Chemical characteristics and health risk assessment of potential toxic elementsin atmospheric PM_{10} around Ashaka cement factory, Gombe, Nigeria

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The study determined the ambient mass concentrations, chemical composition and health risks associated with PM_{10} around Ashaka cement factory, Gombe, Nigeria. The samples were collected for the period (2019-2020). A total of 60 PM_{10} samples were collected and analyzed for seventeen elements using Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES). The data collected were analyzed for descriptive and inferential statistics. The health risk was analyzed for hazard quotient (HQ), hazard index (HI) and cancer risk (CR). The average annual PM_{10} mass concentrations were found to be higher than the annual limit value for air quality standards (40 μgm^{-3}). The HI estimated were >1 for children, while CR values of Cd, Ni, As and Cr for children and Cr for adults were higher than the acceptable value 10^{-6}, indicating children are more probable to develop cancer than adults.

Introduction

Air pollution is the discharge of substances that are capable of infringing the quality of ambient air [1-3]. Air pollution conveys atmospheric particulate matter (PM) incessantly [4,5], which include fine ($PM_{2.5}$) and coarse ($PM_{2.5-10}$) particles that are found to be widely associated with health problems [6]. $PM_{2.5}$ and PM_{10} are emitted from a variety of sources, including combustion processes, cooking, vehicular traffic, industrial emissions, etc [6]. Exposure to fine particulate matter has been reported to have more strong relationships with adverse health outcomes such as respiratory and cardiovascular disease [7].

Environmental pollution with particulate matter (PM) and potential toxic elements (PTEs) is gaining global attention due to their increase caused by rapid urbanization and industrialization in recent years [8-10]. The contamination of the environment with PTEs and PM affects human health, quality of life, and the natural functioning of an ecosystem [11-13]. PTEs are among the most relevant substances emitted during the process of industrial production and are of significant environmental concern due to their wide sources, toxicity, accumulative behaviours and non-biodegradable properties [14,15]. The occurrence of these elements in the environment could be from

natural sources or human activities such as mining, coal combustion, fuel combustion, biomass combustion, cement production, etc [10].

Cement production is one of the major industrial sources of PMs and PTEs, especially zinc, lead, nickel, cadmium, mercury, arsenic and copper. These PTEs are usually generated from combustions of fossil fuels and the processing of the raw materials [16]. Typical raw cement is made up Pb (20 $mgkg^{-1}$), Cu (21 $mgkg^{-1}$), Cr (25 $mgkg^{-1}$) and Zn (53 $mgkg^{-1}$) [17]. The deposition of the potential toxic elements occurred at different distances in the vicinity of cement factories and is influenced by particle size, wind velocity and stack fumes [17], and are capable of deteriorating air quality. PTEs are an important part of PM since they can have both carcinogenic and non-carcinogenic effects [18].

PM is a global issue with the world's population of about 91% living in regions where air pollution exceeded the World Health Organization (WHO) guidance [19]. According to the WHO, air pollution is responsible for the death of about 3.7 million people in 2012, from heart disease and stroke (29%), lung cancer (16%), chronic-obstructive pulmonary related diseases (11%) and respiratory infections (13%) [5,20]. Risk assessment models are used to estimate the health risk of elements including non-carcinogenic risk and carcinogenic risk [8, 21]. Non-carcinogenic risk was reported to be associated with systemic toxicity (e.g., liver, kidney, or generalized toxicity), neurotoxicity (brain pathology), reproductive toxicity (e.g., fertility), etc [22], while carcinogenic risk is associated to lung cancer, gastric carcinoma, brain cancer, etc [23]. Thus, there is a need to investigate the levels of PM in the air around cement factories.

Ashaka cement factory is about 9 km Bajoga, Funakaye local government area of Gombe State, northeastern Nigeria. It was established in 1967, with an installed capacity of 500,000 MT [24] to meet the needs of construction works in the Northeastern part of Nigeria [25]. About 90% of the energy requirements of the factory is realised from coal combustion [26]. This study was therefore carried out to determine the mass concentration, chemical characterization of ambient PM_{10}, and health risk associated with potential toxic elements in the samples with a view to provide information on the extent of contamination of the elements in the PM_{10} and health risk to the residents.

Experimental part

Material and Methods

Study area

The study area is Ashaka Cement Factory, located in Ashaka town, Bajoga, Funakaye Local Government Area, Gombe State, Northeast Nigeria. Ashaka Cement factory is 9 km north of Bajoga. The factory lies between latitudes 10°55'30"N and 11°56'30"N, and longitudes 11°28'30"E and 11°29'30"E (**Figure**

1). The climate of the study area is tropical with dry/harmattan season (November-April) and wet season (May-October) with an average temperature of 25 ºC. The maximum annual rainfall of 800 to 900 mm during August and a minimum of 250 to 350 mm during the early and the later period of the wet season, with a relative humidity range from 60 to 80%.

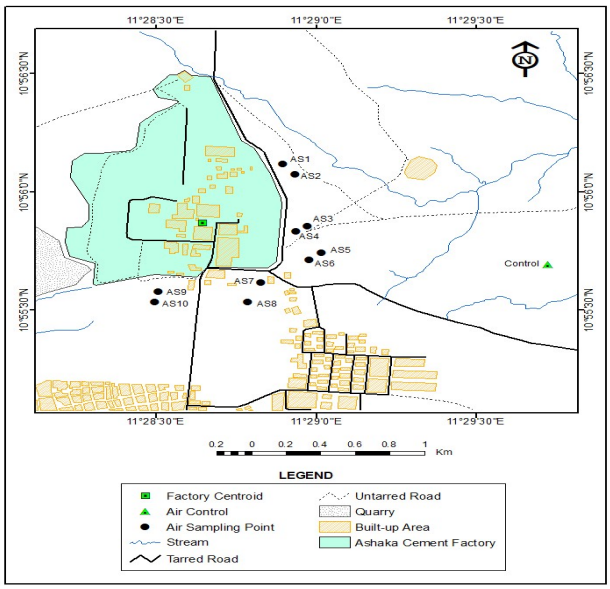

Figure 1. Map of the study area showing the sampling points

Sampling and analysis

Sampling was carried out from June 2019 to May 2020, around the Ashaka cement factory. The air samples were collected using a high-volume air sampler (HiVol 15000) capable of measuring particles under 10 µm in size. Samples were collected in both dry and wet seasons at each sampling location. Filter masses were measured on a microbalance before and after samples collection. The calibration of the sampler was carried out as reported elsewhere [27]. Each retrieved filter was cut into fragments, put into Teflon cups and digested in 20 mL freshly prepared aqua-regia (HNO_3:HCl; 1:3). The resulting solutions were analyzed to determine the contents of the potential toxic elements using inductively coupled optical emission spectrometry (ICP-OES Agilent 720-ES).

Quality control

The ICP-OES (Agilent 720-ES) was calibrated with Accu standard (QCSTD-27) multi-element standard solution. The samples and blank filter were digested with aqua-regia, and the volume was made to 50 mL with distilled water for the quantitative determination of the concentrations in unknown samples, which were estimated by standard internal method. In addition, the mean recovery percentages of the metals ranged from 86.5% to 121%. The limits of detection for As, Ba, Cd, Cr, Cu, Fe, Mn, Mo, Ni, Pb, Sb, Sc, Se, Sr, Ti, V and Zn were 0.003, 0.004, 0.0001, 0.0004, 0.0008, 0.01, 0.0006, 0.0001, 0.005, 0.001, 0.0001, 0.0001, 0.003, 0.003, 0.003, 0.009 and 0.0003 μgm^{-3}, respectively.

Data analysis

The data obtained were subjected to descriptive analysis (mean and standard deviation) and inferential (Pearson correlation, t-test and principal component analysis) statistics using SPSS software version 25. Pearson correlation and principal component analysis were adopted to determine the origins of the collected particles, while t-test was used to

determine seasonal significance at $p < 0.05$ [28, 29].

Health risk assessment

The exposure of PTEs determined in PM_{10} was assessed for human health effect using the model designed by the United States Environmental Protection Agency (USEPA) and other relative studies [8,21,30]. The three potential exposure pathways of PTEs in PMs are inhalation, ingestion and dermal contact [8,21, 30, 31-33], according to equations 1-6.

$$ADD_{inh}=\frac{C \times InhR \times EF \times ED}{PEP \times BW \times AT} \quad (1)$$

$$ADD_{derm} = \frac{C \times SA \times AF \times ABS \times EF \times ED \times CF}{BW \times AT} \quad (2)$$

$$ADD_{ing} = \frac{C \times IngR \times EF \times ED \times CF}{BW \times AT} \quad (3)$$

Non-carcinogenic risk assessment

The hazard quotient (HQ) was used to estimate the non-carcinogenic effect of PTEs in PM and was evaluated using the expression below.

$$HQ = \frac{ADD}{RfD} \quad (4)$$

Hazard index (HI) is the sum of multiple-route HQ (US EPA) [34]. A HI value >1 implies that non-carcinogenic effects may occur, the higher the value of HI, the higher the likelihood of non-carcinogenic effects (USEPA) [30].

$$HI = \sum_{n}^{i} HQ_i \quad (5)$$

Carcinogenic risk assessment

Carcinogens risk was also estimated using equation 6

$$CR = ADD_{inh} \times CSF_{inh} \quad (6)$$

Where; ADD = average daily exposure dose of elements in PM ($\mu gm^{-3}day^{-1}$), RfD = reference dose, and CSF = cancer slope factor ($\mu gm^{-3}day^{-1}$) [20, 33, 35, 36, 37]. The values of RfD and CSF are presented in **Table 1** (All Tables are presented on Supplementary Information).

The CR values below 1 × 10-6 are considered insignificant, while the CR values above 1×10^{-4} indicate harmful effects to human beings [38]. The parameters and input assumptions for exposure assessment are presented in **Table 2.**

Results and discussion

PM_{10} mass concentrations

The seasonal variations and average annual mass concentrationsof PM_{10} during the study period are presented in **Figure 2.** The average PM_{10} concentrations were (802 ± 23.50 μgm^{-3}) in the dry season and (587 ± 13.65 μgm^{-3}) in the wet season with the annual concentration of 1389 μgm^{-3}. The PM_{10} mass concentrations in the dry season are significantly higher than those in the wet season; this is mainly related to harmattan period in the dry season, which leads to increasing the levels of dust concentration in the atmosphere between December to February. The annual average mass concentration of 115.75 μgm^{-3} obtained in this study exceeded the PM_{10} average annual concentration for air quality standards (20 and 40 μgm^{-3}) by 478.75% and 189.38% [41,42], respectively. However, the annual mass concentrations of PM_{10} in this study was lower than the 1552 μgm^{-3} reported around a

cement factory in Hattar, Huripur, Pakistan [43] and the 3200 μgm^{-3} around a cement plant in Changping, China [9], but higher than the annual concentrations of 227.60 μg·m^{-3} in Accra metropolis of Ghana [44] and 502.30 μgm^{-3} in Ibadan, Nigeria [27].

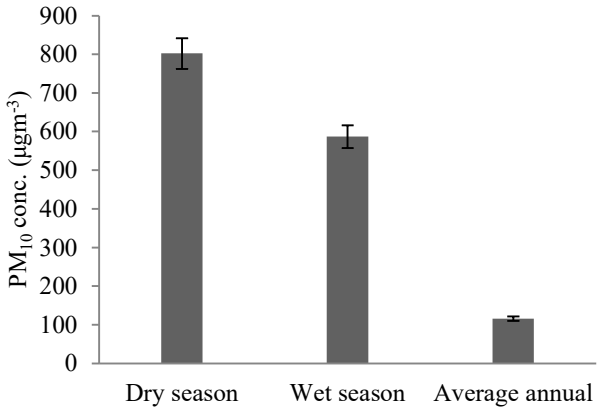

Figure 2. PM_{10} seasonal and average annual mass concentrations during study period

Seasonal variation in concentrations of potential toxic elementsin PM_{10}

Average concentrations of PTEs in PM_{10} samples are presented (**Tables 9** and **10**) in dry and wet seasons. The mean concentrations of the 17 potential toxic elementsin the different seasons are presented in **Table 3.** The results showed a trend of the variation in the concentrations of the elements. The concentrations of elements in the dry season are significantly higher than those in the wet season, except Mn. That may be due to the impact of production activities and dust episode of harmattan in the dry season. The distributions of elements in PM_{10} during dry season were in the descending order Fe > Zn > Mn > Ti > Sr > Cu > Ba > Pb > Cr > V > Ni > As > Sb > Sc > Cd > Se > Mo, while the concentrations in wet season followed the order Fe > Zn > Mn > Ti > Sr > Ba > Cr > V > Pb > Cu > Ni > As > Sb > Cd > Mo > Sc > Se. The results revealed a significant difference (p> 0.05) among the elemental concentrations of As, Cr, Pb and Sc during the dry and wet seasons. The seasonal variations of elements in atmospheric PMs might be influenced by local emission sources, wind direction and meteorological conditions [45,46].

The highest concentrations (μgm^{-3}) of As (0.02), Cr (0.073), Ni (0.10), Pb (0.16), Cd (0.19) and Mn (0.63) obtained were above the maximum tolerance limits of 0.006, 0.00025, 0.02, 0.0005, 0.005 and 0.15 μgm^{-3}, respectively [41,47]. The high concentrations of these elements in PM_{10} obtained around the vicinity of the cement factory suggest that the cement production is the major source of these elements in study area(combustion of coal and processing the raw materials). The anthropogenic activities are the key sources of Cr, Mn, Pb and Zn [48, 49]. Calcium is the major fingerprint for cement; unfortunately, this element has not been measured in the present study. Among the elements present in PM_{10}, Cu, Ni, Fe, Cr and Zn have been the main toxic elements based on their ability to support electron exchange [50-52] and create reactive oxygen species [53,54]. Elements such as Cd, Ni, Cr and Pb were established to be in significant amounts in the PM_{10} and therefore, they may pose a severe risk to human health [52,55].

Table 4 presents the elemental constituents of PM_{10} reported elsewhere in the world, e.g., Jeddah, Saudi Arabia [49], Beijing, China [56], Agra, India [57], Changping, China [9], Ibadan, Nigeria [27], Changhua, Taiwan [58], Accra, Ghana [44], and Lahore, Pakistan [59]. In comparison, the mean concentrations of Mo, Pb, Cu, Mn, Se and Ba in Beijing, China [56], were above the values obtained in this study, while Cu, Fe and Zn in this study were higher than the concentrations reported in Agra, India [57] and Cr, Ni, Cu, Sr, Zn, As and Fe in Jeddah, Saudi Arabia [49]. The high Ba concentration observed in the study may be due to its nature as witherite and baryte accumulate in cement production [60, 61].

Pearsoncorrelation analysis

Pearson correlation analysis for element concentration in the PM_{10} samples was presented in **Table 5.** The correlation analysis showed that the majority of element pairs have strong positive correlations, $r > 0.6$ ($p < 0.01$) for Fe/As, Mn/Ba, Ni/Ba, Pb/Cd, Pb/Cu, Sb/Cd, Sb/Cu, Sb/Pb, Sr/Cr, Sr/Mn, Sr/Ni, Ti/Ba, Ti/Mn, Ti/Ni, Ti/Sr, V/Ni and Zn/Pb, and $r > 0.4$ ($p < 0.05$) for Cr/As, Fe/Cr, Ni/As, Sr/As, Sr/Fe, Ti/Cr, Ti/Mo, V/Ba, V/Sr, V/Ti, Zn/As and Zn/Cd. However, Se/Mo had strong negative correlation ($r = -0.6$; $p < 0.01$). Most element pairs demonstrated strong significance ($p < 0.05$ and $p < 0.01$), indicating their simultaneous release from the production activities. The anti-correlation of Se with Mo might indicate different emission sources aside from cement production activities.

Principal component analysis

The results of the principal component analysis (PCA) are presented in **Table 6**. Four factors were identified that explained a cumulative variance of 77% of the total PM_{10} data set. As, Ba, Mn, Ni, Pb, Sr, Ti and V were loaded in factor 1 with 26% variance. This factor could emanate from anthropogenic sources, such as production and combustion of fossil fuel. Factor 2 was characterized by Cr, Fe, Ni, Sr and Zn with 23% of the variance identified, which could probably originate from emissions of machines and vehicles used in the vicinity of the factory. Factor 3 has high loadings for Cr, Cu, Sb and Zn, having a total variance 19% identified, while factor 4 was significant for only Mo with 9% variance identified. This component may indicate contributions from lithogenic and paedogenic origins.

Health risk assessment

Non-carcinogenic risk assessment of elements

The results of average daily exposure dose (ADD) are presented in **Table 11**. The results of hazard quotient (HQ), Hazard index (HI) and Cancer risk (CR) of the elements for both children and adults from three routes of exposure; (inhalation, ingestion and dermal contact) are presented in **Tables 7** and **8**. The results for HQ_{inh} were in the order Mn > Ni > As > Cr > Ba > Pb > Sb > Cu > Cd > Se > Zn for

children, and Mn > Ni > As > Cr > Ba > Se > Pb > Sb > Cu > Cd > Zn for adults in dry season, while in wet season it was Zn > Mn > Ni > As > Cr > Ba > Cu > Cd > Sb > Pb > Se for children, and Zn > Mn > Ni > Cr > Ba > Cd > Cu > As > Sb > Pb > Se for adults. HQ_{ing} was in the order As > Pb > Cr > Sb > Cd > Sr > Cu > Ni > Se > Zn > Mn > Ba > Mo for children and Pb > Cr > Sb > Cd > Ni > Cu > Se > Zn > Mn > As > Ba > Mo > Sr for adults in dry season, while in wet season it was As > Cr > Sb > Pb > Se > Mn > Cd > Ni > Zn > Ba > Cu > Mo > Sr for children, and Cr > Sb > Pb > Se > Mn > Cd > Ni > Zn > Ba > Cu > As > Mo > Sr for adults. HQ_{derm} for both children and adults were in the order Mn > Cr > Zn > Pb > Ni > Cd > Cu in dry and wet seasons. The calculated HQ for the three main exposure routes showed that ingestion of particulate matter pose greater health risk effect followed by inhalation and dermal contact pathways. This order is in conformity with previously reported studies [56, 62,63]. The values of the total hazard index (HI) revealed that children and adults were less than one for inhalation and dermal contact, suggesting no non-carcinogenic adverse health effects. However, the HI of ingestion was greater than 1 for children, but less than 1 for adults, indicating deleterious effects for children.

Carcinogenic risk assessment of elements

The carcinogenic risks (CR) of the elementsare presented in **Table 8.** Cancer risk by inhalation are the highest. The values obtained were Cr (1.39×10^{-4}), Ni (6.70×10^{-6}) for children, and Cr (1.50×10^{-5}) for adults in the dry season, while the values were Cr (6.43×10^{-5}) Cd (3.04×10^{-6}) and Ni (2.61×10^{-6}) for children and Cr (7.64×10^{-6}) for adults in the wet season. The CR values of Cr and Ni for children, and Cr for adults in the dry season were above 10^{-6}, while CR values of Cd, Cr and Ni for children and Cr adults were above 10^{-6}, which exceeded the threshold and suggested a possible cancer development by residents. The ingestion exposure pathways present the highest CR values for As (3.07×10^{-6}) and As (1.42×10^{-6}) for children in dry and wet seasons respectively. As have been reported to be mainly produced during coal burning [64]. Dermal contact revealed the highest CR value for Ni (1.88×10^{-6}) for children in the dry season. Results revealed that children are more vulnerable to health risks than adults. The inhalation of PMs in the study may pose a more carcinogenic risk than ingestion and dermal contact pathways. The cancer risk values obtained in the present study are similar to the values reported in previous studies [8,65-67].

Conclusion

This study assessed the concentrations of potential toxic elements and health risk in PM_{10} around the Ashaka factory in Gombe, Nigeria. The concentrations of As, Cd, Cr, Mn, Ni and Pb were above the tolerance limits. The multivariate statistical analysis of PCA showed four factors that are mostly anthropogenic in nature, establishing the contribution of cement production activities. The health risk associated

elements in PM_{10} samples indicated that the exposure pathways for HQs were in the distribution pattern ofingestion > inhalation > dermal, while the HI for children was greater than 1, indicating adverse health effects. The cancer risk value of elements to children was higher than the acceptable value 10^{-6}, thereby suggesting probable cancer development. The health risk assessment revealed that children were more vulnerable than adults.

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Disclosure statement

The authors declare that there exist no conflict of interest.

References

[1] Araújo IPS, Costa DB, deMorales RJB. Identification and Characterization of Particulate Matter Concentrations at Construction Jobsites. Sustainability. 2014;6:7666-7668.

[2] Angaye TCN, Abowei JFN. Evaluation of suspended particulate matter (SPM) around municipal solid waste dumpsites in yenagoa metropolis, Nigeria. MOJ Toxicol. 2018;4(2):54-57.

[3] Enetimi IS, Tariwari CAN, Odangowei, IO. Environmental and Health Risk Assessment of Particulate Matter Associated With Dusty Football Field. J. Exper. Clin. Toxic. 2019;1(2):1-6.

[4] Cao JJ, Shen ZX, Chow JC, Watson JG, Han YM. Winter and summer $PM_{2.5}$ chemical compositions in fourteen Chinese cities. J. Air. Waste. Manage. 2012;62:1214-1226.

[5] Wu L, Luo XS, Li H, Cang L, Yang J, Yang J, Zhao Z, Tang M. Seasonal Levels, Sources, and Health Risks of Heavy Metals in Atmospheric $PM_{2.5}$ from Four Functional Areas of Nanjing City, Eastern China. Atmosphere, 2019;10:419

[6] Turki MH, Atef MFM, Essam AM. Risk Assessment of Particulate Matter (PM_{10}) in Makkah, Saudi Arabia. Int. J. Environ. Ecol. Eng. 2015;9(8):947-954.

[7] Ferdos KM, Jalil J, Hamed G, Mohammad RS, Mohammad H, Davoud B, Mika S. Characterizing of fine particulate matter (PM_{10}) on the platforms and outdoor areas of underground and surface subway stations. Hum. Ecol. Assess. 2017;24(4):1016-1029.

[8] Weerasundara L, Magana-Arachchi DN, Ziyath AM, Goonetilleke A, Vithanage M. Health risk assessment of heavy metals in atmospheric deposition in a congested city environment in a developing country: Kandy City, Sri Lanka. J. Environ. Manage.2018;220:198-206.

[9] Yang Z, Tang S, Zhang Z, Liu C, Ge X, Characterization of PM_{10} surrounding a cement plant with integrated facilities for co-processing of hazardous wastes, J. Clean. Prod. 2018;186:831-839.

[10] Liu X, Ouyang W, Shu Y, Tian Y, Feng Y, Zhang T, Chen W. Incorporating bioaccessibility into health risk assessment of heavy metals in particulate matter originated from different sources of atmospheric pollution. Environ. Poll. 2019;254:113113.

[11] Juneng L, Latif MT, Tangang F. Factors influencing the variations of PM_{10} aerosol dust in Klang Valley, Malaysia during the summer. Atmos. Environ 2011;45:4370-4378.

[12] Abolude DS, Davies OA, Barak Z, Opabunmi OO. Analysis of Heavy Metals in water and Sediment of Bindare Streams, Chikaji Industrial Area Sabon Gari. Int. J. Sci. Res. Environ. Sci. 2013;1(6):115-121.

[13] Azhari A, Halim NDA, Mohtar AAA, Aiyub K, Latif MT, Ketzel M. Evaluation and Prediction of PM_{10} and $PM_{2.5}$ from Road Source Emissions in Kuala Lumpur City Centre. Sustainability, 2021;13:5402.

[14] Yu R, Yuan X, Zhao Y, Hu G, Tu X. Heavy metal pollution in intertidal sediments from Quanzhou Bay, China. J. Environ. Sci. 2008;20(6):664-669.

[15] Sulaiman MB, Santuraki AH, Isa KA, Oluwasola OH. Geo-accumulation and Contamination Status of Heavy Metals in Selected MSW Dumpsites Soil in Gombe, Nigeria. Bim. J. Sci. Technol. 2018;2(2):31-41.

[16] Gupta RK, Majumdar D, Trivedi JV, Bhanarkar AD. Particulate matter and elemental emissions from a cement kiln. Fuel Proc. Techno. 2012;104:343-351.

[17] Joshua OO, Liziwe LM, Nomsa GB. Trace Metals in Soil and Plants around a Cement Factory in Pretoria, South Africa. Pol. J. Environ. Stud. 2015;24(5):2087-2093.

[18] Izhar S, Goel A, Chakraborty A, Gupta T. Annual trends in occurrence of submicron particles in ambient air and health risk posed by particle bound metals. Chemosphere, 2016;146:582-590.

[19] Alifa M, Bolster D, Mead MI, Latif MT, Crippa P. The influence of meteorology and emissions on the spatio-temporal variability of PM_{10} in Malaysia. 2020;246:105107

[20] Lee BJ, Kim B, Lee K. Air pollution exposure and cardiovascular disease. Toxicol. Res. 2014;30:71-75.

[21] Ghosh S, Rabha R, Chowdhury M, Padhy PK. Source and chemical species characterization of PM10 and human health risk assessment of semi-urban, urban and industrial areas of West Bengal, India. Chemosphere. 2018;207:626-636.

[22] EPA. Sustainable Futures / P2 Framework Manual 2012 EPA-748-B12-001 8. Non-Cancer Human Health Hazard Screening Protocol. 2012. https://www.epa.gov/sites/default/files/2015-05/documents/08.pdf

[23] Angel JM, Abel EL, DiGiovanni J. Genetic Determinants of Cancer Susceptibility. Compr. Toxico. 2018;7:330-360.

[24] Grosheva EL, Voronskaya GN, Pastukhove MV. Trace element bioavailavility in Lake Baikal. Aquat. Ecosys. Health Mange. 2000;3:229-234.

[25] Gurama HM, Sani AA, Omotainse SO, Garba ST. Assessment of some Essential Metals contents of limestone and soil samples from Ashaka cement factory, Funakaye Local Government Area, Gombe State, Nigeria. Algerian J. Mat. Chem. 2020;3(2):113-123.

[26] Matthew TK, Mayeen UK, Yusoff MA, Wan Hasiah BA, David AB, Khalid SA. Assessment of health risk due to the exposure of heavy metals in soil around mega coal-fired cement factory in Nigeria. Results in Physics. 2018;11:755-762.

[27] Odeshi TA, Ana GREE, Sridhar MKC, Olatunji AO, Abimbola AF. Outdoor air particle-bound trace metals in four selected communities in Ibadan, Nigeria. Environ. Geochem. Health. 2014;36(4):755-764.

[28] Wei Z, Wang D, Zhou H, Qi Z. Assessment of soil heavy metal pollution with principal component analysis and Geoaccumulation index. Procedia. Environ. Sci. 2011;10:1946-1952.

[29] Nguyen TH, Hoang HNT, Bien N.Q., Tuyen LH, Kim KW. Contamination of heavy metals in paddy soil in the vicinity of Nui Phao multi-metal mine, North Vietnam. Environ. Geochem. Health. 2020;42(12):4141-4158.

[30] USEPA, Supplemental Guidance for Developing Soil Screening Levels for Superfunda. Sites. OSWER 9355.424. Office of Solid Waste and Emergency Response (2001).

[31] Wcisło E, Ioven D, Kucharski R, Szdzuj J. Human health risk assessment case study: an abandoned metal smelter site in Poland. Chemosphere, 2002;47:507-515.

[32] Kurt-Karakus PB. Determination of heavy metals in indoor dust from Istanbul, Turkey: estimation of the health risk. Environ. Int. 2012;50:47-55.

[33] Liu X, Zhai Y, Zhu Y, Liu Y, Chen H, Li P, Peng C, Xu B, Li C, Zeng C. Mass concentration and health risk assessment of heavy metals in size-segregated airborne particulate matter in Changsha. Science of the Tot. Environ. 2015;517:215-221.

[34] USEPA, Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual (Part F, Supplemental Guidance for Inhalation Risk Assessment).

Office of Superfund Remediation and Technology Innovation, Washington, D.C. (2009).

[35] Lianga B, Lib X., Maa K, Lianga S. Pollution characteristics of metal pollutants in PM2.5 and comparison of risk on human health in heating and non-heating seasons in Baoding, China. Ecotox. Environ. Safety. 2019;170:166-171.

[36] Liu Y, Li S, Sun C, Qi M, Yu X, Zhao W and Li X. Pollution Level and Health Risk Assessment of $PM_{2.5}$-Bound Metals in Baoding City Before and After the Heating Period. Int. J. Environ. Res. Public Health. 2018;15(10):2286

[37] Adamiec E, Jarosz-Krzemińska E. Human Health Risk Assessment associated with contaminants in the finest fraction of sidewalk dust collected in proximity to trafficked roads. Scientific Reports. 2019;9(1):16364.

[38] Hu X, Zhang Y, Ding ZH, Wang TJ, Lian HZ, Sun YY, Wu JC. Bioaccessibility and health risk of arsenic and heavy metals (Cd, Co, Cr, Cu, Ni, Pb, Zn and Mn) in TSP and PM2.5 in Nanjing, China. Atmos. Environ. 2012;57:146-152.

[39] USEPA, Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment). Office of Superfund Remediation and Technology Innovation, Washington, D.C. (2004).

[40] USEPA, Guidance for Evaluating the Oral Bioavailability of Metals in Soils for Use in Human Health Risk Assessment. (2007).

[41] WHO, World Health Organization expert consultation: Available evidence for the future update of the WHO Global air quality guidelines (AQGs), World Health Organisation Regional Office for Europe, Copenhagen (2016).

[42] EU, Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe (2008). (https://eur-lex.europa. eu/eli/dir/2008/50/oj) accessed 29 May 2020.

[43] Ahmad W, Nisa S, Nafees M, Hussain R. Assessment of particulate matter (PM_{10}& $PM_{2.5}$) and associated health problems in different areas of cement industry, Hattar, Huripur. J Sci Techno Univ Peshawar. 2013;37(2):7-15.

[44] Sulemana R, Boohene M, Sossou KB. Assessment of Heavy Metal Concentrations in Particulate Matter (PM_{10}) in the Ambient Air of Selected Roadsides in the Accra Metropolis of Ghana, West Africa. J. App. Thought. 2018;6(1):34-54.

[45] Cheng MC, You CF, Cao J, Jin Z. Spatial and seasonal variability of water-soluble ions in $PM_{2.5}$ Aerosols in 14 major cities in China. Atmos. Environ. 2012;60:182-192.

[46] Kuo CY, Lin CY, Huang LM,Wang S, Shieh PF, Lin YR, Wang JY. Spatial variations of the aerosols in river-dust episodes in Central Taiwan. J. Hazard. Mater. 2010;179:1022-1030.

[47] EEA, Air quality in Europe-2020 report. ISSN 1977-8449 http:// www.eea.europa.eu/publications/air-quality-in-europe-2020 (2020).

[48] Slezakova K, Pereira MC, Reis MA, Alvimferraz MC. Influence of traffic emissions on the composition of atmospheric particles of different sizes – Part 1: concentrations and elemental characterization. J. Atmos. Chem. 2007;58(1):55-68.

[49] Mansour AA. Characteristics and Risk Assessment of Heavy Metals in Airborne PM_{10} from a Residential Area of Northern Jeddah City, Saudi Arabia. Pol. J. Environ. Stud. 2016;25(3):939-949.

[50] Contini D, Cesari D, Donateo A, Chirizzi D, Bellosi F. Characterization of PM_{10} and $PM_{2.5}$ and their metals content in different typologies of sites in South-Eastern Italy. Atmosphere. 2016;5(2):435-453.

[51] Sen S, Bizimis M, Tripathi SN, Paul D. Lead isotopic fingerprinting of aerosols to characterize the sources of atmospheric lead in an industrial city of India. Atmos. Environ. 2016;129:27-33.

[52] Das A, Singh G, Habib G, Kumar A. Non-carcinogenic and Carcinogenic Risk Assessment of Trace Elements of $PM_{2.5}$ During Winter and Pre-monsoon Seasons in Delhi: A Case Study. Exposure and Health, 2020;12:63-77.

[53] Sun H, Shamy H, Klutz T, Muoz AB, Zhong M, Laulicht F, Alghamdi MA, Khoder MI, Chen LC, Costa M. Gene expression profiling and pathway analysis of human bronchial epithelial cells exposed to airborne particulate matter collected from Saudi Arabia. Toxicol. Appl. Pharmacol. 2012;265(2):147-157.

[54] Das A, Kumar A, Habib G, Perumal V. Identifying knowledge gaps in incorporating toxicity of particulate matter constituents for developing regulatory limits on particulate matter. Int. J. Chem. Mol. Nucl. Mater Metall. Eng. 2016;10(7):914-918.

[55] Li WJ, Chen SR, Xu YS, Guo XC, Sun YL, Yang XY, Wang ZF, Zhao XD, Chen JM, Wang WX. Mixing state and sources of submicron regional background aerosols in the northern Qinghai-Tibet Plateau and the influence of biomass burning. Atm. Chem. Phys. 2015;15:13365-13376.

[56] Cui L, Wu Z, Han P, Taira Y, Wang H, Meng Q, Feng Z, Zhai S, Yu J, Zhu W, Kong Y, Wang H, Zhang H, Bai B, Lou Y, Ma Y. Chemical content and source apportionment of 36 heavy metal analysis and health risk assessment in aerosol of Beijing. Environ. Sci. Poll. Res. 2020;27:7005-7014.

[57] Kulshrestha A, Satsangi PG, masih J, taneja A. Metal concentration of $PM_{2.5}$ and PM_{10} particles and seasonal variations in urban and rural environment of Agra, India. Sci. Tot. Environ. 2009;407 6196-6204.

[58] Hsu CY, Chiang HC, Lin SL, Chen MJ, Lin TY, Chen YC. Elemental characterization and source apportionment of PM_{10} and $PM_{2.5}$in the western coastal area of central Taiwan. Sci. Tot. Environ. 2016;541:1139-1150.

[59] Von Schneidemesser E, Stone EA, Quraishi TA, Shafer MM, Schauer JJ. Toxic metals in the atmosphere in Lahore, Pakistan. Sci. Tot. Environ. 2010;408:1640-1648.

[60] Yu NV. Standards for the contents of heavy metals in soils of some states. Ann. Agrarian Sci. 2016;14(3):257-263.

[61] Tyopine AA, Sikakwe GU, Obalum SE, Okoye COB. Relative distribution of rare-earth metals alongside alkaline earth and alkali metals in rhizosphere of agricultural soils in humid tropical environment. Environ. Monit. Assess. 2020;192:504.

[62] Lyu Y, Zhang K, Chai F. Atmospheric size-resolved trace elements in a city affected by non-ferrous metal smelting: indications of respiratory deposition and health risk. Environ. Poll. 2017;224:559-571.

[63] Men C, Liu R, Xu F. Pollution characteristics, risk assessment, and source apportionment of heavy metals in road dust in Beijing, China. Sci. Total. Environ. 2018;612:138-147.

[64] Farshid V, Xu ZH, Rajender G. Trace elements in coal: associations with coal and minerals and their behavior during coal utilization a review. Fuel. 2010;89:904-911.

[65] Zheng N, Liu J, Wang Q, Liang Z. Heavy metals exposure of children from stairway and sidewalk dust in the smelting district, northeast of China. Atmos. Environ. 2010;44:3239-3245.

[66] Du Y, Gao B, Zhou H, Ju X, Hao H, Yin S. Health risk assessment of heavy metals in road dusts in urban parks of Beijing, China. Procedia. Environ. Sci. 2013;18:299-309.

[67] Lu X, Zhang X, Li LY, Chen H. Assessment of metals pollution and health risk in dust from nursery schools in Xi'an, China. Environ. Res. 2014;128:27-34