Investigation of Variation in Ambient PM_{10} Levels within an Urban-Industrial Environment

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Abstract

Major factors responsible for variation occurring in ambient particulate levels in urban areas are, growing of a number of stationary and mobile sources of particulate matter and meteorological parameters. The work presented here focused on the effect of meteorological parameters on ambient PM levels and the relationship of those levels at industrial complexes with their components at receptor ambient sites. Seven monitoring stations were identified in the study area for the measurement of PM_{10} levels during 2005-06. Of the seven sampling stations three were located in three major industrial complexes in the study area, and the remaining four were taken as receptor zones of particulate matter. All receptor-PM_{10} values showed moderate correlation with specific industrial complexes. Most of the receptors showed PM_{10} levels exceeding Indian NAAQS for residential areas. An inverse relationship between PM_{10} levels and meteorological parameters has been obtained.

***Keywords*:** Ambient particulate; Source-receptor relationship; Seasonal variation; Urban area.

INTRODUCTION

Large urban centers of developing countries face difficult environmental problems arising from the growth of industrial complexes. They are receiving significant environmental damage due to the air pollutants (Bohm and Saldiva, 2000). Major sources of urban air pollution in India include coal combustion, oil refineries and industrial manufacturing facilities (Slanina *et al.,* 1995; Murray *et al.,* 2001). Automobile exhaust, emissions from small-scale workshops and soil-derived aerosols are additional sources (Sharma, 2002). Aerodynamic diameter is important for particulate transport, collection

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and human respiratory track deposition. In 1987, the National Ambient Air Quality Standards (NAAQS) for particulate matter (PM) were revised to use PM_{10} (particles less than 10 microns in size), rather than total particulate suspended matter, as the indicator for NAAQS due to its significance to the human respiratory system (Federal Register, 1997). A growing body of literature demonstrates that inhabitants of air polluting areas are increasingly sensitive to the effects of fine particulate pollution. Elevated concentration of fine particulate matter has been associated with lower heat rate variability, post-neonatal infant mortality and the frequency of cardiac arrhythmic events (Bobak and Leon, 1999; Loomis *et al.,* 1999; Pope *et al.,* 1999; Peters *et al.,* 2000).

Meteorological parameters play a significant role in transport, diffusion and natural cleansing in the atmosphere. The air pollution cycle consist of three phases: release of air pollutant at the sources, transport and diffusion in the atmosphere, and reception by people, plants and animals (Goel and Trivedy, 1998; EPA, 2003). The presented study focused on investigating dispersion patterns of ambient PM_{10} in urban environment of Raipur, Chhattisgarh in India, factors that affect it as a result of industrial complexes around the city, and on the variation in local meteorological parameters. Also taken into account is the relationship of ambient receptors with ambient sources (specifically industrial complexes) of PM_{10}. A uniform area network using a rectilinear system was used for monitoring and sampling (Goel and Trivedy, 1998).

DESIGN AND METHODOLOGY

Sampling design

The dispersion and transport of suspended particulate matter (SPM) in the atmosphere, which is of prime concern for air pollution researchers, are affected by meteorological parameters (wind speed, relative humidity, wind direction and temperature). Pollutant dispersion depends on downwind transport by prevailing winds. Urban industrial complexes play significant roles in ambient PM levels as indicated when monitored at receptor zones (Goel and Trivedy, 1998; Sharma, 2002). On the basis of these factors, we measured ambient PM_{10} in selected residential/ commercial locations in Raipur, District Raipur, Chhattisgarh. Three major industrial complexes (Urla, Siltara and Mandir Hasoud) located on outskirts of the city (Fig. 1) were identified as source sites for ambient monitoring of PM_{10} and were selected for monitoring PM_{10} and investigating relationships of receptor-PM_{10} levels.

The study began with the identification of sampling sites for ambient monitoring on the basis of previously reported wind rose data and local activity patterns of the city (Goel and Trivedy, 1998; Envirotech, 2000; EPA, 2003). The study area was divided into four receptor zones. A wind rose diagram for the sampling period was also prepared using meteorological data provided by a local meteorological station (Fig. 2). A description of the sampling sites is presented in Table 1.

Fig. 1. Location map of source and receptor sites of Raipur, Chhattisgarh, India.

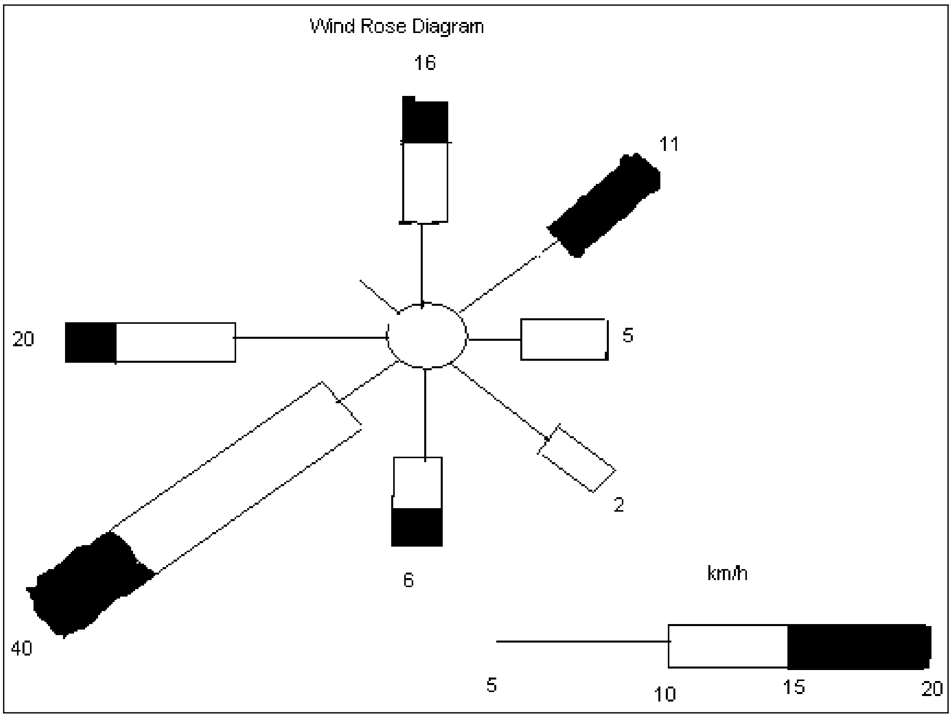


Fig. 2. Wind rose diagram in Raipur during the study period (Wind speed in km/h).

Table 1. Description of sampling sites in Raipur City, Chhattisgarh.

S. No.	Site Code	Site Name	Local Source Description
Receptor site			
1	R-1	Balgangadhar tilak ward, Raipur	Small-scale welding and automobile workshops.
2	R-2	Sunder-nagar, Raipur	Residential area. household cooking.
3	R-3	Budha-talab, Raipur	Commercial area, traffic emission.
4	R-4	M.G. Ward, Raipur	New building construction.
Source site			
5	S-5	Urla industrial complex, Raipur.	Mostly casting and chemical industries, medium-scale workshops.
6	S-6	Siltara industrial complex, Raipur.	Mostly sponge iron industries,
7	S-7	Mandir Hasoud industrial complex, Raipur.	Medium-scale steel industries.

A set of two respirable dust samplers (RDS) (Envirotech, Model APM 460) was used for the sampling. Each sampler was positioned at source and receptor sites simultaneously. Samplers were operated at the height of 10 feet for 24 hours (8 hourly basis). Average sampler flow rate was 1.1 m^3/min. Ten samples were taken at each site during each of three seasons (winter, summer and post-monsoon) throughout the sampling period of December 2005-October 2006. The interval of multiple sampling at each site was four days due to limited availability of the sampler. A total of 30 PM_{10} samples from seven sampling sites were collected (Gajhghate and Hasan, 1999; Envirotech, 2000; EPA, 2003).

Sample collection, preparation and statistical analysis

All PM_{10} samples were collected in glass microfiber filter sheets (size 8”x10”, Whatman), which have low resistance to air flow, a low affinity for moisture, and 98% collection efficiency for particle sizes of 0.5 micron or larger. The filters were attached with a respirable dust sampler. Pre- and post-sampling treatment of filter papers was carried out in moisture-free desiccators followed by drying in an oven (60℃) for 24 hours. All pre- and post-sampling treated filters were weighed using a 5-digit, single-pan, top-loading balance (Sartorius Model R 200 D). Geometric mean and standard deviation of multiple measurements at each site were calculated. Meteorological parameters (wind velocity and relative humidity) were recorded during the sampling days and were used for evaluating correlation coefficients with PM_{10} levels at each site (Envirotech, 2000; Sharma, 2002).

Mean values of PM_{10} levels and their correlation with meteorological parameters are presented in Table 2. Regression analysis of PM_{10} levels between each receptor site with all three source sites (sampling sites No. 5, 6 and 7) was performed using Microsoft Excel. All regression graphs are presented in Figs. 3 (a-d).

RESULTS AND DISCUSSION

PM_{10} levels (annual average) occurring for various sources and receptor sites are presented in Table 2. Unexpectedly, urban receptor sites showed higher concentration of PM_{10} levels compared to the industrial complex source sites. PM_{10} levels in receptor sites were found to be in the range of 166.20 ± 83.08 μg/m^3 to 314.13 ± 95.99 μg/m^3, while the range for source site PM_{10} was 105.91 ± 24.37 μg/m^3 to 202.33 ± 31.08 μg/m^3. PM_{10} levels of all sites exceeded the Indian National Ambient Air Quality Standards (NAAQS) (Residential: 60 μg/m^3 and industrial: 120 μg/m^3 annual average) (CPCB, 2006), except one source site, No. 5 (Urla), where it was observed that the annual standard deviation for receptor site-PM_{10} levels were 3 to 4 times higher compared to source site PM_{10} levels. The reason for this deviation can be explained by variation patterns and meteorological parameters (Goel and Trivedy, 1998; EPA, 2003). Regression and correlation analysis of each receptor-PM_{10} site with each of the three PM_{10} sources are presented in Fig. 3 and Table 3 respectively. A different pattern of correlation of source site PM_{10} levels with all selected receptor sites (R-1, R-2, R-3 and R-4) PM_{10} levels was observed. Receptor site R-1 showed the highest correlation with source site S-5, while receptor site R-2 showed highest correlation with source site S-7. The other two receptor sites (R-3, R-4) showed moderate correlations with all selected source-PM_{10} levels.

Slope values occurring in regression analysis between source-receptor PM_{10} levels is a statistical tool for investigating source contribution at receptor sites (EPA, 2003). If an independent variable regresses with a dependent variable, then slope value explains the infiltration factor of an independent variable to a dependent variable. In a regression analysis between source PM_{10} (industrial complexes) and receptor PM_{10} measurements, source PM_{10} values were taken as independent variables and receptor PM_{10} values were taken as dependent variables (Geller *et al.,* 2002). In the case of Fig. 3 (a), a highest slope value was obtained in S-5/R-1 regression analysis, justifying the correlation values presented in Table 2. Receptor site R-2 (Sunder Nagar) and source site S-7 (Mandir Hasoud) were observed as major contributors of PM_{10} levels.

Regression analysis (Fig. 3) showed that local sources of dust generation are also significant factors in the occurrences of higher PM_{10} levels in receptor sites (sites 1, 2, 3, 4). A number of welding and automobile workshops located at R-1 are another factor of higher PM_{10} levels. Insignificant correlation values of R-3 and R-4 with all source sites (5, 6 and 7) are also due to local commercial, construction and high traffic activities.

It has been reported that generation of fine particulates (lower micron size) is related to the higher temperature processes (Volkovic, 1983). During the survey of industrial complexes (Urla, Siltara, Mandir Hasoud), it was observed that most of the industrial units have moderate temperature-based manufacturing processes. An integrated steel plant having high-temperature manufacturing processes is located 40 km from the city to the southwest (Fig. 2). Wind direction during the sampling year was 27% northeasterly or northerly. The effect of meso-scale transport of steel plant-emitted fine particulate among receptor sites of Raipur might be another factor of variation in high PM_{10} levels.

Meteorological factors have the greatest influence on the diffusion and transport of air pollutants (Goel and Trivedy, 1998; EPA, 2003). An investigation into the relationship of ambient PM_{10} levels and meteorological parameters (wind velocity and relative humidity) was also carried out. An inverse relation occurred. Source sites R-5 and R-6, and receptor site R-1 showed moderate inverse relation with relative humidity. In most previously reported studies, inverse relation of ambient PM with meteorological parameters have been evaluated (Goel and Trivedy, 1998; Gupta *et al.,* 2006). Season wise (winter, post rainy, summer) a mixed trend of inverse relationships occurred at all sites.

Table 2. Annual average PM_{10} levels and their correlation statistics in selected monitoring locations of Raipur, India.

Source sites	S-5 (105.9 ± 24.37)*	S-6 (125.67 ± 29.63)	S-7 (202.33 ± 31.08)
Receptor Sites	Correlation statistics (r)		
R-1 (314.13 ± 95.99)	0.648	0.163	0.128
R-2 (166.20 ± 83.08)	0.37	0.389	0.663
R-3 (210.32 ± 111.62)	0.437	0.461	0.50
R-4 (181.8 ± 71.55)	0.54	0.150	-0.018

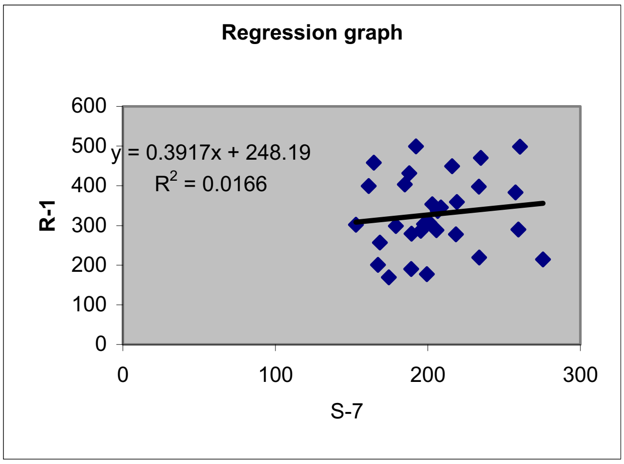
*Values in parenthesis: Annual average PM_{10} levels ($\mu g/m^3$) (Geometric mean ± standard deviation).

Table 3. Annual correlation of source and receptor sites with meteorological parameter.

Site	RH Max*	RH Min**	w. v.***
R-1	-0.572	-0.461	-0.072
R-2	-0.475	0.634	0.047
R-3	-0.409	-0.607	-0.346
R-4	-0.334	-0.114	0.02
S-5	-0.61	-0.46	-0.26
S-6	-0.57	-0.52	-0.03
S-7	-0.24	-0.3	-0.37

*Relative Humidity (maximum), **Relative Humidity (minimum), ***Wind Velocity.

a-1



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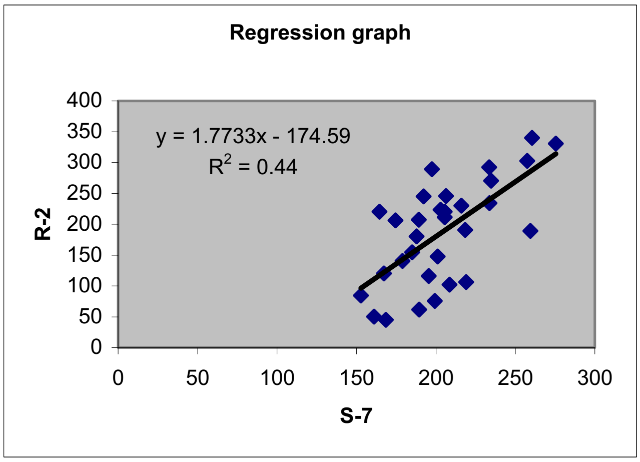

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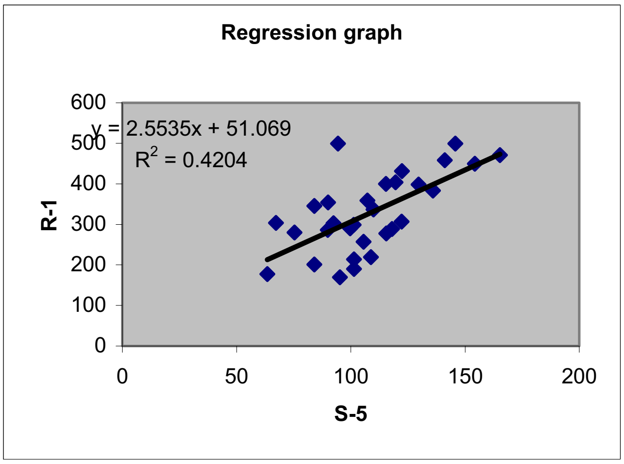

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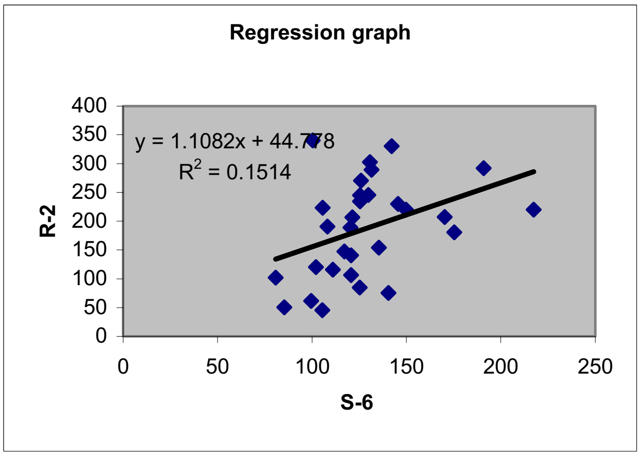

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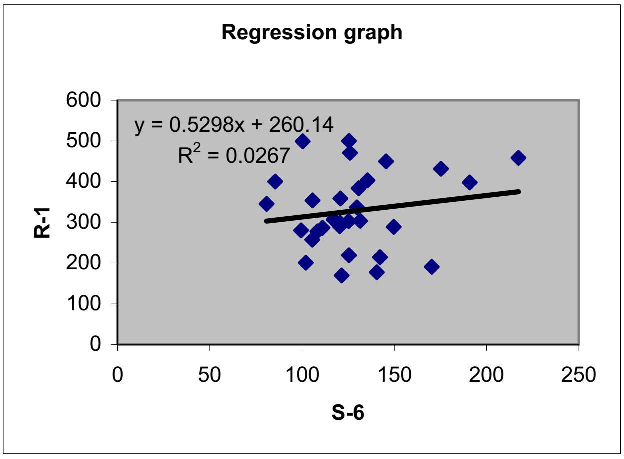

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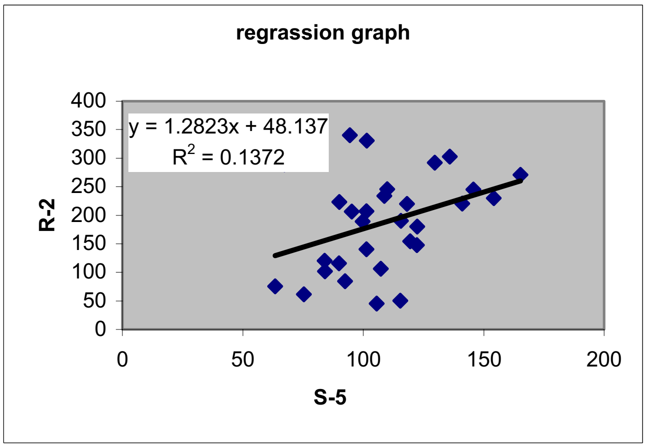
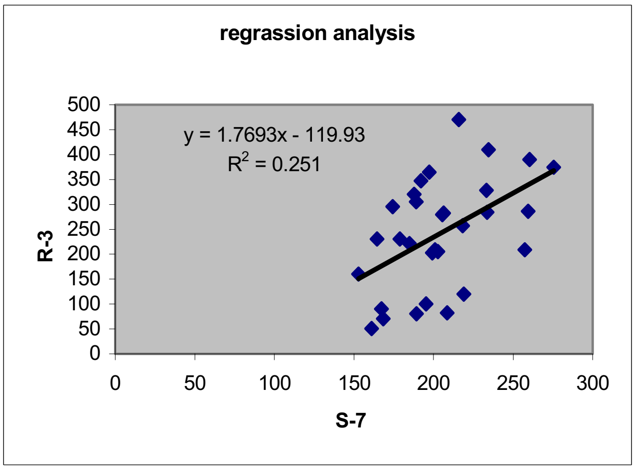


Fig. 3(a). Regression graph of source-receptor ambient PM_{10} levels monitored in an urban area for receptor site R-1.

Fig. 3(b). Regression graph of source-receptor ambient PM_{10} levels monitored in an urban area for receptor site R-2.

c-1



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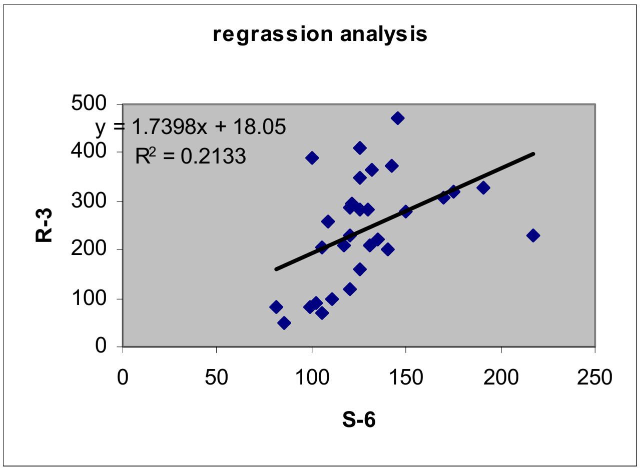

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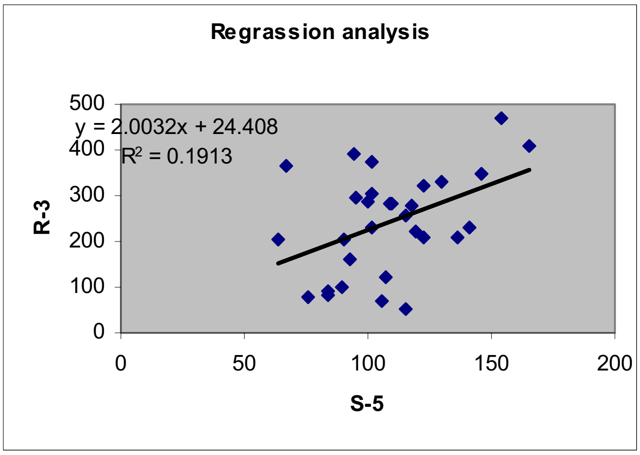
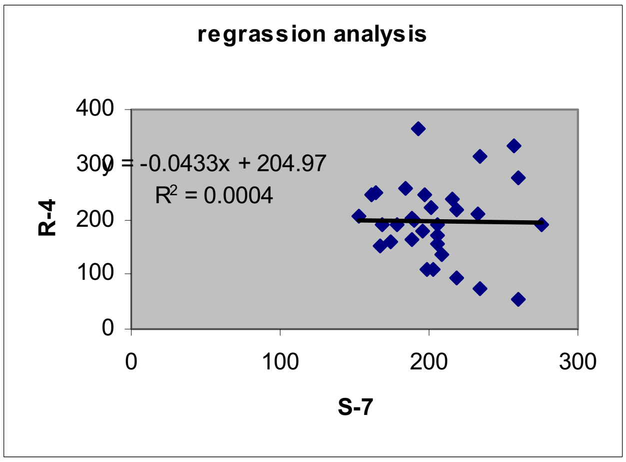


Fig. 3(c). Regression graph of source-receptor ambient PM_{10} levels monitored in an urban area for receptor site R-3.

d-1



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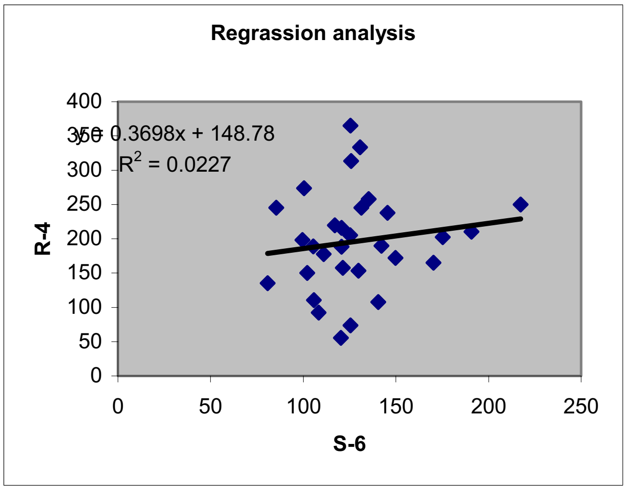

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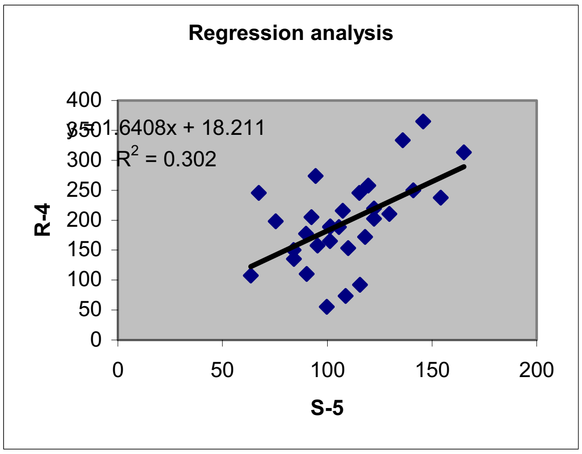

Fig. 3(d). Regression graph of source-receptor ambient PM_{10} levels monitored in an urban area for receptor site R-4.

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