
Chemical characteristics and health risk assessment of potential toxic elements in atmospheric PM₁₀ around Ashaka cement factory, Gombe, Nigeria

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Supplementary Material

Table 1. Reference doses and slope factors through three exposure pathways of PTEs in PM

Elements	Inhalation		Ingestion		Dermal	
	RfD	SF	RfD	SF	RfD	SF
As	1.50E-05	4.30E-03	3.00E-04	1.20E+01	-	-
Ba	5.00E-04	-	2.00E-01	-	-	-
Cd	1.00E-03	6.40E+00	1.00E-03	1.50E+01	1.00E-05	-
Cr	6.00E-05	4.20E+00	3.00E-03	5.00E-01	2.86E-05	2.00E+01
Cu	1.02E-02	-	4.00E-02	-	4.02E-02	-
Mn	1.84E-03	-	4.60E-02	-	1.43E-05	-
Mo	-	-	5.00E-03	-	-	-
Ni	5.40E-03	8.40E-01	2.00E-02	8.40E-01	2.06E-2	4.25E+01
Pb	3.52E-03	-	3.50E-03	-	5.25E-04	4.20E-02
Sb	3.00E-04	-	4.00E-04	-	-	-
Se	5.00E-03	-	5.00E-03	-	-	-
Sr	-	-	6.00E-01	-	-	-
Zn	3.01E-01	-	3.00E-01	-	6.00E-02	-

Table 2. Parameters and input assumptions for exposure assessment in PMs

Parameters	Definition	Unit	Values for Age group		References
			Child	Adult	
C	Concentration of elements in the PMs	μgm^{-3}			
EF	Exposure frequency	days/year	180	180	[39]
ED	Exposure duration	years	6	24	[39]
AF	Adherence factor of soil to skin	$\text{mg}/\text{cm}^2/\text{event}$	0.2	0.07	[39]
CF	Conversion factor	kg/mg	10^{-6}	10^{-6}	[39]
BW	Body weight	kg	15	70	[39]
AT	Average time	days	365	365	[39]
AT	Average time for carcinogens	days	$\text{ED} \times 365$	$\text{ED} \times 365$	[39]
SA	Skin surface area	cm^2	2800	5700	[39]
ABS	Dermal absorption factor	-	0.001	0.001	[39]
PEF	Particulate emission factor	m^3/kg	1.36×10^9	1.36×10^9	[34]
InhR	Inhalation rate	m^3/day	20	7.63	[34]
IngR	Ingestion rate	mg/day	60	30	[40]

Table 3. Seasonal variations in concentrations of potential toxic element ($\mu\text{g m}^{-3}$) in PM_{10} samples in the vicinity of Ashaka cement factory, Gombe, Nigeria

	Elements	As	Ba	Cd	Cr	Cu	Fe	Mn	Mo	Ni	Pb	Sb	Sc	Se	Sr	Ti	V	Zn
Dry season	Mean	0.013	0.076	0.003	0.041	0.084	19.315	0.210	0.001	0.024	0.056	0.004	0.003	0.001	0.111	0.145	0.031	0.456
	STD	0.050	0.676	0.065	0.186	1.049	4.806	0.205	0.001	0.024	0.054	0.003	0.003	0.001	0.110	0.144	0.030	0.374
	Min	0.005	0.019	<0.0001	0.015	0.027	14.176	0.100	0.020	0.028	0.052	0.100	0.009	0.007	0.021	0.016	0.002	0.019
	Max	0.020	0.243	0.019	0.073	0.300	30.100	<0.0006	<0.0001	0.070	0.165	<0.0001	0.001	<0.0003	0.212	0.300	0.113	1.045
	Mean	0.008	0.067	0.001	0.019	0.013	13.262	0.182	0.001	0.009	0.014	0.002	0.001	0.001	0.068	0.108	0.018	0.183
Wet season	STD	0.062	0.060	0.000	0.137	0.074	13.870	0.165	0.020	0.088	0.080	0.070	0.006	0.030	0.057	0.072	0.013	0.246
	Min	<0.003	<0.004	<0.0001	0.005	0.005	3.203	0.066	<0.0001	<0.0005	0.003	<0.0001	<0.0001	<0.0003	0.022	<0.003	<0.0009	0.017
	Max	0.017	0.211	0.011	0.051	0.261	45.90	0.631	0.006	0.018	0.027	0.022	0.002	0.010	0.160	0.246	0.037	0.709
Annual	Mean	0.052	0.083	0.031	0.220	0.720	60.530	0.280	0.001	0.150	0.410	0.017	0.023	0.001	0.430	0.360	0.131	2.741
	STD	0.097	0.480	0.065	0.303	1.081	161.210	1.690	0.024	0.322	0.580	0.031	0.033	0.040	0.960	0.961	0.362	5.450
	WHO	0.006	-	0.005	0.00025	-	-	0.15	-	0.02	0.0005	-	-	-	-	-	-	-

Table 4. Potential toxic element concentrations in PM₁₀ samples in this present study and other studies

Study sites	As	Ba	Cd	Cr	Cu	Fe	Mn	Mo	Ni	Pb	Sb	Sc	Se	Sr	Ti	V	Zn	References
Gombe, Nigeria ($\mu\text{g}/\text{m}^3$)	0.0520	0.0830	0.0310	0.2200	0.7200	60.5300	0.2800	0.0010	0.1500	0.4100	0.0170	0.0230	0.0010	0.4300	0.3600	0.1310	2.7410	Present study
Jeddah, Saudi Arabia ($\mu\text{g}/\text{m}^3$)	0.0024	-	0.0498	0.0044	0.0084	20.404	0.5540	-	0.0056	0.0080	-	-	-	0.0203	1.6670	0.0176	0.0207	[49]
Beijing, China ($\mu\text{g}/\text{m}^3$)	0.0270	2.060	0.0047	0.0222	1.1500	6.1700	2.1200	0.0111	0.0120	1.9300	0.0033	-	0.0110	0.0647	0.1240	0.1110	0.4760	[56]
Agra, India ($\mu\text{g}/\text{m}^3$)	-	-	-	0.3000	0.0400	2.9000	0.9000	-	0.2000	1.1000	-	-	-	-	-	-	0.5000	[57]
Changping, China ($\mu\text{g}/\text{m}^3$)	0.0660	0.0260	0.0020	0.0220	0.5600	90.000	2.3000	-	0.0080	0.0690	0.0070	1.7000	0.0100	1.8000	-	0.0210	38.000	[9]
Ibadan, Nigeria($\mu\text{g}/\text{m}^3$)	-	2.8500	-	1.2500	1.0000	510.00	8.5000	-	0.4500	-	-	-	-	-	-	-	49.400	[27]
Changhua, Taiwan ($\mu\text{g}/\text{m}^3$)	0.0034	0.0123	0.0007	0.0307	0.0157	0.5710	0.0201	0.0016	0.0098	0.2120	0.0029	-	-	0.0050	0.0555	0.0107	0.1310	[58]
Accra, Ghana($\mu\text{g}/\text{m}^3$)	-	-	0.0002	-	0.0005	-	0.0048	-	-	0.0005	-	-	-	-	-	-	0.0005	[44]
Lahore, Pakistan($\mu\text{g}/\text{m}^3$)	0.0220	0.1200	0.0770	0.0300	0.0730	8.2000	0.3000	0.0022	0.0180	4.4000	0.0660	0.0018	0.0066	0.0430	0.5600	0.0210	11.000	[59]

Table 5. Pearson correlation coefficients for potential toxic elements in PM₁₀ samples in the vicinity of Ashaka cement factory, Gombe, Nigeria

Metals	As	Ba	Cd	Cr	Cu	Fe	Mn	Mo	Ni	Pb	Sb	Sc	Se	Sr	Ti	V	Zn
As	1																
Ba	-0.143	1															
Cd	0.259	0.155	1														
Cr	0.473*	0.067	-0.057	1													
Cu	0.257	0.170	0.967**	0.060	1												
Fe	0.789**	-0.189	0.029	0.449*	0.075	1											
Mn	0.030	0.721**	0.168	0.212	0.160	0.135	1										
Mo	-0.157	0.228	0.037	0.320	0.089	-0.134	0.171	1									
Ni	0.641*	0.671**	0.007	0.424	0.092	0.436	0.383	0.145	1								
Pb	0.323	0.164	0.926**	0.218	0.970**	0.150	0.225	0.212	0.141	1							
Sb	0.226	0.085	0.691**	-0.074	0.572**	-0.135	0.008	0.133	-0.088	0.661**	1						
Sc	0.339	-0.297	-0.122	0.163	-0.091	0.338	-0.172	0.002	0.009	-0.050	-0.154	1					
Se	0.218	-0.160	0.033	0.144	0.030	0.134	-0.082	-0.667**	-0.058	0.044	-0.047	-0.123	1				
Sr	0.464*	0.469*	-0.028	0.676**	0.056	0.473*	0.678**	0.293	0.709**	0.186	-0.134	0.112	-0.090	1			
Ti	0.123	0.707**	-0.002	0.487*	0.048	-0.005	0.693**	0.488*	0.639**	0.156	0.000	-0.055	-0.282	0.835**	1		
V	0.270	0.516*	-0.094	0.398	-0.071	0.330	0.442	0.207	0.566**	-0.004	-0.091	0.146	-0.192	0.449*	0.540*	1	
Zn	0.485*	-0.046	0.557*	0.374	0.612**	0.370	0.212	0.054	0.173	0.649**	0.203	0.250	-0.050	0.372	0.254	0.221	1

*. Correlation is significant at the 0.05 level (2-tailed).

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

Table 6. Factor loading matrix (after varimax rotation), eigenvalues and variances PM₁₀ samples

Metals	Component			
	Factor 1	Factor 2	Factor 3	Factor 4
As	0.862	0.005	0.266	-0.198
Ba	0.927	-0.200	0.141	0.041
Cd	-0.001	-0.034	0.979	-0.072
Cr	0.228	0.691	0.053	0.197
Cu	0.022	0.045	0.967	-0.029
Fe	-0.007	0.883	0.021	-0.175
Mn	0.818	0.042	0.180	0.020
Mo	0.228	-0.012	0.111	0.869
Ni	0.688	0.532	0.013	-0.024
Pb	0.954	0.148	0.064	0.051
Sb	-0.051	-0.155	0.722	0.039
Sc	-0.326	0.454	-0.122	0.312
Se	-0.098	0.111	0.026	-0.833
Sr	0.683	0.592	0.040	0.173
Ti	0.819	0.194	0.073	0.384
V	0.545	0.405	-0.083	0.213
Zn	-0.040	0.503	0.631	0.159
Eigenvalues	5.448	4.835	3.986	1.946
Variance (%)	25.945	23.024	18.983	9.265
Cumulative (%)	25.945	48.969	67.952	77.217

Values in bold correspond to each variable to the factor for which the squared cosine is the largest

Table 7. Non-carcinogenic risks of PM₁₀ samples around Ashaka cement factory in dry and wet seasons

Elements	Age group	Dry season			Wet season		
		Inhalation	Ingestion	Dermal	Inhalation	Ingestion	Dermal
		HQ	HQ	HQ	HQ	HQ	HQ
As	Child	4.19E-06	8.53E-04	-	2.58E-06	5.26E-04	-
	Adult	4.48E-07	9.20E-06	-	2.76E-09	5.63E-06	-
Ba	Child	7.34E-07	7.50E-06	-	6.48E-07	6.60E-06	-
	Adult	7.88E-08	8.05E-06	-	6.94E-08	7.10E-06	-
Cd	Child	1.45E-08	5.92E-05	2.21E-07	4.83E-07	1.97E-05	7.36E-08
	Adult	1.55E-09	6.34E-05	3.37E-08	5.18E-08	2.11E-05	1.12E-08
Cr	Child	3.30E-06	2.70E-04	9.02E-04	1.53E-06	1.25E-04	1.22E-03
	Adult	3.55E-07	2.89E-04	4.02E-04	1.82E-07	1.34E-04	1.87E-04
Cu	Child	3.63E-08	4.15E-05	1.55E-07	5.62E-07	6.40E-06	2.49E-08
	Adult	3.88E-09	4.45E-05	2.36E-08	1.21E-08	6.88E-06	3.65E-09
Mn	Child	2.04E-05	2.96E-05	2.70E-02	1.76E-05	2.56E-05	2.34E-02
	Adult	2.04E-06	3.17E-05	4.13E-03	1.89E-06	2.75E-05	3.58E-03
Mo	Child	-	3.94E-06	-	-	3.94E-06	-
	Adult	-	4.22E-06	-	-	4.22E-06	-
Ni	Child	8.29E-06	4.30E-05	2.15E-06	3.11E-06	1.62E-05	8.06E-07
	Adult	8.86E-07	4.61E-05	3.28E-07	3.32E-07	1.73E-05	1.23E-07

Pb	Child	7.70E-08	3.14E-04	1.03E-05	1.92E-08	7.89E-05	2.58E-09
	Adult	8.24E-09	3.37E-04	2.13E-06	2.06E-09	8.46E-05	3.94E-10
Sb	Child	4.83E-08	1.98E-04	-	2.42E-08	9.88E-05	-
	Adult	5.18E-09	2.11E-04	-	2.60E-09	1.06E-04	-
Se	Child	9.66E-09	3.94E-05	-	9.66E-10	3.94E-05	-
	Adult	1.04E-08	4.22E-05	-	1.04E-10	4.22E-05	-
Sr	Child	-	3.62E-06	-	-	2.23E-06	-
	Adult	-	3.90E-06	-	-	2.39E-06	-
Zn	Child	7.34E-09	3.00E-05	1.40E-05	6.62E-05	1.20E-05	5.62E-06
	Adult	7.87E-10	3.22E-05	2.13E-06	6.77E-06	1.29E-05	8.57E-07
HI	Child	2.32E-03	3.82E+00	4.53E-01	2.32E-03	3.82E+00	4.53E-01
	Adult	9.91E-04	6.02E-01	1.11E-01	9.91E-04	6.02E-01	1.11E-01

Table 8. Carcinogenic risks of PM₁₀ samples around Ashaka cement factory in dry and wet season

Elements	Age group	Dry season			Wet season		
		Inhalation	Ingestion	Dermal	Inhalation	Ingestion	Dermal
		CR	CR	HQ	CR	CR	CR
As	Child	2.70E-13	3.07E-06	-	1.66E-13	1.42E-06	-
	Adult	2.89E-14	3.30E-08	-	1.78E-14	2.03E-08	-
Cd	Child	9.14E-08	8.88E-07	-	3.04E-06	2.96E-07	-
	Adult	9.77E-09	9.51E-07	-	3.26E-07	3.17E-07	-
Cr	Child	1.39E-04	4.05E-07	5.16E-07	6.43E-05	1.88E-07	7.00E-07
	Adult	1.50E-05	4.34E-07	3.10E-07	7.64E-06	2.02E-07	1.07E-07
Ni	Child	6.70E-06	4.26E-07	1.88E-06	2.61E-06	1.60E-07	7.06E-07
	Adult	7.27E-07	4.56E-07	2.87E-07	2.79E-07	1.71E-07	1.08E-07
Pb	Child	-	-	4.33E-09	-	-	1.08E-09
	Adult	-	-	6.59E-10	-	-	1.65E-10

Table 9. The average concentration (n=3) of potential toxic elements ($\mu\text{g}\cdot\text{m}^{-3}$) in PM_{10} in dry season.

Elements	As	Ba	Cd	Cr	Cu	Fe	Mn	Mo	Ni	Pb	Sb	Sc	Se	Sr	Ti	V	Zn
AS1	0.005	0.088	0.011	0.021	0.261	14.177	0.212	<0.0001	0.013	0.138	0.002	0.001	0.001	0.059	0.076	0.004	0.923
AS2	0.020	0.100	0.019	0.030	0.301	18.567	0.280	0.001	0.016	0.165	0.032	0.001	0.001	0.090	0.144	0.021	0.866
AS3	0.011	0.026	<0.0001	0.015	0.027	18.023	<0.0006	<0.0001	0.001	0.018	<0.0001	0.100	<0.0003	0.022	0.020	0.023	0.020
AS4	0.020	0.034	<0.0001	0.046	0.030	30.100	0.300	<0.0001	0.032	0.034	<0.0001	0.009	<0.0003	0.198	0.232	0.045	1.046
AS5	0.012	0.084	<0.0001	0.073	0.042	20.692	0.210	<0.0001	0.017	0.041	<0.0001	0.002	0.007	0.151	0.144	0.011	0.284
AS6	0.010	0.101	<0.0001	0.063	0.032	19.898	0.288	0.002	0.021	0.040	<0.0001	0.002	<0.0003	0.109	0.200	0.113	0.632
AS7	0.010	0.026	<0.0001	0.037	0.042	17.965	0.143	<0.0001	0.010	0.016	<0.0001	0.001	<0.0003	0.091	0.101	0.006	0.147
AS8	0.019	0.243	0.001	0.041	0.54	23.833	0.343	0.001	0.100	0.034	<0.0001	0.001	0.001	0.212	0.300	0.079	0.198
AS9	0.010	0.019	<0.0001	0.029	0.008	14.593	0.127	<0.0001	0.007	0.005	0.002	0.003	<0.0003	0.025	0.016	0.002	0.180
AS10	0.011	0.034	<0.0001	0.057	0.043	15.299	0.200	0.006	0.022	0.064	0.004	0.002	<0.0003	0.154	0.212	0.004	0.271

AS=Air sample

Table 10. The average concentration (n=3) of potential toxic elements ($\mu\text{g}\cdot\text{m}^{-3}$) in PM_{10} in wet season.

Elements	As	Ba	Cd	Cr	Cu	Fe	Mn	Mo	Ni	Pb	Sb	Sc	Se	Sr	Ti	V	Zn
AS1	0.014	<0.004	0.001	0.016	0.005	17.373	0.108	0.006	0.004	0.010	<0.0001	0.001	0.010	0.014	<0.003	0.005	0.130
AS2	0.006	0.079	<0.0001	0.017	0.010	3.203	0.091	0.001	0.004	0.012	0.022	0.001	<0.0003	0.022	0.101	0.018	0.017
AS3	0.013	0.074	0.001	0.051	0.027	26.507	0.2003	<0.0001	0.021	0.027	<0.0001	0.002	<0.0003	0.154	0.166	0.037	0.709
AS4	0.006	0.079	<0.0001	0.017	0.010	3.203	0.091	0.001	0.004	0.012	<0.0001	0.001	<0.0003	0.022	0.101	0.018	0.017
AS5	0.009	0.017	<0.0001	0.005	0.010	8.953	0.066	<0.0001	<0.0005	0.003	<0.0001	0.001	<0.0003	0.035	0.072	<0.0009	0.551
AS6	<0.003	0.086	0.001	0.010	0.010	3.583	0.147	0.001	0.005	0.008	<0.0001	0.001	<0.0003	0.030	0.118	0.018	0.019
AS7	0.017	0.016	<0.0001	0.021	0.011	45.900	0.216	<0.0001	0.021	0.021	<0.0001	0.002	0.001	0.088	0.010	0.034	0.141
AS8	<0.003	0.211	<0.0001	0.012	0.008	5.341	0.631	<0.0001	0.007	0.014	<0.0001	<0.0001	<0.0003	0.160	0.246	0.031	0.034
AS9	0.011	0.027	0.001	0.034	0.025	14.970	0.124	<0.0001	0.018	0.027	0.001	0.001	<0.0003	0.122	0.151	0.002	0.97
AS10	<0.003	0.086	<0.0001	0.010	0.010	3.583	0.147	0.001	0.005	0.008	0.001	0.001	<0.0003	0.030	0.118	0.018	0.019

AS=Air sample

Table 11. Average daily exposure dose (ADD) of the elements PM₁₀ samples around Ashaka cement factory in dry and wet seasons

Elements	Age group	Dry season			Wet season		
		Inhalation	Ingestion	Dermal	Inhalation	Ingestion	Dermal
		ADD	ADD	ADD	ADD	ADD	ADD
As	Child	6.29E-11	2.56E-07	2.39E-08	3.87E-11	1.58E-07	1.47E-08
	Adult	6.73E-12	2.75E-09	3.65E-09	4.14E-12	1.69E-09	2.25E-09
Ba	Child	3.67E-10	1.50E-06	1.40E-07	3.24E-10	1.32E-06	1.23E-07
	Adult	3.94E-11	1.61E-06	2.14E-07	3.47E-11	1.42E-06	1.88E-08
Cd	Child	1.45E-11	5.92E-08	5.52E-09	4.83E-12	1.97E-08	1.84E-09
	Adult	1.55E-12	6.34E-08	8.43E-10	5.18E-13	2.11E-08	2.81E-10
Cr	Child	1.98E-10	8.09E-07	2.58E-08	9.19E-11	3.75E-07	3.50E-08
	Adult	2.13E-11	8.67E-07	1.15E-08	1.09E-11	4.02E-07	5.34E-09
Cu	Child	4.06E-10	1.66E-06	1.55E-07	6.29E-11	2.56E07	2.49E-08
	Adult	4.35E-11	178E-06	2.36E-08	1.35E-10	2.75E-07	3.65E-09
Mn	Child	1.02E-09	4.14E-06	3.87E-07	8.80E-10	3.59E-06	3.35E-07
	Adult	1.09E-10	4.44E-06	5.90E-08	9.43E-11	3.85E-06	5.12E-08
Mo	Child	4.83E-12	1.97E-08	1.84E-09	4.83E-12	1.97E-08	1.84E-09
	Adult	5.18E-13	2.11E-08	2.81E-10	5.18E-13	2.11E-08	2.81E-10
Ni	Child	1.16E-10	4.73E-07	4.42E-08	4.35E-11	1.78E-07	1.66E-08
	Adult	1.24E-11	5.07E-07	6.75E-09	4.66E-12	1.90E-07	2.53E-09

Pb	Child	2.71E-10	1.10E-06	1.03E-07	6.77E-11	2.76E-07	2.58E-08
	Adult	2.90E-11	1.18E-06	1.57E-08	7.25E-12	2.96E-07	3.94E-09
Sb	Child	1.93E-11	7.90E-08	7.36E-09	9.67E-12	3.95E-08	3.68E-09
	Adult	2.07E-12	8.45E-08	1.12E-09	1.04E-12	4.22E-08	5.62E-10
Sc	Child	1.45E-11	5.92E-08	5.52E-09	4.83E-12	1.97E-08	1.84E-09
	Adult	1.55E-12	6.34E08	8.43E-10	5.18E-13	2.11E-08	2.81E-09
Se	Child	4.83E-10	1.97E-08	1.84E-09	4.83E-12	1.97E-08	1.84E-09
	Adult	5.18E-13	2.11E-08	2.81E-10	5.18E-13	2.11E-08	2.81E-09
Sr	Child	5.37E-12	2.18E-06	2.04E-07	3.29E-10	1.34E-06	1.25E-07
	Adult	5.75E-11	2.35E-06	3.12E-08	3.52E-11	1.44E-06	1.91E-08
Ti	Child	7.01E-10	2.86E-06	2.67E-07	5.22E-10	2.13E-06	1.99E-07
	Adult	7.51E-11	3.06E-06	4.08E-08	5.60E-11	2.28E-06	3.04E-08
V	Child	1.50E-10	6.12E-06	5.71E-08	8.70E-11	3.55E-07	3.31E-08
	Adult	1.61E-11	6.55E-07	8.71E-09	9.32E-12	3.80E-07	5.06E-09
Zn	Child	2.21E-09	9.01E-06	8.41E-07	8.85E-10	3.61E-06	3.37E-09
	Adult	2.37E-10	9.66E-06	1.28E-07	9.48E-11	3.86E-06	5.14E-08
