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Studies on Interrelations among SO_2, NO_2 and PM_{10} Concentrations and Their Predictions in Ambient Air in Kolkata

Sayanti Kar[1,2], Phalguni Mukherjee[3]
[1]Department of Environmental Studies, Women's Christian College, Kolkata, India
[2]Department of Environmental Science, Asutosh College, Kolkata, India
[3]Department of Mathematics and Post Graduate Department of Environmental Science, Asutosh College, Kolkata, India
Email: phalguni.mukherjee@gmail.com

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ABSTRACT

In this paper we have first of all studied the interrelations among the concentrations of SO_2, NO_2 and PM_{10} and then predicted their future level of concentrations in the ambient air of Kolkata. The data collected from West Bengal Pollution Control Board website have been used to construct second degree, third degree and four degree polynomial equations using MATLAB software. Since a curve in a small interval can be approximated by a line segment in that small interval, we have observed that better result can be achieved if we replace the curves piece meal wise in small intervals by line segments during January-April, May-August and September-December months. The multiple regression equations among the aforesaid three parameters have been established to predict the value of each parameter in terms of the remaining two. A further improvement in terms of reducing the number of dependent variables has been made using the results of correlation coefficients. Finally, we have predicted the value of each parameter in terms of only one dependent variable.

Keywords: Ambient Air; Multiple Correlation-Coefficients; Kolkata

1. Introduction

Metropolitan city like Kolkata has been suffering from various types of health hazards problems for long time due to air pollution. Risk assessments for the toxic pollutants are widely used in different countries as a regulatory decision making processes to combat air pollution [1]. In the mega cities of India such as Mumbai, Delhi and Kolkata, PM_{10} has exceeded the regulatory limits [2,3]. It has been found from available data that the presence of particulate matter (PM_{10}) is highest in the atmosphere of Kolkata. Among the pollutants listed in NAAQS [4] one of the most notorious pollutants is PM_{10}. It is well known that PM_{10} is responsible for respiratory hazards in human health. Such particulates can also obstruct lung function without reacting chemically, by depositing in human lungs and interfering with normal functioning [5]. Moreover, it takes part in formation of sulphurous smog. One of the main sources of existence of PM_{10} in air is vehicular pollution. Various typical anthropogenic activities like intense transportation, Industrial and commercial activities are prevailing in urban areas, particularly in the metropolitan cities [1,6-8]. It is also known that increased level of Sulphur-dioxide (SO_2) and Nitrogen-dioxide (NO_2) lead to the formation of different types of secondary pollutants in environment. Studies reveal that the occurrence is mainly due to expanding industries and growing number of vehicles within the state. The West Bengal Pollution Control Board (WBPCB) had initiated air quality monitoring of Kolkata through a limited number of stations in 1992 and subsequently expanded its monitoring network to systematic pattern from December 1998 [9]. At present the air quality of Kolkata is monitored through 16 fixed monitoring stations as mentioned in Methods and Materials.

2. Objective

Our main objective is to study the interrelations among the concentrations of SO_2, NO_2 and PM_{10}, and to use these results to predict each of these three pollutants in the city of Kolkata. We have used MATLAB software on the available data to suitably fit second degree, third degree and fourth degree curves for each parameter. It has been found that the best predictions for some of the parameters are obtained sometimes for second degree, sometimes for third degree and sometimes for fourth degree curves—but no unique curve is obtained to make best predictions for all the three parameters. Since a curve in a small interval can be approximated by a line segment in that small interval, we have considered the curves piece meal wise from January to April, May to August and September to December for all the parameters. Then we have approximated the curves obtained in the above time periods by suitable line segments and found predictions are quite encouraging. Next we find multiple regression equations among PM_{10}, SO_2 and NO_2 and predict the approximate value of one of the parameters in terms of remaining two. Further, we have found out the correlation between each pair of parameters and used these results to reduce the number of dependent variables from two to one and predict any one of the parameters in terms of only one (dependent) parameter.

3. Methods and Materials

The average value of 24 hr daily ambient air quality information has been collected during the period of 2003-2010 for all three pollutants and subsequently their monthly averages have been obtained for each of these pollutants (**Tables 1-3**).

Table 1. The average month wise data for NO_2 (Source: Daily Ambient Air quality Information [10]; WBPCB) in terms of (μg/m³).

MONTH	2003	2004	2005	2006	2007	2008	2009	2010
January	82.24	74.50	93.90	96.00	95.10	91.90	98.90	106.00
February	71.85	73.30	91.90	74.20	76.40	81.10	87.10	92.50
March	58.46	51.90	63.70	59.00	65.60	69.70	69.90	70.20
April	46.40	44.30	39.40	43.70	43.90	62.72	51.80	50.20
May	42.30	46.60	37.60	41.90	48.40	52.42	43.60	42.60
June	40.80	51.10	36.30	45.90	42.70	44.10	45.80	43.80
July	36.60	40.90	36.70	44.40	43.80	47.49	41.10	39.40
August	36.40	30.10	40.90	42.40	39.90	44.80	35.10	38.40
September	42.90	31.80	37.90	44.90	43.70	43.80	42.80	37.30
October	46.70	47.20	48.90	62.20	56.60	65.50	62.90	49.60
November	73.40	77.20	77.90	72.20	61.50	87.80	71.40	66.70
December	82.90	100.30	101.20	84.90	84.80	94.50	105.90	80.10

Table 2. The average month wise data for SO_2 (Source: Daily Ambient Air quality Information [10]; WBPCB) in terms of (μg/m³).

MONTH	2003	2004	2005	2006	2007	2008	2009	2010
January	11.50	15.30	17.40	17.80	9.00	9.00	10.20	11.80
February	8.30	14.20	15.60	11.40	6.30	10.80	9.00	10.70
March	3.80	10.30	7.70	6.90	5.50	5.50	7.20	9.20
April	3.60	5.50	5.40	5.60	4.80	5.30	5.60	7.90
May	2.50	5.20	4.70	4.90	4.90	4.60	5.30	5.90
June	2.00	5.40	4.50	4.90	4.60	4.60	5.20	5.10
July	2.30	5.10	3.60	4.50	4.70	5.00	5.00	5.10
August	2.40	3.70	4.30	4.20	4.60	5.40	4.90	5.00
September	3.00	3.60	3.90	4.50	4.80	6.00	5.40	5.00
October	4.20	5.60	5.90	4.60	5.40	6.50	8.00	6.20
November	9.70	11.70	11.40	4.90	5.10	8.60	8.70	8.10
December	11.70	19.40	18.00	6.20	5.90	10.80	11.30	10.10

*2008 February data was not available in the website. So we have used the average value of February Months of the rest seven years.

Study Area

Study area selected by WBPCB includes 16 stations in the city Kolkata, they are at Dunlop Bridge, Picnic Garden, Tollygunge, Hyde Road, Behala Chowrasta, Beliaghata, Salt Lake, Tapsia, Baishnabghata, Ultadanga, Mominpore, Moulali, Shyambazar, Gariahat, Minto Park, Rajarhat New Township.

4. Results and Discussion

These primary data have been used to get non-linear curve for each case. We then use MATLAB to predict their concentrations by second degree, third degree and fourth degree equation (**Tables 4-12**).

The results thus obtained are quite good except in a few cases. So for obtaining better result in terms of accuracy, we have again divided the entire data into three segments *i.e.* from January-April, May-August and September-December. In each case we get linear equations (**Figures 1-9**) and the predictions made are quite encouraging.

Table 3. The average month wise data for PM_{10} (Source: Daily Ambient Air quality Information [10]; WBPCB) in terms of (μg/m³).

MONTH	2003	2004	2005	2006	2007	2008	2009	2010
January	204	196	211	202	223	174	195	178
February	186	186	203	154	118	140	163	167
March	68	137	150	126	91	81	107	93
April	60	94	81	62	45	54	56	46
May	57	71	64	51	46	45	40	36
June	47	64	59	46	31	39	38	34
July	41	56	51	38	32	36	34	28
August	45	51	52	34	32	32	31	28
September	47	51	50	37	34	40	37	34
October	55	62	52	86	67	81	83	63
November	132	131	122	128	110	125	115	130
December	218	230	209	207	191	176	174	176

Table 4. Prediction of NO_2 using second degree equation.

MONTH	AVERAGE	PRED	OBS	PERCENTAGE ERROR
1	92.32	96.17	94.67	−1.59
2	81.04	77.48	81.42	4.84
3	63.56	62.39	60.68	−2.81
4	47.80	50.90	43.93	−15.87
5	44.43	43.03	40.98	−4.99
6	43.81	38.76	36.72	−5.55
7	41.30	38.09	31.73	−20.06
8	38.50	41.04	32.17	−27.57
9	40.64	47.59	37.77	−26.00
10	54.95	57.75	59.66	3.20
11	73.51	71.52	59.10	−21.01
12	91.83	88.89	127.40	30.23

Table 5. Prediction of SO_2 using second degree equation.

MONTH	AVERAGE	PRED	OBS	PERCENTAGE ERROR
1	12.75	12.99	9.26	−40.32
2	10.79	10.09	8.41	−19.93
3	7.01	7.73	5.51	−40.23
4	5.46	5.92	5.58	−6.01
5	4.75	4.65	5.47	14.95
6	4.54	3.94	4.88	19.32
7	4.41	3.77	5.09	25.93
8	4.31	4.15	5.44	23.68
9	4.53	5.08	5.80	12.39
10	5.80	6.56	8.61	23.82
11	8.53	8.59	7.48	−14.77
12	11.68	11.16	11.60	3.80

Table 6. Prediction of PM_{10} using second degree equation.

MONTH	AVERAGE	PRED	OBS	PERCENTAGE ERROR
1	198	210	207	−1.48
2	165	153	174	12.24
3	107	106	100	−6.25
4	62	71	67	−5.57
5	51	46	46	−0.29
6	45	32	40	18.83
7	40	30	34	12.57
8	38	38	32	−18.47
9	41	57	42	−35.76
10	69	87	153	43.10
11	124	128	162	20.98
12	198	180	210	14.33

Table 7. Prediction of NO_2 using third degree equation.

MONTH	AVERAGE	PRED	OBS	PERCENTAGE ERROR
1	92.32	92.99	94.60	1.70
2	81.04	77.77	81.42	4.49
3	63.56	64.41	60.68	−6.15
4	47.80	53.32	43.93	−21.36
5	44.43	44.86	40.98	−9.48
6	43.81	39.44	36.72	−7.41
7	41.30	37.44	31.73	−17.98
8	38.50	39.23	32.17	−21.95
9	40.64	45.21	37.77	−19.71
10	54.95	55.77	59.66	6.52
11	73.51	71.29	59.10	−20.62
12	91.83	92.15	127.40	27.67

Table 8. Prediction of SO_2 using third degree equation.

MONTH	AVERAGE	PRED	OBS	PERCENTAGE ERROR
1	12.75	12.80	9.26	−38.18
2	10.79	10.10	8.41	−20.14
3	7.01	7.85	5.51	−42.51
4	5.46	6.06	5.58	−8.68
5	4.75	4.76	5.47	12.91
6	4.54	3.98	4.88	18.54
7	4.41	3.72	5.09	26.88
8	4.31	4.03	5.44	25.95
9	4.53	4.92	5.80	15.20
10	5.80	6.42	8.61	25.48
11	8.53	8.55	7.48	−14.24
12	11.68	11.33	11.60	2.33

Table 9. Prediction of PM_{10} using third degree equation.

MONTH	AVERAGE	PRED	OBS	PERCENTAGE ERROR
1	198	199	207	3.87
2	165	154	174	11.67
3	107	113	100	−13.30
4	62	79	67	−18.09
5	51	53	46	−14.17
6	45	35	40	12.94
7	40	27	34	19.45
8	38	32	32	1.42
9	41	49	42	−15.83
10	69	80	153	47.69
11	124	127	162	21.58
12	198	191	210	9.03

Table 10. Prediction of NO_2 using fourth degree equation.

MONTH	AVERAGE	PRED	OBS	PERCENTAGE ERROR
1	92.32	93.89	94.60	0.75
2	81.04	77.03	81.42	5.39
3	63.56	63.51	60.68	−4.67
4	47.80	52.97	43.93	−20.57
5	44.43	45.21	40.98	−10.32
6	43.81	40.25	36.72	−9.60
7	41.30	38.28	31.73	−20.64
8	38.50	39.70	32.17	−23.41
9	40.64	45.10	37.77	−19.40
10	54.95	55.24	59.66	7.40
11	73.51	71.11	59.10	−20.31
12	91.83	93.85	127.40	26.34

Table 11. Prediction of SO_2 using fourth degree equation.

MONTH	AVERAGE	PRED	OBS	PERCENTAGE ERROR
1	12.75	13.18	9.26	−42.33
2	10.79	9.79	8.41	−16.40
3	7.01	7.47	5.51	−35.54
4	5.46	5.91	5.58	−6.00
5	4.75	4.91	5.47	10.28
6	4.54	4.31	4.88	11.72
7	4.41	4.06	5.09	20.27
8	4.31	4.18	5.44	23.12
9	4.53	4.79	5.80	17.49
10	5.80	6.06	8.61	29.67
11	8.53	8.26	7.48	−10.44
12	11.68	11.75	11.60	−1.31

Table 12. Prediction of PM_{10} using fourth degree equation.

MONTH	AVERAGE	PRED	OBS	PERCENTAGE ERROR
1	198	205	207	0.75
2	165	148	174	14.70
3	107	107	100	−6.84
4	62	77	67	−14.28
5	51	55	46	−19.21
6	45	40	40	−0.61
7	40	33	34	3.65
8	38	34	32	−5.38
9	41	46	42	−9.13
10	69	73	107	31.62
11	124	121	162	25.20
12	198	197	210	6.36

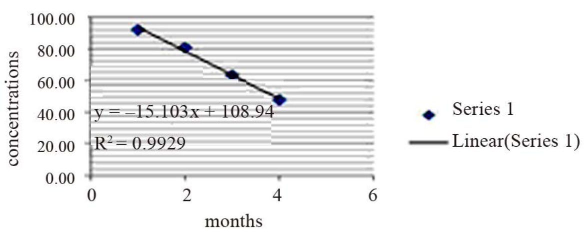

Figure 1. Linear equation of NO_2 during January-April.

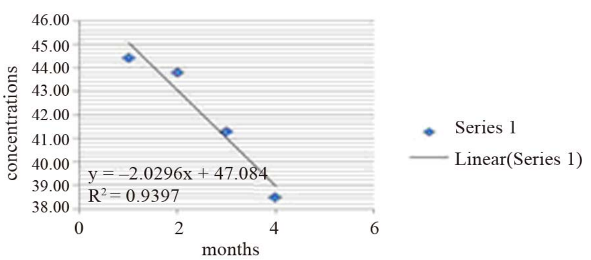

Figure 2. Linear equation of NO_2 during May-August.

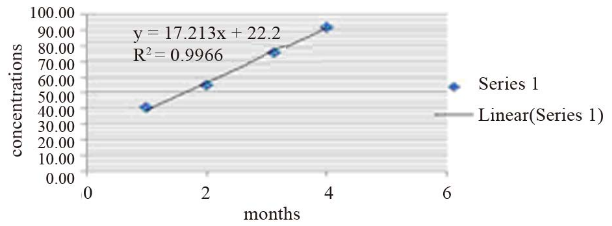

Figure 3. Linear equation of NO_2 during September-December.

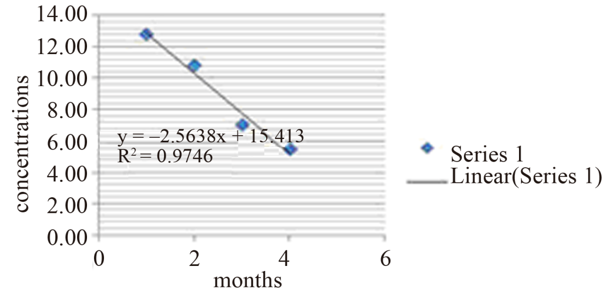

Figure 4. Linear equation of SO_2 during January-April.

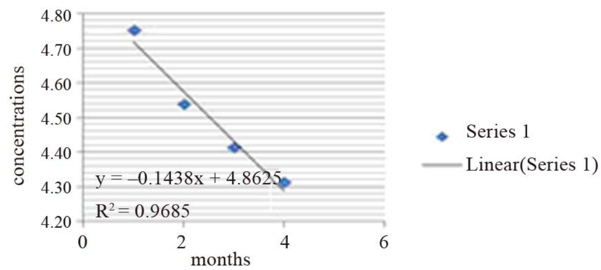

Figure 5. Linear equation of SO_2 during May-August.

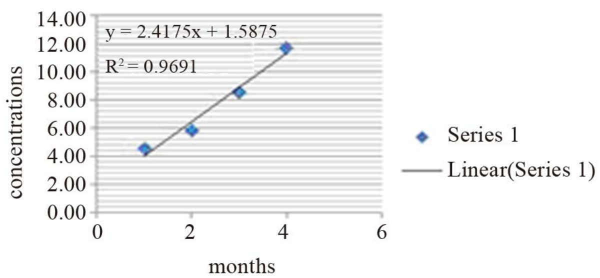

Figure 6. Linear equation of SO_2 during September-December.

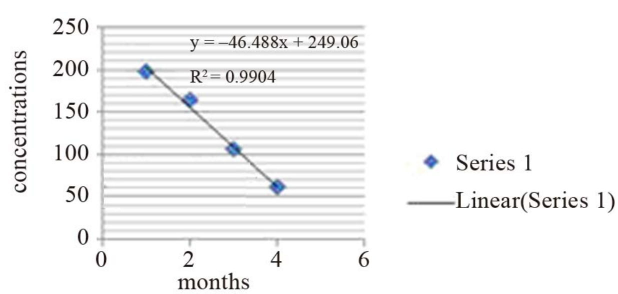

Figure 7. Linear equation of PM_{10} during January-April.

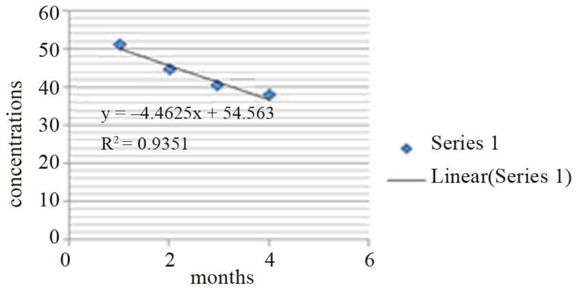

Figure 8. Linear equation of PM_{10} during May-August.

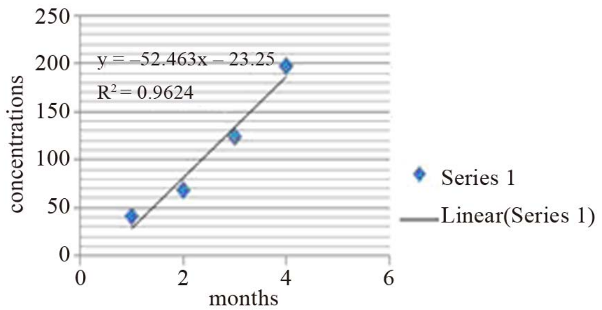

Figure 9. Linear equation of PM_{10} during September-December.

The prediction of NO_2 during January-April is given by the equation

$$y = -15.10x + 108.94 \tag{1}$$

The prediction of NO_2 during May-August is given by the equation

$$y = -2.02x + 47.08 \tag{2}$$

The prediction of NO_2 during September-December is given by the equation

$$y = 17.21x + 22.2 \tag{3}$$

The prediction of SO_2 during January-April is given by the equation

$$y = -2.56x + 15.41 \tag{4}$$

The prediction of SO_2 during May-August is given by the equation

$$y = -0.14x + 4.86 \tag{5}$$

The prediction of SO_2 during September-December is given by the equation

$$y = 2.41x + 1.58 \tag{6}$$

The prediction of PM_{10} during January-April is given by the equation

$$y = -46.48x + 249.06 \tag{7}$$

The prediction of PM_{10} during May-August is given by the equation

$$y = -4.46x + 54.56 \tag{8}$$

The prediction of PM_{10} during September-December is given by the equation

$$y = -52.46x - 23.25 \tag{9}$$

Results obtain from line segments are tabulated as (**Tables 13-15**).

Explanation of data given in **Table 13**: NO_2: Average values of NO_2 during 2003-2010; PRED: Predicted value of NO_2 obtained from **Figures 1-3**; OBS: Month wise observed values of 2011.

Explanation of data given in **Table 14**: SO_2: Average values of SO_2 during 2003-2010; PRED: Predicted value of SO_2 obtained from **Figures 4-6**; OBS: Month wise observed values of 2011.

Explanation of data given in **Table 15**: PM_{10}: Average values of PM_{10} during 2003-2010; PRED: Predicted value of PM_{10} obtained from **Figures 7-9**; OBS: Month wise observed values of 2011.

Table 13. Prediction of NO_2.

MONTH	NO_2	PRED	2011 OBS	PERCENTAGE ERROR
1	92.32	93.80	94.67	0.92
2	81.04	78.70	81.42	3.34
3	63.56	63.60	60.68	−4.81
4	47.80	48.50	43.93	−10.40
5	44.43	45.05	40.98	−9.93
6	43.81	43.02	36.73	−17.13
7	41.30	40.99	31.74	−29.14
8	38.50	38.96	32.18	−21.07
9	40.64	39.41	37.80	−4.26
10	54.95	56.62	58.25	2.80
11	73.51	73.83	59.11	−24.90
12	91.83	91.04	127.40	28.54

Table 14. Prediction of SO_2.

MONTH	SO_2	PRED	2011 OBS	PERCENTAGE ERROR
1	12.75	12.85	9.30	−38.14
2	10.79	10.28	8.40	−22.43
3	7.01	7.72	5.50	−40.38
4	5.46	5.16	5.60	7.89
5	4.75	4.72	5.50	14.20
6	4.54	4.58	4.90	6.61
7	4.41	4.43	5.10	13.08
8	4.31	4.29	5.40	20.56
9	4.53	4.00	5.80	30.97
10	5.80	6.42	8.40	23.56
11	8.53	8.84	7.50	−17.84
12	11.68	11.26	11.60	2.97

Table 15. Prediction of PM_{10}.

MONTH	PM_{10}	PRED	2011 OBS	PERCENTAGE ERROR
1	198	203	207	2.16
2	165	156	174	10.32
3	107	110	100	−9.56
4	62	63	67	5.85
5	51	50	46	−8.91
6	45	46	40	−14.10
7	40	41	34	−21.12
8	38	37	32	−14.75
9	41	29	42	30.43
10	69	82	107	23.66
11	124	134	162	17.20
12	198	187	210	11.14

We have divided the entire data into three segments, for each segment we have established a multiple regression equation involving all the three parameters. The segment-wise equations are as follows:

$$\text{January-April: } x_1 = -75.18 + 2.44x_2 + 3.79x_3 \quad (10)$$

$$\text{May-August: } x_1 = -100.67 - 0.25x_2 + 34.35x_3 \quad (11)$$

September-December:

$$x_1 = -51.47 - 0.49x_2 + 25.23x_3 \quad (12)$$

The results obtain from the above three equations are shown in **Table 16**.

Next we consider the average values of NO_2, SO_2 and PM_{10} from January-April, during 2003-2010 to find linear relations between every pair of parameters. The results for all the segments are shown in the following figures and tables.

The correlation co-efficient of each of the three parameters during January-April, May-August, September-December are shown in **Tables 17-19** and **Figures 10-18** respectively.

$$y = 0.169x - 3.064 \text{ i.e. } x_3 = 0.169x_2 - 3.064 \quad (13)$$

$$y = 17.867x - 28.017 \text{ i.e. } x_1 = 17.867x_3 - 28.017 \quad (14)$$

$$y = 0.3243x + 28.097 \text{ i.e. } x_2 = 0.3243x_1 + 28.097 \quad (15)$$

$$y = 0.063x + 1.834 \text{ i.e. } x_3 = 0.063x_1 + 1.834 \quad (16)$$

$$y = 31.34x - 97.72 \text{ i.e. } x_1 = 31.34x_3 - 97.72 \quad (17)$$

$$y = 0.401x + 24.60 \text{ i.e. } x_2 = 0.401x_1 + 24.60 \quad (18)$$

$$y = 0.141x - 1.592 \text{ i.e. } x_3 = 0.141x_2 - 1.592 \quad (19)$$

$$y = 21.76x - 58.18 \text{ i.e. } x_1 = 21.76x_3 - 58.18 \quad (20)$$

$$y = 0.319x + 30.79 \text{ i.e. } x_2 = 0.319x_1 + 30.79 \quad (21)$$

In the following table we have shown linear relations between every pair of parameters for all the three segments.

From **Table 16** and **Table 20** we put together the results in **Table 21** where we have predicted each parameter.

1) In terms of remaining two parameters;
2) In terms of one of the remaining parameters.

Table 16. Prediction of x_1, x_2 and x_3 with the help of multiple regression equations involving all the parameters during the segments (January-April, May-August, and September-December).

MONTHS	PREDICTED	OBSERVED	PERCENTAGE ERROR
FOR x_1			
January-April	123	137	10.22
May-August	70	38	−84.21
September-December	123	131	6.11
FOR x_2			
January-April	75.73	70.18	−7.91
May-August	162.43	35.41	−358.71
September-December	56.77	70.64	19.63
FOR x_3			
January-April	10.76	7.19	−49.65
May-August	4.29	5.22	17.82
September-December	8.58	8.31	−3.25

Table 17. Correlation co-efficient of each three parameters during January-April.

January-April x_2	x_3	x_1	x_2
NO_2	SO_2	PM_{10}	NO_2
92.32	12.75	198	92.32
81.04	10.79	165	81.04
63.56	7.01	107	63.56
47.80	5.46	62	47.80
r_{23}=0.989	r_{13}=0.993	r_{12}=0.999	

Table 18. Correlation co-efficient of each three parameters during May-August.

May-August x_2	x_3	x_1	x_2
NO_2	SO_2	PM_{10}	NO_2
44.43	4.75	51	44.43
43.81	4.54	45	43.81
41.30	4.41	40	41.30
38.50	4.31	38	38.50
r_{23} = 0.911	r_{13} = 0.992	r_{12} = 0.884	

For all the three segments a mentioned earlier, we have also calculated errors in each case.

If we study the above data, it is interesting to observe that the prediction of PM_{10} (x_1) concentration is more accurate when we use known concentration of NO_2 (x_2) only (*i.e.* x_1 gives the best result when $x_1 = f(x_2)$ is considered). Again using known PM_{10} concentration the more accurate value of NO_2 can be measured during January to August. For last segment less error for prediction of NO_2 has been encountered when known SO_2 concentration is used. From the following table we can find the minimum errors for prediction of each parameter during different segments.

Season-wise identification of dependent variable to predict each parameter with minimum error are given in **Table 22**.

Table 19. Correlation co-efficient of each three parameters during September-December.

September-December	x_2	x_3	x_1	x_2
	NO_2	SO_2	PM_{10}	NO_2
	40.64	4.53	41	40.64
	54.95	5.80	69	54.95
	73.51	8.53	124	73.51
	91.83	11.68	198	91.83
	$r_{23} = 0.993$	$r_{13} = 0.999$	$r_{12} = 0.990$	

Table 20. Predicted value of x_1, x_2 and x_3 considering every pair of parameters.

Month		Predicted	Observed	Percentage Error		Predicted	Observed	Percentage Error		Predicted	Observed	Percentage Error
January-April	$x_1 = f(x_3)$	100	137	27.01	$x_2 = f(x_1)$	72.48	70.18	−3.28	$x_3 = f(x_2)$	8.80	7.19	−22.39
	$x_1 = f(x_2)$	130	137	5.11	$x_2 = f(x_3)$	60.67	70.18	13.55	$x_3 = f(x_1)$	9.24	7.19	−28.51
May-August	$x_1 = f(x_3)$	66	38	−73.68	$x_2 = f(x_1)$	39.84	35.41	−12.51	$x_3 = f(x_2)$	4.06	5.22	22.22
	$x_1 = f(x_2)$	27	38	29.21	$x_2 = f(x_3)$	53.75	35.41	−51.79	$x_3 = f(x_1)$	4.33	5.22	17.04
September-December	$x_1 = f(x_3)$	123	131	6.11	$x_2 = f(x_1)$	72.58	70.64	−2.75	$x_3 = f(x_2)$	8.45	8.31	−1.68
	$x_1 = f(x_2)$	126	131	3.82	$x_2 = f(x_3)$	70.24	70.64	0.57	$x_3 = f(x_1)$	8.69	8.31	−4.57

Table 21. Comparative studies of errors for different cases.

Month		Predicted	Observed	Percentage Error		Predicted	Observed	Percentage Error		Predicted	Observed	Percentage Error
January-April	$x_1 = f(x_2,x_3)$	123	137	10.22	$x_2 = f(x_1,x_3)$	75.73	70.18	−7.91	$x_3 = f(x_1,x_2)$	10.76	7.19	−49.65
	$x_1 = f(x_3)$	100	137	27.01	$x_2 = f(x_1)$	72.48	70.18	−3.28	$x_3 = f(x_2)$	8.80	7.19	−22.39
	$x_1 = f(x_2)$	130	137	5.11	$x_2 = f(x_3)$	60.67	70.18	13.55	$x_3 = f(x_1)$	9.24	7.19	−28.51
May-August	$x_1 = f(x_2,x_3)$	70	38	−84.21	$x_2 = f(x_1,x_3)$	162.43	35.41	−358.71	$x_3 = f(x_1,x_2)$	4.29	5.22	17.82
	$x_1 = f(x_3)$	66	38	−73.68	$x_2 = f(x_1)$	39.84	35.41	−12.51	$x_3 = f(x_2)$	4.06	5.22	22.22
	$x_1 = f(x_2)$	27	38	29.21	$x_2 = f(x_3)$	53.75	35.41	−51.79	$x_3 = f(x_1)$	4.33	5.22	17.04
September-December	$x_1 = f(x_2,x_3)$	123	131	6.11	$x_2 = f(x_1,x_3)$	56.77	70.64	19.63	$x_3 = f(x_1,x_2)$	8.58	8.31	−3.25
	$x_1 = f(x_3)$	123	131	6.11	$x_2 = f(x_1)$	72.58	70.64	−2.75	$x_3 = f(x_2)$	8.45	8.31	−1.68
	$x_1 = f(x_2)$	126	131	3.82	$x_2 = f(x_3)$	70.24	70.64	0.57	$x_3 = f(x_1)$	8.69	8.31	−4.57

Table 22. Season-wise identification of dependent variable to predict each parameter with minimum error.

MONTH	Minimum error for predicted value of $PM_{10}(x_1)$	Minimum error for predicted value of NO_2 (x_2)	Minimum error for predicted value of $SO_2(x_3)$
January-April	$f(x_2)$	$f(x_1)$	$f(x_2)$
May-August	$f(x_2)$	$f(x_1)$	$f(x_1)$
September-December	$f(x_2)$	$f(x_2)$	$f(x_2)$

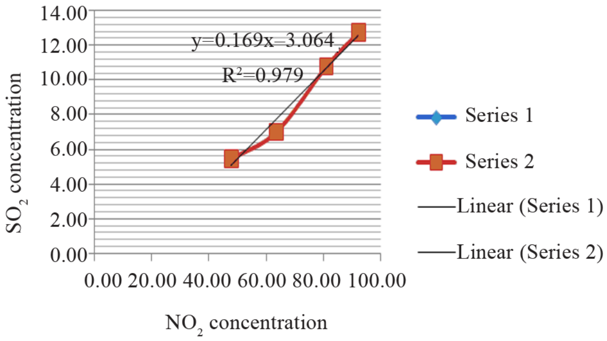

Figure 10. Interrelation between SO_2 and NO_2.

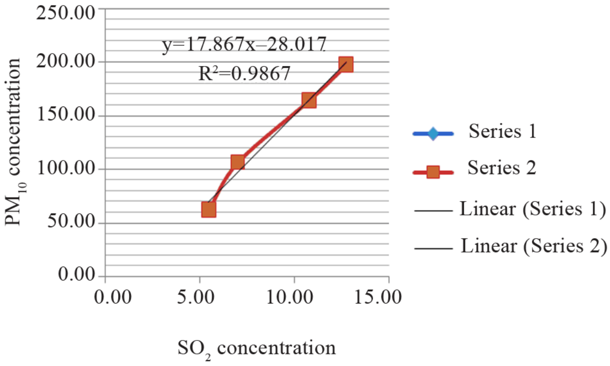

Figure 11. Interrelation between SO_2 and PM_{10}.

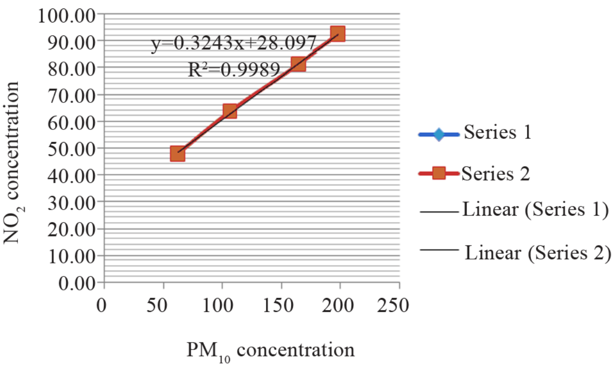

Figure 12. Interrelation between NO_2 and PM_{10}.

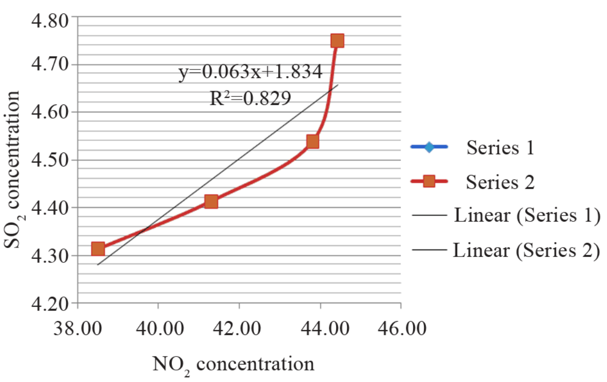

Figure 13. Interrelation between PM_{10} and SO_2.

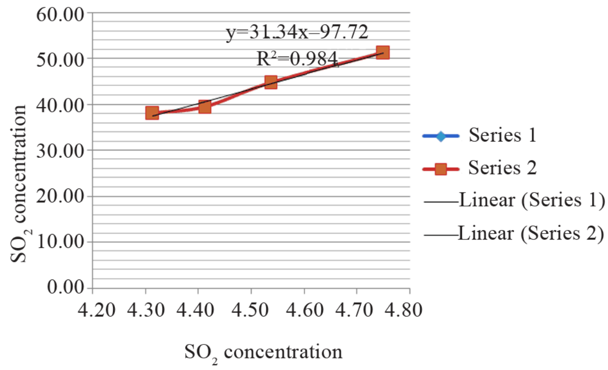

Figure 14. Interrelation between NO_2 and PM_{10}.

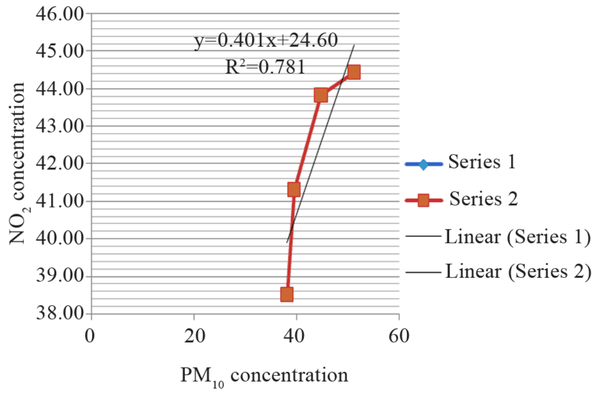

Figure 15. Interrelation between NO_2 and SO_2.

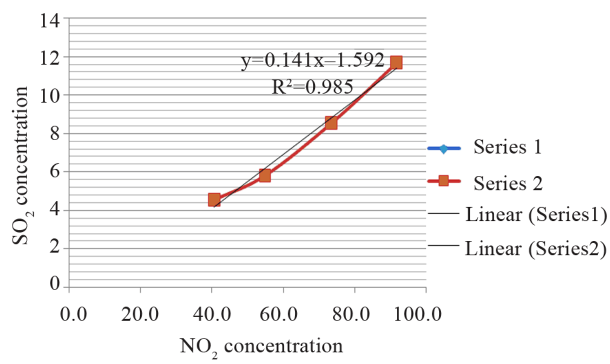

Figure 16. Interrelation between NO_2 and SO_2.

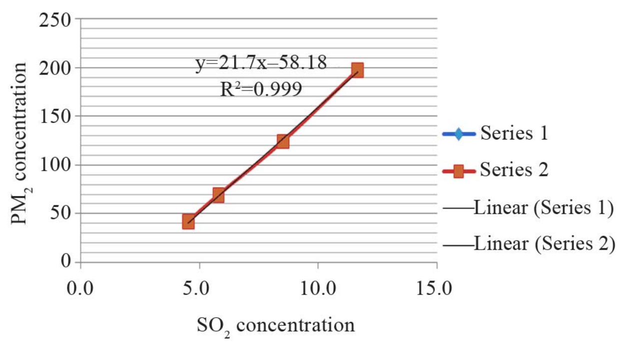

Figure 17. Interrelation between PM_{10} and SO_2.

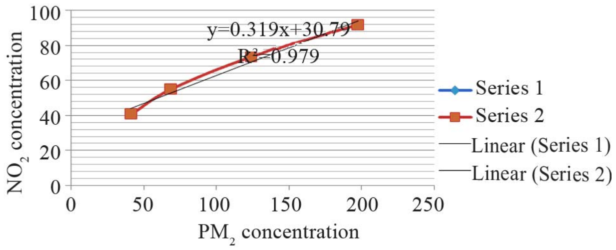

Figure 18. Interrelation between NO_2 and PM_{10}.

5. Conclusion

As different parameters are involved for dispersion of pollutants in atmosphere, it is not possible to achieve 100% accuracy for prediction in most of the cases due to different climatic parameters, sampling errors etc. Our study involves the prediction of major three types of pollutants and tries to give an idea about their levels which may help many future activities. If we follow the method given in our paper we find that instead of collecting all types of data, we need to measure only two types of parameters depending on the time periods. For example, prediction of PM_{10} can be made using the value of any one of the parameters NO_2 and SO_2. However, it is interesting to observe that prediction of PM_{10} is more accurate when only the value of NO_2 is used instead of SO_2. Thus during the process of data collection if sample of NO_2 is only collected, our purpose would be served and, consequently, the cost involved in the field work to collect samples can be significantly reduced. As we know SO_2, NO_2 and PM_{10} have very negative impact of on our society; their predictions may help us adopt necessary preventive measure time to time to ensure better living conditions.

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