1      | 539.7           | 541.6           | 0.4      | 458.9           | 463.9           | -1.1     | 519.1           | 420.2           | -0.3     |
| 7        | 7           | 425.3           | 421.4            | 0.9      | 557.7           | 558.1           | -0.1     | 480.2           | 478.1           | 0.4      | 438.7           | 435.6           | 0.7      |
| 8        | 8           | 439.2           | 440.5            | -0.3     | 569.9           | 572.9           | -0.5     | 492.1           | 490.6           | 0.3      | 449.5           | 449.4           | 0.02     |
| 9        | 9           | 461.5           | 458              | 0.7      | 583.9           | 586.2           | -0.4     | 508.2           | 501.9           | 1.2      | 465.5           | 461.9           | 0.8      |
| 10       | 10          | 473.3           | 474.3            | -0.2     | 592.3           | 598.3           | -1       | 518.4           | 512.3           | 1.2      | 480.6           | 473.4           | 1.5      |

Table 4: Experimental and predicted PM$_{10}$ concentration with percent error.

![Figure 2](image_url)

Figure 2: Comparison of experimental and predicted PM$_{10}$ concentrations at five sampling sites for paddy crop for (2a) pre-harvesting (2b) during harvesting and (2c) post-harvesting periods.
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Figure 3: Comparison of experimental and predicted PM_{10} concentrations at five sampling sites for wheat crop for (3a) pre-harvesting (3b) during harvesting and (3c) post-harvesting periods.

| Sampling Periods | Statistical parameters |
|------------------|------------------------|
|                  | Regression Equation    | R² | Mean | MPSD | RMSE | SSE | SE |
| Pre-Harvesting   | y=220.95x^{0.3318}     | 0.987 | 373.872 | 0.0298 | 7.38 | 0.035 | 8.225 |
| During harvesting| y=381.9x^{0.195}       | 0.99 | 517.248 | 0.151 | 6.552 | 0.001 | 7.255 |
| Post-Harvesting  | y=327.7x^{0.1941}      | 0.99 | 443.201 | 0.0149 | 5.398 | 0.008 | 5.945 |

Table 5: Regression equation and statistical parameters for PM_{10} concentration for paddy crop.

| Sampling Periods | Statistical parameters |
|------------------|------------------------|
|                  | Regression Equation    | R² | Mean | MPSD | RMSE | SSE  | SE |
| Pre-Harvesting   | y=276.67x^{0.2333}     | 0.991 | 398.51 | 0.017 | 5.306 | 0.013 | 5.809 |
| During harvesting| y=457.82x^{0.126}      | 0.994 | 555.87 | 0.008 | 3.975 | 0.0001 | 4.444 |
| Post-Harvesting  | y=416.07x^{0.1171}     | 0.992 | 498.18 | 0.008 | 3.58  | 0.0001 | 3.986 |

Table 6: Regression equation and statistical parameters for PM_{10} concentration for wheat crop.
regression model for prediction of PM$_{2.5}$ concentrations for both paddy and wheat crops for pre-, during and post-harvesting periods.

Comparisons of the PM$_{2.5}$ concentrations for paddy and wheat crops, between predicted and experimental values are shown in Figure 5a-5c and in Figure 6a-6c respectively. From Figure 5a-5c and Figure 6a-6c, it is evident that predictions of PM$_{2.5}$ concentrations using developed non-linear regression models, are in close agreement with experimental PM$_{2.5}$ concentrations within the maximum error bands of ± 4.7%, which is within the acceptable limit.

The statistical parameters ($R^2$, Mean, MPSD, RMSE, SSE and SE) using predicted values are determined by using their basic definitions and expressions available in literature [10] are presented in Tables 8 and 9 for paddy and wheat crops respectively.

From these tables it is evident that RMSE values are quite low and hence, predictions of PM$_{2.5}$ concentrations are in close agreement with the experimental PM$_{2.5}$ concentrations.

From the analysis of both PM$_{10}$ and PM$_{2.5}$ concentrations, it is evident that crop residue burning does effect the PM$_{10}$ and PM$_{2.5}$ concentrations in ambient air during, pre- and post-harvesting periods and are observed in much higher concentrations (617.2 μg/m$^3$ for PM$_{10}$ and 176.3 μg/m$^3$ for PM$_{2.5}$), than the permissible standards of NAAQS (2009). As per NAAQS (2009), the PM$_{10}$ concentration in ambient air is 100 μg/m$^3$ (24hr Average) while PM$_{2.5}$ concentration is 60 μg/m$^3$ (24hr average) [8]. In order to predict the concentrations of PM$_{10}$ and PM$_{2.5}$ in ambient air for both paddy and wheat crops (pre-, during and post-harvesting periods), non-linear regression equations (power function for PM$_{10}$ and exponential function for PM$_{2.5}$) are developed, which are found accurate in prediction of PM$_{10}$ and PM$_{2.5}$ concentrations in present work. However, they need to be verified with experimental results in future studies.

**Conclusion**

The primary objective of this study was to develop regression-based models to predict the PM$_{10}$ and PM$_{2.5}$ concentrations in ambient air where crop residue burning is practiced. In the present work, using experimental results of PM$_{10}$ and PM$_{2.5}$ measured in Mandi-Gobindgarh (Punjab state) in India due to crop residue burning during pre- and post-harvesting periods for paddy and wheat crops are utilized to develop non-linear regression models to predict PM$_{10}$ and
Figure 5: Comparison of experimental and predicted PM$_{10}$ concentrations at five sampling sites for paddy crop for (5a) pre-harvesting (5b) during harvesting and (5c) post-harvesting periods.

Figure 6: Comparison of experimental and predicted PM$_{2.5}$ concentrations at five sampling sites for wheat crop for (6a) pre-harvesting (6b) during harvesting and (6c) post-harvesting periods.
PM$_{2.5}$ concentration for paddy crop

| Sampling Periods | Regression Equation | Statistical parameters |
|------------------|---------------------|------------------------|
| Pre-Harvesting   | $y = 56.031e^{0.11x}$ | $R^2 = 0.998$, Mean = 107.804, MPSD = 0.017, RMSE = 1.729, SSE = 0.0001, SE = 1.921 |
| During harvesting| $y = 85.246e^{0.093x}$ | $R^2 = 0.998$, Mean = 147.483, MPSD = 0.012, RMSE = 1.607, SSE = 0.0007, SE = 1.789 |
| Post-Harvesting  | $y = 66.763e^{0.097x}$ | $R^2 = 0.998$, Mean = 118.367, MPSD = 0.014, RMSE = 1.383, SSE = 0.004, SE = 1.496 |

Table 8: Regression equation and statistical parameters for PM$_{2.5}$ concentration for paddy crop.

PM$_{10}$ concentrations. PM$_{2.5}$ concentrations are best described by a non-linear power functions while PM$_{10}$ concentrations are well described by exponential functions, as evident from high $R^2$ values ($R^2>0.99$) and low RMSE values in almost all cases studied. These regression equations are based on present experimental results, therefore, they need to be verified in future studies.

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References

1. PPCB (2010) Action plan for the abatement of pollution in critically polluted area of Mandi Gobindgarh.
2. CPCB (2000) “Parivesh” Annual report for session 1999-2000, from Environmental Information System (ENVIS) from Central Pollution Control Board.
3. Gao X, Ma C, Zhang F, Wang Y (2002) Analysis on the current status of utilization of crop straw in China. Journal of Huazhong Agricultural University 21: 242-247.
4. Singh N, Mittal SK, Agarwal R, Awasthi A, Gupta PK (2010) Impact of rice crop residue burning on levels of SPM, SO2 and NO2 in the ambient air of Patiala (India). International Journal of Environmental Analytical Chemistry 90: 829-843.
5. Gupta S, Gupta C, Grewal DS (2013) Air Pollution in Punjab with Special Reference to Mandi-Gobindgarh and Surrounding Areas: An analytical study; IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT) 2319-2402.
6. Demuzere M, Lipzig NPV (2010) A new method to estimate air-quality levels using a synoptic-regression approach. Part I: Present-day O3 and PM10 analysis. Atmospheric Environment 44: 1341-1355.
7. Akpinar EK, Akpinar S, Oztop HF (2009) Statistical Analysis of Meteorological Factors and Air Pollution at Winter Months in Elazığ, Turkey. Journal of Urban and Environmental Engineering 3: 7-16.
8. CPCB (2003) “Guidelines for Ambient Air Quality Monitoring” Report under Central Pollution Control Board, Ministry of Environment & Forests.
9. CPCB (2011) “Guidelines for the Measurement of Ambient Air Pollutants, Volume-I” Report under Central Pollution Control Board, Ministry of Environment & Forests.
10. Zahra F (2013) Studies on Interactions and Adsorption dynamics of Cr (VI) Removal by Emblica Officinalis leaf powder, Ph.D thesis awarded in 2013 at MNNIT, Allahabad.