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Particulate Matter Pollution around a Cement Industry and its Potential Effect

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Authors' contributions

This work was carried out in collaboration among all authors. Author VEA designed the study, performed the statistical analysis, wrote the protocol, wrote the first draft of the manuscript and managed the analyses of the study. Authors NU and BOE managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Analysis of particulate matter (PM) $PM_{2.5}$ and PM_{10} was done around a cement company in Rivers State, Nigeria. Measurements were taken for the concentration of $PM_{2.5}$ and PM_{10} and other atmospheric parameters at intervals of 100 m up to 1000 m and field observation was carried out for two days. The temperature of the area varied between 26.6 degrees and 33.3 degrees, relative humidity was between 70.2 and 98.2% and the wind speed ranged from 0.2 to 3.6 m/s. The minimum PM_{10} and $PM_{2.5}$ values were 38 and 18 µg/m^3 respectively and the maximum PM_{10} and $PM_{2.5}$ values were 616 and 298 µg/m^3 respectively. A two way analysis of variance was done at 5 % level of significance to determine the influence the time the measurement was taken and the distance from the stack have on the particulate matter concentration. *P* values were lower than *P* = .05 therefore, the null hypothesis was rejected. The pollution index for PM_{10} was determined and about 86% of the pollution index are above 100, 80% are above 150 and about 21% is above 400. About 96% of the pollution index for $PM_{2.5}$ is above 100, 87% are above 150 and about 21% are above 300. As shown on Air quality index charts, values between 100 and 150 are unhealthy for sensitive groups, values above 150 are unhealthy, and values above 300 are hazardous while values above 400 are very hazardous. It is concluded that the ground level concentration of PM_{10} and $PM_{2.5}$ up to 1200 m from the stack is generally unhealthy for the receptors.

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Keywords: Particulate matter; pollution index; hazardous; atmospheric parameters.

1. INTRODUCTION

The natural air consists of Nitrogen (78%), Carbon (iv) oxide (0.03%), water vapour (1%) and trace gases, although the actual composition can be slightly different depending on the location, elevation and season. Contaminants such as dust, fumes, odour and smoke can occur naturally or man made in quantities, characteristics and over a period that can cause an alteration in the state of the atmosphere and ultimately lead to air pollution [1,2]. Air pollution is the influx of particulate matter, biological molecules or other toxic substances into the earth's atmosphere resulting in incidence of diseases, mortality and damage to other living organisms and degradation of the environment. Air pollution may come from natural or anthropogenic sources. Some of the natural sources includes: dust from arid lands and volcanic gas, while anthropogenic sources include: emissions from industries and vehicles, dust from construction activities etc. Atmospheric dust is of particular interest in dry climates. Mineral dusts are also of concern as they contain high concentrations of toxic metals [3-6]. The concentration of particulate matter in the atmosphere is controlled mostly by weather patterns; wind speed and direction, relative humidity, rainfall and the topography of the area [7]. The stability of the atmosphere affects pollution released from different elevations from the ground level differently [8].

Anthropogenic air pollution has serious impact on the health of people. The transformation, reaction and morphing of the pollutants cause chronic and acute diseases on a local and global scale [9]. The criteria pollutants are: Particulate matter (PM), CO, SO_2 NO_2, O_3, and Pb (lead). According to the Environmental Protection Agency [10], Particulate Matter is a "mixture of extremely small particles and liquid droplets". A particulate matter of less than 10 microns is of particular concern because at this size, the particles can easily penetrate the lungs. $PM_{2.5}$ which is smaller in comparison to PM_{10} travels farther because of its lighter weight [11]. A study was done and it was concluded that particles when discharged into the air undergo different reactions and movement and that this movement is caused by transport, dispersion and deposition [12]. Transport is induced by a time-averaged wind flow, dispersion occurs as a result of local turbulence and deposition which comprises diverse processes like precipitation, scavenging and sedimentation causes downward movement of pollutants in the atmosphere thereby driving pollutants to the lithosphere [13].

The cement industry often contributes significantly to the imbalances of the environment with respect to air pollution. Smoke stacks from cement companies generate contaminants in amounts that are enough to pollute the environment. The environmental emissions of concern are nitrogen oxides (NO_x), sulphur dioxide (SO_2) and grey dust [14]. The cement industry contributes about 6% of the greenhouse gases in the atmosphere especially CO_2 [15,16]. The main aim of mitigating pollution in the cement industry is to minimize the ambient particulate levels emitted from cement industries by reducing the mass load emitted from stacks, fugitive emissions and other sources [17]. World health organization (WHO) states that about 2.4 million people die every year due to air pollution and studies suggest that 500,000 people die from cardiopulmonary diseases associated with breathing in inhalable particulate matter [18]. Air pollution is very detrimental to humans, plants and other organisms [19]. Exposure of plants and animals to cement particulates for a short period may not cause very serious problems. However, a prolonged exposure is likely to cause serious irreversible damage to tissues and organs [20]. Most industries are only concerned with the air quality around their base of operation; however, more focus should be given to regions downwind where the pollutants may be transported to. This work is focused on the analysis of concentration of particulate matter $PM_{2.5}$ and PM_{10} at specific distances downwind and determining the air pollution index.

2. MATERIALS AND METHODS

2.1 Study Location

The study was conducted around a cement production facility in Rivers state, Nigeria with coordinates 4°48'59.0"N 7°03'51.1"E. The town is a residential area with little subsistence agricultural practice. The major source of livelihood in the area is business (restaurant, stores and supermarkets). The area would have been good for fishing activities because of the presence of fresh water bodies. However there is a very low population of aquatic life here and this is probably because most industries in the area

Table 1. Breakpoint and AQI index

O_3 (ppb)	O_3 (ppb)	$PM_{2.5}$ (μg/m^3)	PM_{10} (μg/m^3)	CO (ppm)	SO_2 (ppb)	NO_2 (ppb)	AQI	AQI
C_{low} - C_{high} (avg)	C_{low} - C_{high} (avg)	C_{low}- C_{high} (avg)	C_{low} - C_{high} (avg)	C_{low} - C_{high} (avg)	C_{low} - C_{high} (avg)	C_{low} - C_{high} (avg)	I_{low} - I_{high}	**Category**
0-54 (8-hr)	-	0.0-12.0 (24-hr)	0-54 (24-hr)	0.0-4.4 (8-hr)	0-35 (1-hr)	0-53 (1-hr)	0-50	Good
55-70 (8-hr)	-	12.1-35.4 (24-hr)	55-154 (24-hr)	4.5-9.4 (8-hr)	36-75 (1-hr)	54-100 (1-hr)	51-100	Moderate
71-85 (8-hr)	125-164 (1-hr)	35.5-55.4 (24-hr)	155-254 (24-hr)	9.5-12.4 (8-hr)	76-185 (1-hr)	101-360 (1-hr)	101-150	Unhealthy for Sensitive Groups
86-105 (8-hr)	165-204 (1-hr)	55.5-150.4 (24-hr)	255-354 (24-hr)	12.5-15.4 (8-hr)	186-304 (1-hr)	361-649 (1-hr)	151-200	Unhealthy
106-200 (8-hr)	205-404 (1-hr)	150.5-250.4 (24-hr)	355-424 (24-hr)	15.5-30.4 (8-hr)	305-604 (24-hr)	650-1249 (1-hr)	201-300	Very Unhealthy
-	405-504 (1-hr)	250.5-350.4 (24-hr)	425-504 (24-hr)	30.5-40.4 (8-hr)	605-804 (24-hr)	1250-1649 (1-hr)	301-400	Hazardous
-	505-604 (1-hr)	350.5-500.4 (24-hr)	505-604 (24-hr)	40.5-50.4 (8-hr)	805-1004 (24-hr)	1650-2049 (1-hr)	401-500	Very Hazardous

Source: UEPA 2011

release their effluents into the water body. The settlement pattern here is nucleated and linear along the major roads. It is a developing area with high population growth every year due to the presence of industries and employment opportunities.

2.2 Sampling Technique

Measurements were taken at distances away from the stack following the direction of the wind. The first reading was taken at a distance of 20 m away from the smokestack in the wind direction and at a height of 1.5 m from ground level. This was repeated at 100 m intervals until a total distance of 1000 m was covered. Relative humidity, ambient temperature and wind speed were also measured. An anemometer was used to determine the wind speed and the wind direction. A GPS was used to determine the coordinates of each station. Field observations were carried out in the morning, afternoon and evening for 2 days because production was done only twice in the week.

2.3 Mathematical Methods

To calculate the pollutant index at each sampling point, Equation (1) [21] was used.

$$I_P = \frac{I_{Hi} - I_{Lo}}{BP_{Hi} - BP_{Lo}}\left(C_p - BP_{Lo}\right) + I_{Lo} \quad (1)$$

Where,

$\mathrm{I_p}$ = the index for pollutant p
$\mathrm{C_p}$ = the rounded concentration of pollutant p (µg/m^3)
$\mathrm{BP_{Hi}}$ = the breakpoint that is greater than or equal to $\mathrm{C_p}$
$\mathrm{BP_{Lo}}$ = the breakpoint that is less than or equal to $\mathrm{C_p}$
$\mathrm{I_{Hi}}$ = the air quality index (AQI) value corresponding to $\mathrm{BP_{Hi}}$
$\mathrm{I_{Lo}}$ = the AQI value corresponding to $\mathrm{BP_{Lo}}$

The breakpoint values are derived from EPA's AQI table. Table 1 shows breakpoint values and AQI classification.

3. RESULTS AND DISCUSSION

3.1 Atmospheric Parameters

It was observed that the highest temperature was 33.3℃ and lowest was 26.6℃. At high temperature, dispersion is faster leading to a lower pollutant concentration and at lower temperature, dispersion is slower. It was observed that the highest relative humidity was 98.2% and lowest was 70.2%. It was observed that the highest wind speed was 3.9 m/s and lowest was 0.2 m/s. The wind is observed to be blowing westward. The morning wind blows to the south- west (SW) direction, the afternoon has its direction to the north- west (NW) likewise the evening.

3.2 Particulate Matter

Figs. 1 and 2 showed that the evenings had the highest concentrations of particulate matter, except at locations 7 and 8 which had the highest $PM_{2.5}$ measurements of 284 and 264 µg/m^3 respectively for the afternoon. A possible reason why the evenings were the worse is that the atmospheric vertical dispersion in the evenings is low, because a temperature inversion is setting in. Hence, all the pollutants released at this time and the pollutants that have subsided during the day cannot be effectively dispersed, resulting in higher ground level concentrations of particulate matter. In Fig. 1, locations 1 to 6 was observed to have higher ground level concentration of pollutants in the evenings followed by a decline in location 7 and then a spike at locations 8 to 11. Also, the same trend was observed from Fig. 2 except from locations 7 to 11 where the afternoon observations show consistently high values with a gradual decrease further from the stack. This could be as result of atmospheric turbulence during the day which causes the pollutants to reach ground level quickly as they are released from the stack. During the day, unstable conditions could occur because the ground is heated by the sun leading to thermal and density stratification which are usually very unstable. This leads to high vertical mixing rate which usually occurs over a short period of time before complete dispersion takes place.

On the second day as seen in Fig. 3 and 4, the mornings generally saw a higher ground level concentration of pollutants. This may be due to the fact that a temperature inversion still exists in the mornings, and it takes the rising sun to break the inversion. Hence, pollutants released in the morning or the evening the previous day will not be adequately dispersed or may be re-suspended in the air due to wind action. Locations 6, 8 and 10 were observed to have higher values compared to other locations. However, all the observed values where seen to looping possibly as a result of cross wind effect.

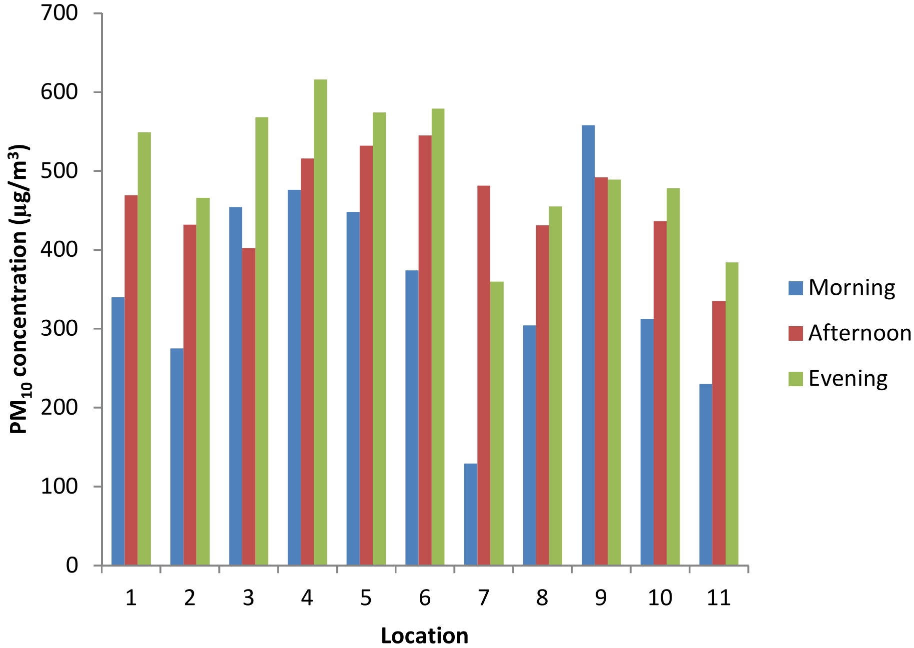

Fig. 1. Variation of PM_{10} concentrations at different sampling points on day 1

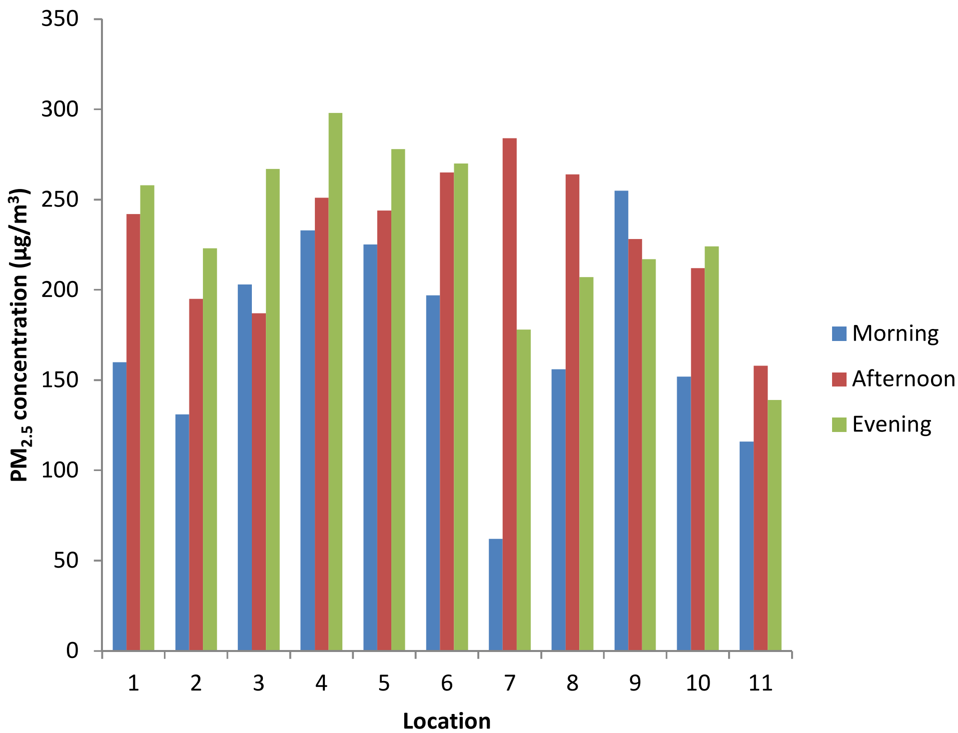

Fig. 2. Variation of $PM_{2.5}$ concentrations at different sampling points on day 1

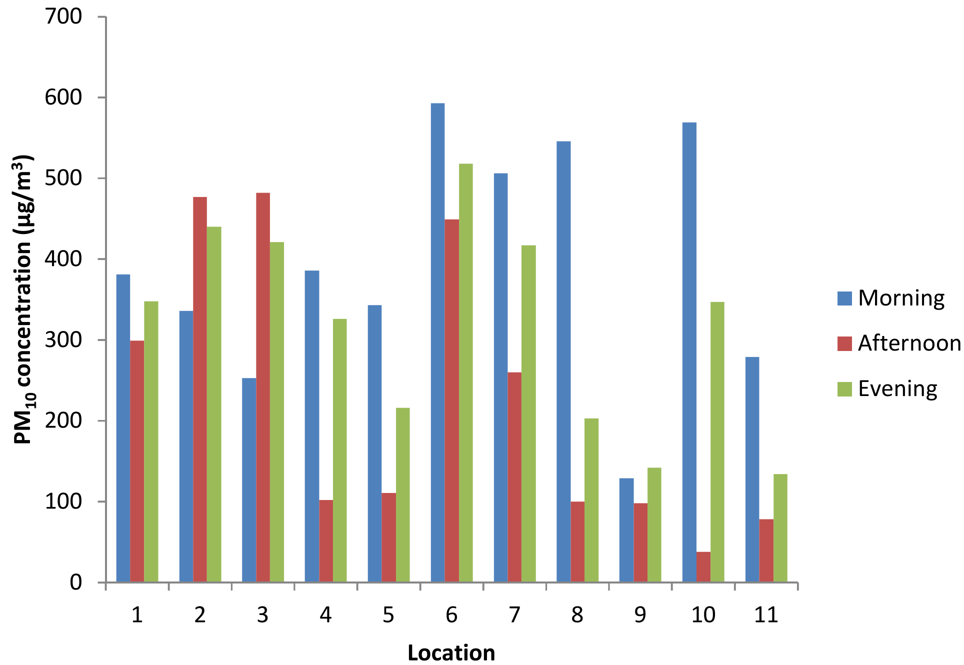

Fig. 3. Variation of PM_{10} concentrations at different sampling points on day 2

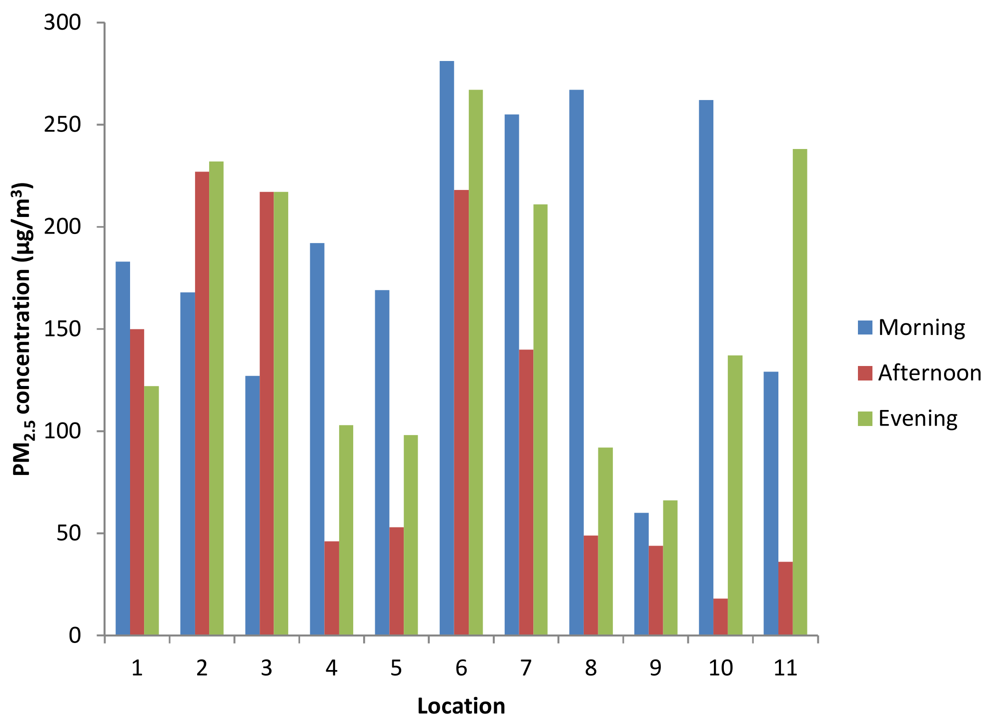

Fig. 4. Variation of $PM_{2.5}$ concentrations at different sampling points on day 2

Table 2. PM_{10} analysis of variance on day 1

Source of variation	SS	df	MS	F	P-value	F crit
Distance	179001.20	10	17900.12	4.44	0.0022	2.35
Time of Day	126938.60	2	63469.30	15.73	7.87E-05	3.49
Error	80714.06	20	4035.70			
Total	386653.9	32				

SS = Sum of squares; df = Degrees of freedom; MS = Mean squares; F = F-statistic

Table 3. $PM_{2.5}$ analysis of variance on day 1

Source of variation	SS	df	MS	F	P-value	F crit
Distance	40055.58	10	4005.56	2.70	0.028	2.35
Time of Day	26000.06	2	13000.03	8.75	0.0019	3.49
Error	29702.61	20	1485.13			
Total	95758.24	32				

SS = Sum of squares; df = Degrees of freedom; MS = Mean squares; F = F-statistic

Table 4. PM_{10} analysis of variance on day 2

Source of variation	SS	df	MS	F	P-value	F crit
Distance	406899.2	10	40689.92	2.94	0.019	2.35
Time of Day	152385.9	2	76192.94	5.50	0.012	3.49
Error	276884.8	20	13844.24			
Total	836169.9	32				

SS = Sum of squares; df = Degrees of freedom; MS = Mean squares; F = F-statistic

Table 5. $PM_{2.5}$ analysis of variance on day 2

Source of variation	SS	df	MS	F	P-value	F crit
Distance	92904.06	10	9290.41	2.45	0.043	2.35
Time of Day	37556.06	2	18778.03	4.94	0.018	3.49
Error	75977.94	20	3798.90			
Total	206438.1	32				

SS = Sum of squares; df = Degrees of freedom; MS = Mean squares; F = F-statistic

The minimum PM_{10} and $PM_{2.5}$ values were 38 and 18 µg/m^3 respectively which occurred in the afternoon of the second day and 900 m away from the starting point. The maximum PM_{10} and $PM_{2.5}$ values were 616 and 298 µg/m^3 respectively which occurred in the evening of the first day and 300 m away from the start points. A two-way analysis of variance was done at 5% level of significance to determine the influence the time the measurement was taken and the distance from the stack have on the values observed. As shown in Tables 2 to 5, the *P* values were lower than .05, which indicates that there is significant difference in the measurements taken at different time of day and at different distances.

To determine the significance of these measured pollutants, the Pollutant Index (PI) was calculated using Equation (1) and the breakpoint of the pollutant's concentration is read from Table 1 corresponding to its index value. The calculation was done for all the stations for the two days and the results are shown in Tables 6 and 7 representing the first and the second day respectively.

The pollution index was ranked from largest to lowest and the percentile was computed using Equation (2) [22,23].

$$P = \frac{m}{n+1} \quad (2)$$

Where P is percentile, m is the rank number and n is the total number of data.

Table 6. Calculated index values for the first day (PM in μg/m^3)

	Morning				Afternoon				Evening			
Dist (m)	**PM_{10}**	**PI**	**$PM_{2.5}$**	**PI**	**PM_{10}**	**PI**	**$PM_{2.5}$**	**PI**	**PM_{10}**	**PI**	**$PM_{2.5}$**	**PI**
0	340	193.07	160	210.41	469	356.14	242	291.68	549	445.00	258	292.58
100	275	160.90	131	188.80	432	309.77	195	245.10	466	352.38	223	245.10
200	454	337.34	203	253.03	402	268.43	187	237.17	568	464.00	267	238.07
300	476	364.91	233	282.76	516	412.00	251	301.50	616	512.00	298	301.50
400	448	329.82	225	274.83	532	428.00	244	293.66	574	470.00	278	294.56
500	374	228.26	197	247.08	545	441.00	265	315.37	579	475.00	270	315.37
600	129	87.63	62	142.51	481	371.18	284	334.20	360	208.17	178	333.30
700	304	175.25	156	206.45	431	308.52	264	314.38	455	338.60	207	313.48
800	558	454.00	255	305.46	492	384.96	228	277.80	489	381.20	217	277.80
900	312	179.21	152	202.49	436	314.78	212	261.95	478	367.42	224	261.95
1000	230	138.12	116	180.15	335	200.49	158	208.43	384	242.61	139	204.39

Table 7. Calculated index values for the second day (PM in μg/m^3)

	Morning				Afternoon				Evening			
Dist (m)	**PM_{10}**	**PI**	**$PM_{2.5}$**	**PI**	**PM_{10}**	**PI**	**$PM_{2.5}$**	**PI**	**PM_{10}**	**PI**	**$PM_{2.5}$**	**PI**
0	381	238.30	183	233.21	299	172.78	150	199.77	348	197.03	122	183.60
100	336	191.09	168	218.34	477	366.16	227	276.81	440	319.80	232	281.77
200	253	149.51	127	186.50	482	372.43	217	266.90	421	283.71	217	266.90
300	386	245.48	192	242.13	102	74.26	46	111.82	326	186.14	103	172.64
400	343	194.56	169	219.33	111	78.72	53	125.60	216	131.19	98	169.76
500	593	489.00	281	331.23	449	331.08	218	267.89	518	414.00	267	317.35
600	506	402.00	255	305.46	260	153.48	140	194.00	417	278.70	211	260.96
700	546	442.00	267	317.35	100	73.27	49	117.73	203	124.76	92	166.29
800	129	187.63	60	139.37	98	72.28	44	107.89	142	94.06	66	151.29
900	569	471.29	262	312.40	38	35.19	18	55.92	347	196.54	137	192.27
1000	279	162.88	129	187.65	78	62.38	36	91.34	134	90.10	238	287.71

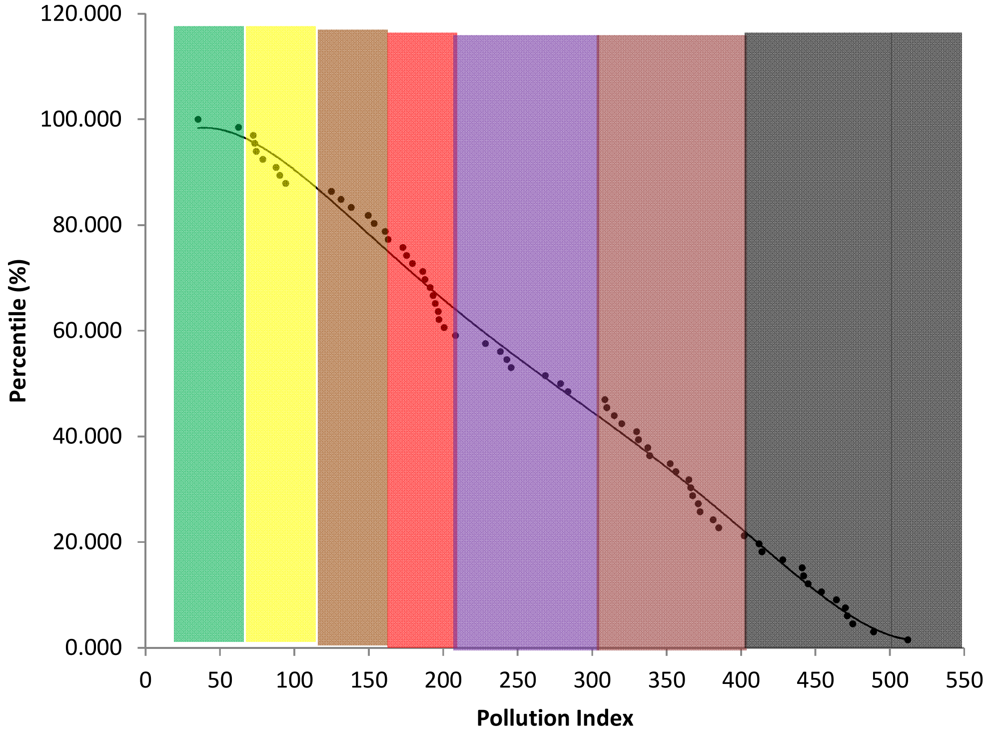

Fig. 5. PM_{10} percentage pollution index over

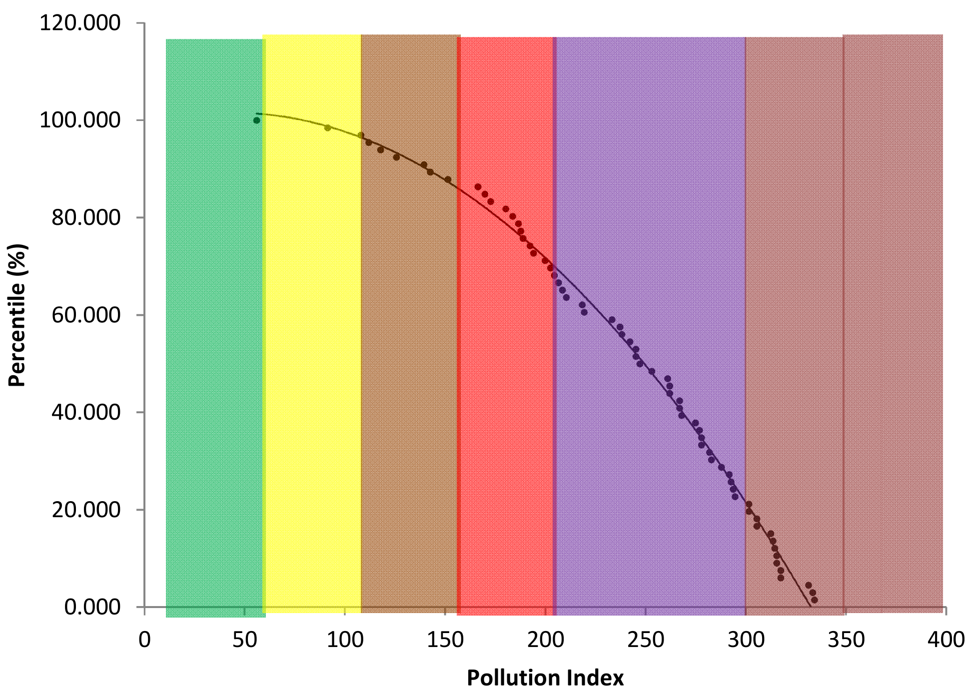

Fig. 6. $PM_{2.5}$ percentage pollution index over

The results are shown as Figs. 5 and 6. As seen in Fig. 5, about 86% of the pollution indices are above 100, 80% are above 150 and about 21% are above 400. Fig. 6 shows that about 96% of the pollution index are above 100, 87% are above 150 and about 21% are above 300. When compared with Table 1, values between 100 and 150 are unhealthy for sensitive groups, values above 150 are unhealthy, and values above 300 are hazardous while values above 400 are very hazardous. This result indicates that the ground level concentration of PM_{10} and $PM_{2.5}$ up to 1200 m from the stack is generally unhealthy for the receptors. Figs. 5 and 6 have been colour coded to represent the AQI category.

4. CONCLUSION

The maximum PM_{10} and $PM_{2.5}$ concentration were observed to be 616 and 298 μg/m^3 respectively. The *P* values obtained from statistical analysis were lower than *P* = .05, which indicates that there is significant difference in the measurements taken at different time of day and at different distances. This shows that there is constant fluctuation in pollutant concentration at the different locations. The pollution index was determined to describe the hazardous nature of the pollution, and it is concluded that the ground level concentration of PM_{10} and $PM_{2.5}$ up to 1020 m from the stack is generally unhealthy for the receptors on the days measurement was done. It is suggested that the emission stack be raised higher than it is and production should be done only at time of day when the atmosphere is stable which are usually early in the mornings and late in the evenings. However, more studies can be done for longer time periods and greater distances to determine the duration and extent of the pollution.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Mackenzie FT, Mackenzie JA. Our changing planet. Prentice-Hall, Upper Saddle River, NJ. 1995;288-307.
2. Muhammad AE, Hassain I, Noorbatcha AI, Zen IH. The effect of Climate and waste composition on leachate and Emission of Gas: A case study in Malaysian Context. Proceeding of The International Conference on Solid Waste Management, Chennai, India. 2007;437-443.
3. Branquinho C, Jayabalou R, Subrahmanyam YV, Jothikumar N, Swarnalatha S. Air pollution in stone crushing industry and associated health effect. Indian Journal Of Environmental Health. 2008;(4):169-73.
4. Shukla EJ, Schwartz J, Bratveit M. Air pollution and daily mortality: A review and meta-analysis. Environmental Research. 1990;(64):36-52.
5. Hirano RS, Singh NA, Shrivastava P, Nath SR, Kumar SS, Singh D, Vivek K. Impact of dust emission on plant vegetation of vicinity of cement plant. Environmental Engineering and Management Journal. 1995;7(1):31-50.
6. Miranda F, Tomaz E. Characterization of urban aerosol in Campinas, Sao Paulo, Brazil. Atmospheric Research. 2008;87: 147-157.
7. Ghim YS, Oh HS, Chang YS. Meteorological effects on evolution high ozone episodes in greater Seoul area. Journal of Air Waste Management. 2001; 51:185-202.
8. Dickson RR. Meteorological factors affecting particulate air pollution of a city. Bulletin of American Meteor. Soc. 1960;42: 556-560.
9. Rawat MN, Banerjee HVN. Air pollution. Tata Mc-Graw Hill, New Delhi. 1996;127.
10. U.S. Environmental protection agency (USEPA). Office of air quality planning and standards, review of national ambient air quality standards for particulate matter: Policy assessment of scientific and technical information. Report No. EPA-452/R-96-013 (USEPA, Washington, D.C, V-2-V24, V-27-V-28, V-71; 2011.
11. Marian PN. Physics of windblown dust. Cambridge University Press, New York. 2000;88-93.
12. Manton MJ. A finite element model of a moist atmospheric boundary layer. Part I — Model Equations. Tellus. 1978;30:219–228.
13. Thomas TW. Numerical weather and climate prediction. Cambridge University Press j. 2010;1(3):13-29.
14. Albeanu NP, Steve S, Kenneth H, Kaya Y. The cement industry and global climate change: Current and potential future cement industry CO2 emissions. Greenhouse Gas Control Technologies –

6th International Conference. Oxford: Pergamon. 2003;995–1000.
15. Najabat A, Abbas J, Muhammad A, Shazada KKA, Muhammad NA, Najaf A, Muhammad RR, Adil H, Xu M. The greenhouse gas emissions produced by cement production and its impact on environment: A review of global cement processing. International Journal of Research (IJR). e-ISSN: 2348-6848, p-ISSN: 2348-795. 2015;2(2):488–500.
16. Zhang J, Liu G, Chen B, Song D, Qi J, Liu X. Analysis of CO2 emission for the cement manufacturing with alternative raw materials: A LCA-based framework. Energy Procedia. 2014;61(0):2541-2545.
17. Ehrlich TO, Oladele EO. Investigation of cytotoxicity and mutagenicity of cement dust using allium cepa test. Res. J. Mutagenesis. 2007;(1):10-18.
18. Meo VS, Mishra MP, Mishra GP. Effect of cement dust pollution on trees and agricultural crops. Asian Environment. 2013;9(1):11-14.
19. Karbassi NA, Shrivastava P, Nath SR, Kumar SS, Singh DK. Impact of dust emission on plant vegetation of vicinity of cement plant. Environmental Engineering and Management Journal. 2008;7(1):31-35.
20. Heather G. Effects of air pollution on agricultural crops. Ministry of agricultural, air pollution on agricultural crops. Ontario, Canada. Order No. 85-002; 2003.
21. Yousefi S, Shahsavani A, Hadei M. Applying EPA's instruction to calculate air quality index (AQI) in Tehran. Journal of Air Pollution and Health. 2019;4(2):81-86.
22. Nwaogazie IL. Probability and statistics for science and engineering practice. Second Edition, University of Port Harcourt Press, Nigeria. 2006;57.
23. Makkonen L, Pajari M, Tikanmaki M. Discussion on plotting positions for fitting distributions and extreme value analysis. Canadian. J. Civ. Eng. 2013; 40:927–929.

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