FUDMA Journal of Sciences (FJS)
ISSN online: 2616-1370
ISSN print: 2645 - 2944
Vol. 10 No. 13, July, 2026, pp 100 – 107
DOI: https://doi.org/10.33003/fjs-2026-1013-5596

Assessment of Heavy Metals and Polycyclic Aromatic Hydrocarbons in Nanoparticulate Banknote Dust from Selected Commercial Banks in Benin Metropolis, Nigeria

Osagie Ferdinand Amayo, *Philip Idemudia Edogun and Justina Ebehirieme Ukpebor

Department of Chemistry, Faculty of Physical Sciences, University of Benin, Benin City, Nigeria.

*Corresponding authors' email: philip.edogun@uniben.edu

Received: 17 Jul. 2026
Accepted: 25 Jul. 2026
Published: 6 Aug. 2026

ABSTRACT
The improper handling of banknotes can accumulate dust that carries pollutants, posing health risks. This study assesses the potential health risk of particulate banknote dust (BND) in two commercial banks (A and B) in Benin Metropolis, Nigeria. About 10 g of BND were collected twice from each bank's tables and equipment with a soft brush and stored in airtight bags. The samples were analyzed for heavy metals using atomic absorption spectrophotometry (AAS), and polycyclic aromatic hydrocarbons (PAHs) using gas chromatography with a flame ionization detector (GC-FID), and the particle size was measured via dynamic light scattering (DLS). The results obtained for particle size ranged from 36.57 to 48.48 nm, indicating a nano-sized nature. The results of heavy metal concentration showed that iron had the highest, at 2,055.00 ± 70.06 mg/kg for location A and 1,934.53 ± 68.64 mg/kg for location B; however, both locations were below WHO/USEPA limits of 10000 mg/kg. Cadmium was recorded as the lowest in locations A (1.82 ± 0.03 mg/kg) and B (0.95 ± 0.15 mg/kg), exceeding permissible limits of 0.8 mg/kg. All 16 EPA priority PAHs were detected in the BND, with location A showing the highest concentration at 4.278 µg/kg, dominated by pyrene, and location B having more phenanthrene. These findings suggest possible health risks for staff and customers from long-term exposure. Therefore, implementing cashless payments and use of personal protective equipment (PPE) for bank staff is recommended.

Keywords: Heavy Metals, Particulate, Banknote Dust (BND), PAHs, GC-FID, DLS

INTRODUCTION

Scientists and researchers have extensively studied and hypothesized about the transmission of toxic materials and disease related to money circulation in the 18th and 19th centuries (Ofoedu et al., 2021). There are also other reported cases of modern pollutants such as microplastics, which have been regarded as one of the emerging pollutants and a critical global environmental challenge (Sulaiman *et al.,* 2026; Igiebor *et al.,* 2025). Subsequently, the presence and isolation of toxicants and pathogenic organisms from the surface of money were confirmed by these postulations (Alemu, 2014; Ofoedu *et al*., 2021). However, due to the large surface area of money, combined with its general use, constant and daily exchange by several individuals, and diverse environment, banknotes are likely agents and carriers of pollutants. As money is exchanged in numerous transactions, it encounters diverse places and people; it accumulates dust, thereby increasing the likelihood of spreading contaminants such as bacteria, fungi, polycyclic aromatic hydrocarbons (PAHs), viruses, and even heavy metals (Urrutia-Pereira *et al*., 2021). Although the level of contamination may be typically lower than that of direct mining and industrial pollution, it nevertheless raises the background exposure level of heavy metals and other contaminants or disease-causing agents to humans. Poor banknote handling has been found to lead to contamination. (Awe *et al*., 2010; Anaam, 2019). Various studies have reported microbial and chemical contamination of banknotes as high-touch surface contaminants. (Gorny, R.L *et.al.,* 2021; Sayan Bhattachryaa, 2020). There are limited studies on banknote dust; however, only a few have investigated it from a forensic perspective to develop analytical methods for detecting illicit drugs in banknote dust (Cecchi et al., 2025).

Studies have shown that frequent contact between different people and banknotes can lead to a high concentration of microorganisms. Paper money can act as an environmental vector that facilitates the spread of potentially dangerous microorganisms (Brady and Kelly, 2000). Human occupational activities, especially those requiring the simultaneous handling of banknotes, may raise the risk of diseases.

The concerns about the occupational safety of those who handle currency (banknotes) are paramount; there is a need to raise public awareness of hygiene and health issues, the need to develop appropriate policies and regulations, and the need for scientific knowledge. An approach to human health risk assessment is therefore important to estimate the possible health hazard from exposure to metals and other potentially toxic elements in dust particles over a specific period. (Envoh and Isiuku, 2020; Envoh**,** 2020).

Therefore, this present work assessed particulate banknote dust (BND) from two selected locations in the Benin metropolis and the environmental health risk using a combination of analytical instruments such as AAS, GC-FID, and DLS for the determination of heavy metals, polycyclic aromatic hydrocarbons (PAHs), and particle sizes, respectively.

MATERIALS AND METHODS

Study Area

Two banks, A and B, were sampled for the study, with A located at Ugbowo Campus of the University of Benin (Lat: 6.390^0 N, Long: 5.61859^0 E) in Ovia North-East Local Government Area, and B located at Ekewan Road (Lat: 6.333776^0 N, Long: 5.6059781^0 E) in Oredo Local Government Area, all in Benin City, Edo State, Nigeria.

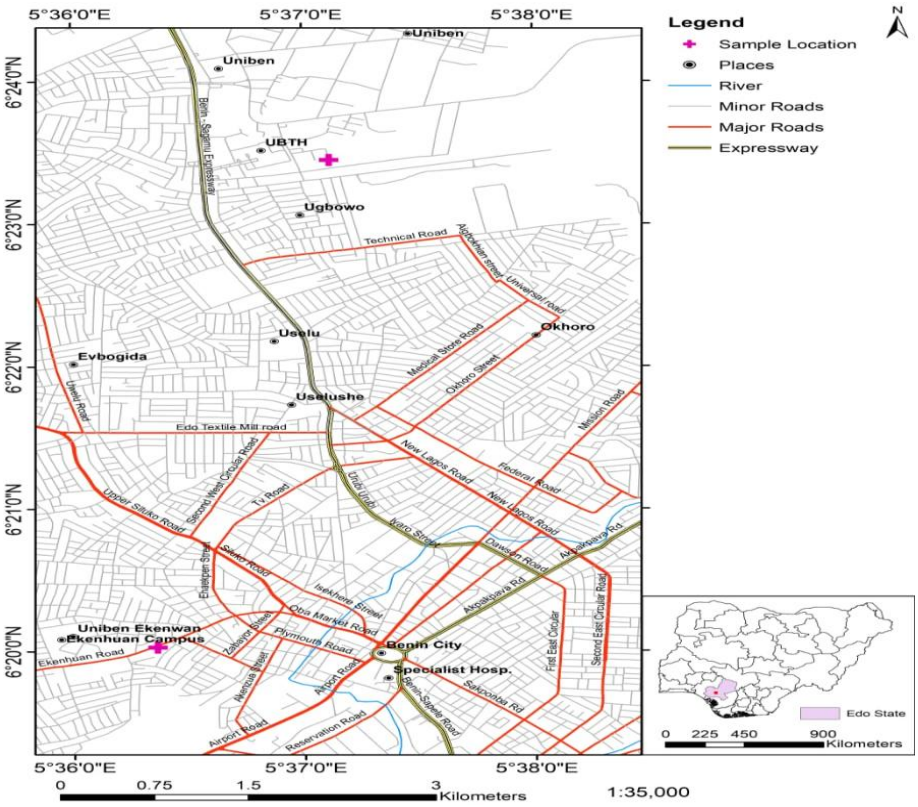

Figure 1: Map Showing the Study Area

Sample Collection

A non-probability convenience sampling technique was employed by brushing banknote dust from counting machines as described by Cecchi and Santoni (2022). Dust particles from banknotes were collected from the two selected commercial banks within the Benin Metropolis. The dust particles were collected twice from the counting machines and tables in the bulk counting room using soft brushes.

About 10 g of the dust particles were sampled twice from the bulk counting room of each bank. The bulk counting room is usually poorly ventilated. The dust samples were labeled A and B, representing the two locations, respectively. The samples were stored properly in airtight zip-lock bags and taken to the laboratory for onward analysis.

Sample Analysis

Particle Size Analysis

The particle size analysis using the dynamic light scattering (DLS) technique is based on Brownian movements.

Heavy Metals Analysis

The dust samples were digested prior to chemical analysis for selected heavy metals (Fe, Cu, Zn, Pb, Cd, Ni, Mn, and Cr) following the procedure as described by Paiko *et al.* (2015) with slight modifications. 1 g of the dust sample was weighed into a 250 mL boiling tube, which had been washed and rinsed with dilute nitric acid. 10 mL of concentrated nitric acid (HNO_3) was measured into the tube containing the sample and heated slowly over a hot plate for 1 hour. The solid residue obtained was then digested with a 10 mL mixture of HNO_3 and $HClO_4$ in the ratio of 3:1. The mixture was left to stand for 10 mins at room temperature before heating on a hot plate for about 2 hrs at 150° C until a white dense fume was observed and a clear solution was obtained. The mixture was left to cool at room temperature, about 20 mL of distilled water was added, and filtered through a Whatman No. 1 filter paper into a 100 mL standard volumetric flask. The solution was then made up to the mark with distilled water. The filtrate was stored in pre-cleaned polyethylene sample bottles ready for analysis.

Heavy metal concentration was determined using an Atomic Absorption Spectrophotometer (Buck Scientific, model 210VGP, made in the United States of America). The settings and operational conditions of the instrument were in accordance with the manufacturer's specifications and the standard method of analysis.

To ensure accuracy and validation, the instrument was calibrated following standard verification, and blank samples were also analyzed. Standards were also routinely analyzed so as to ensure accuracy of results. The blanks helped to ensure that signals produced were truly from the analyte. Replicate samples were also run and mean values calculated so as to minimize errors.

PAH Analysis

Solvent extraction was employed for the PAHs. 10 g of the sample was weighed and transferred into a conical flask; 50 mL of dichloromethane and n-hexane (50:50) were added, and the mixture was placed in the sonic bath for 45 mins. The solvent was then transferred into a round-bottom flask, and the solvent was reduced to about 1 mL. Samples were cleaned up using a silica gel column with a Na_2SO_4 layer to remove any moisture present. The samples were eluted using 15 mL of n-hexane and collected in 20 mL amber vials. The eluent was further reduced to about 1 mL using a blow-down apparatus with compressed air for injection into the GC-FID for PAHs analysis. The Separation of the analytes was done on an HP-5, 30 m x 0.25 m column and analyzed using a GC-FID (Hewlett-Packard, model: 5890 series II, manufactured in the United States of America) in a splitless mode. Nitrogen gas (10.2 psi) was used as a carrier gas at 1.5 ml/min. The injector and detector temperatures were 250^{0}C and 320^{0}C

respectively. Separation was done using the following oven temperature program: start temperature at 80 °C, held for 1 min, then ramped at a rate of 20 ^{0}C/min to 280 ^{0}C, and further ramped at a rate of 2.5^{0}C/min to 300 ^{0}C and held for 10 mins. Peak detection and integration were carried out using *ChemStation* software. Identification and quantification were carried out using an external calibration standard. The amount of each PAHs in the analytes was calculated using the equation below:

Concentration of analyte (*ug/kg*) = $\frac{Ax.\ Vt\ D}{Wd.CF}$

Where:

A_x = Area of the analyte in area count

V_t = Total volume of extract in µl

D = Dilution factor

W_d = dry weight of sample extracted in grams(g)

µCF = Average calibration factor for target PAH analyte

RESULTS AND DISCUSSION

Results of Heavy Metals in Banknote Dust

The mean concentrations of eight heavy metals determined in banknote dust from two commercial banks in Benin Metropolis are presented in Table 1. Iron (Fe) recorded the highest mean concentration in both locations, ranging from 1934.53 ± 68.64 mg/kg in sample B to 2055.00 ± 70.06 mg/kg in sample A. Cadmium had the lowest concentration, ranging from 0.95 ± 0.15 mg/kg to 1.82 ± 0.03 mg/kg for samples B and A, respectively. Lead and nickel ranged from 11.03 ± 1.12 mg/kg to 13.79 ± 0.22 mg/kg and 30.64 ± 0.63 mg/kg to 43.93 ± 5.63 mg/kg, respectively. Chromium and copper ranged from 43.87 ± 5.43 mg/kg to 63.32 ± 10.75 mg/kg and 50.56 ± 4.42 mg/kg to 56.06 ± 2.53 mg/kg respectively, while Mn and Zn ranged from 134.21 ± 22.82 mg/kg to 141.65 ± 38.52 mg/kg and 205.28 ± 5.05 mg/kg to 255.03 ± 5.05 mg/kg respectively. Figure 1 shows the concentration trend for sample A was Fe > Zn > Mn > Cr > Cu > Ni > Pb > Cd, while for sample B it was Fe > Zn > Mn > Cu > Cr > Ni > Pb > Cd. Sample A consistently showed higher concentrations for most metals except Mn. The elevated concentrations in sample A may be attributed to its location in a denser commercial area with higher cash circulation and traffic volume. Contrary to the notion that heavy metals may not be present in banknote dust, the results indicate otherwise and provide insight into the variability of metals in banknotes from the two locations.

Table 1: Heavy Metals Concentration in Locations A and B

Sample	A	B	WHO Standard
Fe(mg/kg)	2055.00 ± 70.06	1934.53 ± 68 .64	10,000.00
Cu(mg/kg)	56.06 ± 2.53	50.56 ± 4.42	36.00
Zn(mg/kg)	255.03 ± 5.05	205.28 ± 5.05	-
Pb(mg/kg)	13.79 ± 0.22	11.03 ± 1.12	100.00
Cd(mg/kg)	1.82 ± 0.03	0.95 ± 0.15	08.00
Ni(mg/kg)	43.93 ± 5.63	30.64 ± 0.63	-
Mn(mg/kg)	134.21 ± 22.82	141.65 ± 38.52	-
Cr(mg/kg)	63.32 ± 10.75	43.87 ± 5.43	-

There are no fixed regulatory permissible limits for heavy metals in dust, as standards vary among USEPA, WHO, and EU for indoor dust and soil. Iron (Fe) is an essential metal for biochemical processes, but toxicity can arise at elevated concentrations or in combination with other compounds (Abdullahi *et al.,* 2022). The Fe concentrations in this study were below the permissible limit of 10,000 mg/kg according to WHO (2019). However, they were significantly lower than 16,945.5 mg/kg for the classroom, which aligns with the studies by Moghtaderi *et al*. (2020). Lead (Pb) concentrations of 13.79 ± 0.22 mg/kg and 11.03 ± 1.12 mg/kg for locations A and B were below the acceptable limit of 100 mg/kg. Wani *et al.* (2015) reported that Pb toxicity affects both adults and children, with children being more vulnerable due to developing tissues. Copper exceeded the WHO limit of 36.00 mg/kg in both locations, while Cd also exceeded the 0.80 mg/kg guideline. Nickel (Ni) concentrations, though below the 25,000 mg/kg soil guideline, are of concern due to documented links with kidney disease, nasal cancer, pulmonary disorders, and increased mortality (Laden *et al* 2000). The studies demonstrated by Genchi *et al.* (2020) that daily exposure to Ni may also pose serious health threats due to its carcinogenic properties. The dominance of Fe and Zn likely reflects sources such as office metallic equipment, ink pigments, anthropogenic activities. Although some metals are within regulatory limits, the detection of toxic metals such as Cd, Cu, Pb, and Ni in nano-sized banknote dust suggests potential exposure through inhalation and dermal contact during cash handling. The possibility of bioaccumulation underscores the need for routine monitoring, provision of adequate PPE for bank staff, and adoption of safer, less cash-dependent payment systems to safeguard workplace health.

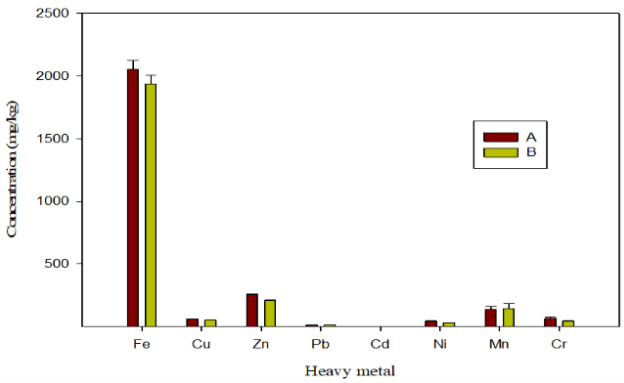

Figure 2: The Concentration of Heavy Metals in Banknote Dust in A and B

Results of PAHs in Banknote Dust

The results from PAHs analysis in Table 2 clearly show that banknote dust contains the 16 priority PAHs. The table below presents the PAHs concentrations measured in the banknote dust from two sampling locations.

Table 2: Concentration of PAH in Banknote Dust

PAH	Concentration (µg/kg)	
	A	B
Naphthalene	<0.01	<0.01
Acenaphthylene	0.028	0.031
Acenaphthene	0.136	0.559
Fluorene	0.038	0.043
Phenanthrene	<0.01	1.167
Anthracene	0.068	0.060
Fluoranthene	0.271	0.237
Pyrene	3.084	0.056
Chrysene	0.166	0.033
Benzo(a)anthracene	0.148	0.110
Benzo(b)fluoranthene	0.072	0.040
Benzo(k)fluoranthene	0.136	0.078
Benzo(a)pyrene	0.025	0.132
Indeno(1,2,3-cd) pyrene	<0.01	<0.01
Dibenzo(a,h)anthracene	0.107	0.086
Benzo(g,h,i)perylene	<0.01	<0.01
∑PAHs	**4.278**	**2.631**

The total of the PAHs as measured showed that sample A has the highest value of approximately 4.278 µg/kg while that of B has a value of approximately 2.631 µg/kg. This could be as a result of the road axis around B, with more population density than the A axis and more commercial activities are being experienced along that axis due to the presence of many markets and other business activities. The concentration of naphthalene was observed to be lower than 0.01 µg/kg for both locations. However, the concentration of acenaphthylene was observed to be higher in Location B with a value of 0.013 µg/kg as compared to that of Location A, whose value was observed to be 0.028 µg/kg. The concentration of fluorene ranges between 0.038 µg/kg and 0.043 µg/kg, respectively, while the concentration of phenanthrene was below 0.01µg/kg in sample A, as compared to sample B with a concentration of 1.167 µg/kg.

Naphthalene, indeno(1,2,3-cd) pyrene and benzo(g,h,i) perylene were below the analytical detection limit (<0.01 µg kg^{-1}) in both sampling locations, indicating minimal contamination from these compounds. However, acenaphthylene, acenaphthene, fluorene, anthracene, fluoranthene, chrysene, benzo(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene and dibenzo(a,h)anthracene were detected in varying concentrations, demonstrating that banknote dust is contaminated with PAHs originating from multiple emission sources. The presence of these compounds is expected because banknotes are continuously exposed to atmospheric particulates, human handling, contaminated surfaces and dusty environments during circulation.

There are a number of PAHs that have been classified as probable or confirmed human carcinogens. Notably, benzo(a)pyrene, a Group 1 carcinogen according to the IARC (2012), was identified at both locations, with a higher concentration in Location B (0.132 µg kg^{-1}) compared to Location A (0.025 µg kg^{-1}). Although its concentration is lower than that of pyrene, benzo(a)pyrene holds significant toxicological importance as it serves as an indicator of carcinogenic PAH contamination (Boström *et.al.,* 2002). Additionally, chrysene, benzo(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, and dibenzo (a,h) anthracene—also detected in the samples—are recognized as carcinogenic PAHs. This indicates that continued occupational exposure to contaminated banknote dust may pose health risks, particularly for bank employees such as cashiers and those working in bulk cash-counting facilities. Grouping the detected PAHs according to molecular weight further provides insight into their probable sources and toxicological implications. The total LMW PAHs (naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene and anthracene) were reported as 0.269 µg kg^{-1} and 1.860 µg kg^{-1} for Locations A and B, respectively, whereas the HMW PAHs collectively contributed 4.010 µg kg^{-1} in Location A and 0.694 µg kg^{-1} in Location B. The predominance of HMW PAHs in Location A suggests that combustion-related sources are the major contributors to PAH contamination in this location, whereas the relatively higher proportion of LMW PAHs in Location B may indicate additional petrogenic inputs or volatilisation-condensation processes. This observation agrees with previous reports that HMW PAHs are generally associated with high-temperature combustion processes, while LMW PAHs are commonly linked with petroleum-related sources (Adami et al., 2000).

The toxicological significance of these findings should not be overlooked. Although LMW PAHs generally exhibit lower carcinogenicity, they can still cause acute toxicity. Conversely, HMW PAHs possess strong carcinogenic, mutagenic and teratogenic properties (Adami et al., 2000). Goldman et al. (2001) further reported that PAHs exhibit toxic, genotoxic and mutagenic properties, while Burchiel (2001) demonstrated their potent immunosuppressive effects. Furthermore, Villeneuve et al. (2002) observed that some HMW PAHs can induce dioxin-like biological activity and interfere with oestrogenic responses. Consequently, the dominance of HMW PAHs, particularly pyrene and other carcinogenic congeners detected in this study, raises concerns regarding chronic occupational exposure among bank workers.

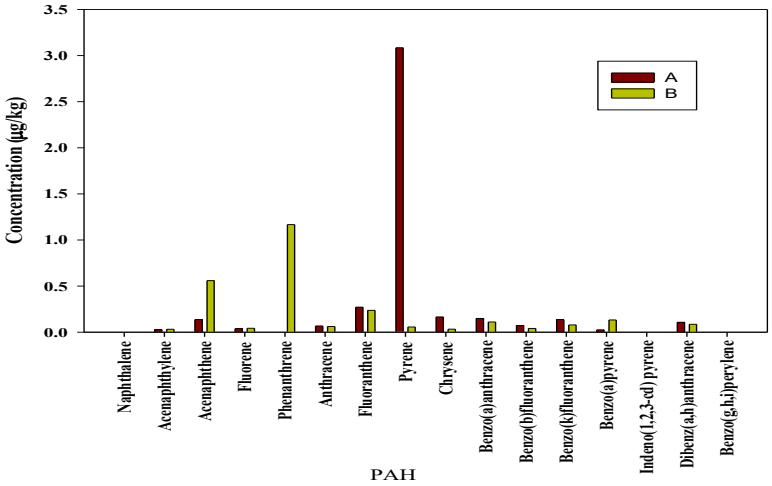

Figure 3: Concentration of the 16 Priority PAHs Obtained in the Different Sampling Locations

Table 3 presents the diagnostic ratios of banknote dust, clearly indicating multiple sources of PAHs detected in samples A and B. These sources encompass both traffic and non-traffic emissions, including the combustion of wood and coal, as well as vehicular emissions and diesel engine exhaust. This diversity in sources likely arises from the fact that banknotes, collected through various business transactions and handling processes, are often accumulated from a wide range of environments before being deposited in banks for safekeeping.

Table 3: Range of Diagnostic Ratios for PAH Sources in Banknote Dust (BND)

PAHs diagnostic ratio	Sample A	Sample B	Sample A (Value ranges)	Sample B (value ranges)	Sample A: Possible sources	Sample B: possible sources	Value ranges from Literature. Marek *et al., 2012*
FL/FL+PYR	1.056	4.084	>0.5	>0.5	Diesel	Diesel	<0.5 petro emission >0.5 diesel emission
ANT/ANT+PHE	2.167	0.000	>0.1	<0.1	Pyrogenic	Petrogenic	<0.1 petrogenic >0.1 pyrogenic
FLA/FLA+PYR	4.084	1.056	>0.5	>0.5	Grass, wood, coal combustion	Grass, wood, coal combustion	<0.4 petrogenic 0.4 – 0.5 fossil fuel >0.5 grass, wood, Coal combustion
BaA/BaA+CHR	1.166	1.033	>0.35	>0.35	Vehicular emission	Vehicular emission	0.2 -0.35 coal combustion >0.35 vehicular emission <0.2petrogenic
BbF/BkF	0.000	0.510	<0.5	>0.5	Grass, wood and coal		>0.5 grass, wood and coal combustion 2.5 – 2.9 (aluminum Smelter emission)
BaP/Bghi	0.000	0.000	<0.6	<0.6	Non-traffic emission	Non-traffic emission	>0.6 (non-traffic) >0.6 (traffic emission)
IcdP/IcdP+BghiP	0.000	0.000	<0.2	<0.2	Petrogenic	Petrogenic	0.5 (photolysis) 0.2 (petrogenic) 0.2 – 0.5 (grass)
∑LMW/∑HMW	0.000	0.000	>0.1	>0.1	Petrogenic	Petrogenic	>0.1 (pyrogenic) >0.1 (petrogenic)

However, the diagnostic ratio of BaA/BaA+CHR with a value of >0.35 was found to be higher than the other diagnostic ratios, as shown in the table above. This strongly suggests that the source of PAHs is more likely to be vehicular emissions. However, some studies show that diagnostic ratios do not change with particle size. The studies of Wang et al. (2006) show that diagnostic ratios are virtually the same in samples of $PM_{2.5}$-PM_{10} and $PM_{2.5}$. Diagnostic ratios applied to fine (2 nm) particulates collected in Beijing were similar with respect to ANT/ (ANT + PHE) and IcdP/(IcdP + BghiP). The values of FLA/(FLA + PYR) were 0.05-0.1 higher, those of BeP/(BeP + BaP) were also slightly higher, but those of BaA/(BaA CHR) were 0.1-0.15 lower for coarse particles. These diagnostic ratios confirmed that the dominant sources of PAHs were the combustion of coal/wood and diesel in the summer (Zhou *et al*., 2005). These studies align with the present study on PAHs bound to particulate matter of banknote dust, reported as 36.57 - 48.4 nm, respectively, which were observed to fall within the nano range.

Particle Size Analysis

Figures 4 and 5 show the dynamic light scattering (DLS) measurements of banknote dust (BDN) particles from two commercial banks in Benin City, which produced a Z-average hydrodynamic diameter of 36.57 and 48.43 nm, and a polydispersity index (PDI) of 0.230 and 0.245, respectively.

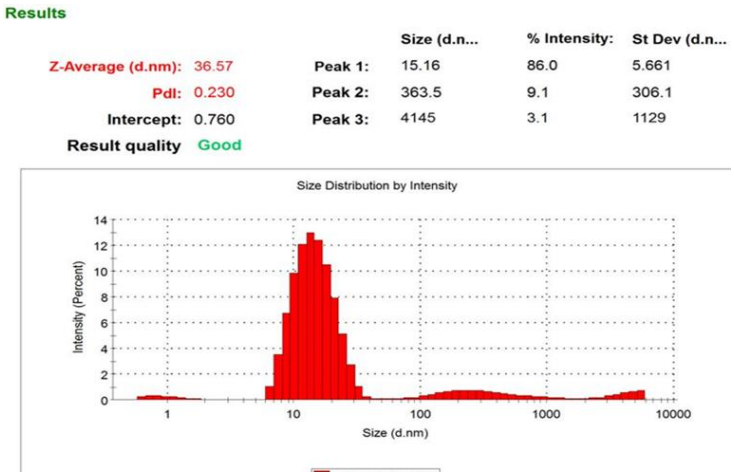

Figure 4: The PDI and Z-Average of Sample A

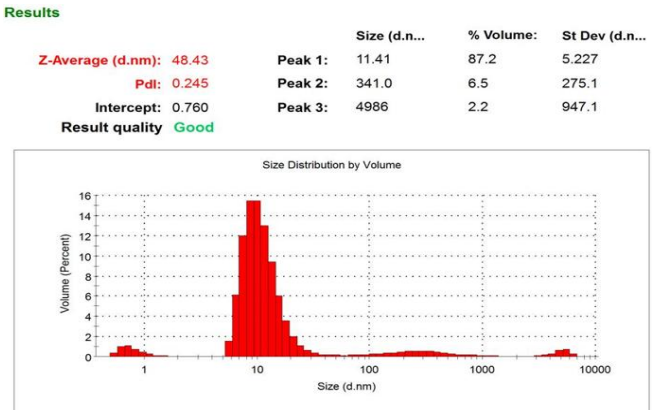

Figure 5: The PDI and Z-Average of Sample B

The Z-average (also called the cumulants mean) is the primary, most stable DLS parameter and represents an intensity-weighted hydrodynamic diameter derived from the cumulant analysis of the intensity autocorrelation function. The PDI is a unitless measure of the width (variance) of the size distribution derived from the second cumulant of the autocorrelation fit. By convention in DLS reporting, PDI values ≤ 0.10 indicate a highly monodisperse suspension, values around 0.10 – 0.20 indicate narrow (near monodisperse) distributions, while values above ~0.20 indicate increasing polydispersity; values above ~0.7 are considered very broad and unreliable for cumulant analysis. A PDI of 0.230 and 0.245 for samples A and B, therefore, indicates a moderately polydisperse sample; the distribution is not narrow and contains a measurable spread of particle sizes or minor populations/aggregates.

Size Regime

Z-average of ~36 nm and ~48 nm for samples A and B places the measured dust fraction in the ultrafine/nanoparticle size range (<100 nm). Ambient urban aerosol studies show substantial number concentrations in the ultrafine mode (tens of nanometers). Thus, the measured Z-average is consistent with a substantial contribution from multiple-related ultrafine particles or fragments/resuspended fine particles in the banknote.

Polydispersity and Sample Complexity

The PDI, as observed in the samples, indicates that the dust particles are moderately polydisperse. For environmental dust, this is expected because atmospheric particulates are typically a mixture of primary particles (combustion-generated ultrafine), accumulation mode particles (coagulated or aged particles), mineral dust fragments and occasional aggregates. The PDI thus reflects a real heterogeneity in the particle population or the presence of a small fraction of larger scatterers (aggregates) that broaden the distribution.

CONCLUSION

This study assessed the potential health risk associated with banknote dust (BND) from selected commercial banks in Benin Metropolis, Nigeria. The results revealed that the dust particles were within the nano range, 36.57 nm to 48.48 nm, which increases the potential for inhalation and dermal absorption. Eight heavy metals were detected, with Fe having the highest concentration and Cd the lowest in both locations. Although Fe and Pb concentrations were below WHO/USEPA permissible limits, Cu and Cd exceeded the WHO limits of 36.0 mg/kg and 0.8 mg/kg, respectively, indicating a health concern. All 16 EPA priority PAHs were also detected, with total PAHs higher in location A. Considering the health risk associated with banknote dust, authorities should enforce exposure limits, banks must supply PPE to staff, and a shift to cashless payments should be encouraged to reduce exposure. More extensive studies in Nigerian banks are recommended to establish baseline contamination levels.

ACKNOWLEDGEMENT

The authors are grateful to the staff of the Department of Chemistry, Faculty of Physical Sciences, University of Benin,

Benin City, Edo State, Nigeria, for providing some of the equipment used in the research.

REFERENCES

Abdullahi, M., Auwal, Y., and Usman, A.H. (2022). Determination of heavy metals (Co, Cu, Cd, Fe, Pb, Zn) in some edible insects and fingerlings in Dutsin-ma town, Fudma Journal of Sciences, 6(04),6–11. https://doi.org/10.33003/fjs-2022-0604-1035

Adami, G., Barbieri, P., Piselli, S., Predonzani, S. and Reisenhofer, E., (2000). Detecting and characterizing source of persistent organic pollutants (PAHs and PCBs) in surface sediment of an industrialized area (Harbour of Trieste, Northan Ariatic sea). *Journal of environmental monitoring* 2:261-265 http://doi:101039/b0009950.

Alemu, A. (2014). Microbial contamination of currency notes and coins in circulation: A potential public health hazard, Biomedicine and Biotechnology, vol. 2(03): 46-53. https://doi.org/10.12691/bb-2-3-2

Anaam, J.A. (2019). A literature review on microbial contamination of paper currency, International Journal of Environmental Chemistry, 5(01): 18–22p. https://www.researchgate.net/publication/334120379

ATSDR, (2008). Chromium Toxicity, Atlanta, Georgia. https://www.atsdr.cdc.gov/csem/ (Accessed 13 August 2025).

Awe, S., Eniola, K.I.T., Ojo, F. T., and Sani, A. (2010). Bacteriological quality of some Nigerian currencies in circulation. African Journal of Microbiological Research 4(21):2231–2234

Boström, C.-E., Gerde, P., Hanberg, A., Jernström, B., Johansson, C., Kyrklund, T., Rannug, A., Törnqvist, M., Victorin, K., & Westerholm, R. (2002). Cancer risk assessment, indicators, and guidelines for polycyclic aromatic hydrocarbons in the ambient air. Environmental Health Perspectives, 110(Suppl 3), 451–488.

Brady, D. H. and Kelly, M.O. (2000). Pathogens associated with currencies, retrospective study of private diagnostic laboratories. University press. 2000.

Burchiel, S.W. and Luster, M.L. (2001). Signaling by Environmental PAHs in Human Lymphocytes. *Journal of Clinical Immunology, 98:2* http;//doi101006/jclim2000.

California Environmental Protection Agency (Cal-EPA) (1994). Memorandum, to Cal/EPA Departments, Boards, and Offices from Standards and Criteria work Group, Office of Environmental Health Hazard Assessment. Subject: *California Cancer Potency Factors:* 134.

Cecchi, T., Giuliani, A. and Catini, C. (2025) 'Green analysis of illicit drugs on banknote dust', *Green Analytical Chemistry*, 12, p. 100218. https://doi.org/10.1016/j.greeac.2025.100218.

Cecchi, T., & Santoni, E. (2022). First liquid chromatography–high resolution mass spectrometry method for the determination of cocaine on banknote dust. *Forensic Toxicology*. 40 (2), 357–365 https://doi.org/10.1007/s11419-022-00627-9

Envoh, C.E. (2020). Bioavailability, average daily does and risk of heavy metals in soils from Children playground within Owerri, Imo State, Nigeria. *Chemistry Africa,* 3:427-438.

Envoh, C.E. and Isiuku, B.O. (2020). Determination and human health risk assessment of heavy metals in food basin soil in Owerri Southeastern Nigeria. Chemistry Africa, 3:1059, 1071 29.*Verla Environmental, AW.*

Genchi, G., Carocci, A., Lauria, G., Sinicropi, M. S., and Catalano, A. (2020). Nickel: Human Health and Environmental Toxicology. *International Journal of Environmental Research and Public Health,* 17(3), 679.

Goldman, R., Enewold, L., Pellizari, E., Beach, J.B., Bowman, E.D., Krishman, S.S., Shield. P. G. (2021). Smoking increases carcinogenic PAHs in Human Lung tissue. Cancer research 61, 6367-6371

Gorny, R.L., Golofit-Szymcak, M., Wojcik-Fatta, A., Cyprowski, M., Stobnicka-Kuplec, A., Lawniczek-Waezyk, A. (2021). Microbial Contamination of money sorting facilities. *Annals of Agricultural and Environmental Medicine,* 28(1):61-71. https://doi.org/10.26444/aaem/132321

IARC (2012) "International Agency for Research on Cancer: Chemical Agents and Related Occupations- A Review of Human Carcinigens." *Monograph on the Evaluation of Carcinogenic Risks to Humans* 100(5),233-240

Igiebor, F. A., Amengialue, O. O., Ugwoke, G., Edogun, P. I., Ogboye, P. O., Obueh, H. O., Egharevba, P. A., Aishuehien, I. I., Ochoyama H., & Uwuigiaren N. J. (2025). Role of microplastics in the global plastics pollution crisis with respect to one health in post covid-19 era. *Emerging Contaminants and One Health Approach*. 1, CRC press, 103-134 https://doi.org/10.1201/9781032623801-6

Laden, F., Joel, S., Frank, E., Douglas, W. (2000). Reduction in fine particulate pollution and mortality. *American journal of respiratory and critical care medicine.* 19; 173(6):667-672.

Letelier, P., Saldias, R., Loren, P., Riquelme, I., and Guzman, N. (2023). MicroRNAs as Potential Biomarkers of Environmental Exposure to Polycyclic Aromatic Hydrocarbons and Their Link with Inflamatiom and Lung Cancer, *international Journal of Molecular Sciences,* 24. https://doi.org/10.3390/ijms242316984.

Moghtaderi, M.M., Ashraf, M.M., Moghtaderi, T.T., Teshnizi, S.H., and Nabavizadeh, S.H. (2020). Heavy metal concentration in classroom dust samples and its relationship with childhood asthma: a study from Islamic Republic of Iran, Eastern Mediterranean Health Journal/Eastern Mediterranean Health Journal, 26(05),594–601. https://doi.org/10.26719/emhj.19.072.

Ofoedu, C.E., Jude, O.I., Ijeoma, M A., Perpetual, Z.O., Charles Odilichukwu, R.O., and Małgorzata, K. (2021). Bacterial contamination of Nigerian currency notes: A comparative analysis of different denominations recovered from local food vendors, PeerJ, 9, p. e10795. https://doi.org/10.7717/peerj.10795

Paiko, Y.B., Nkeruwem, O.N., Tsado, M.T., Dagaci., M.Z. (2015). Proximate, mineral and anti-nutritional composition

of the outer peel and seed coat of *chrysophyllum albidum* (African star apple) obtained from Minna, Niger state, Nigeria. *Jewel Journal of scientific research.*3(1*): 1-6*

Sayaan Bhattacharyya. (2020). Microbial Flora in Currency note: an area of concern. *IP Internal Journal of Medical Microbiology and Topical Diseases,* 6(2):90-91.

Sulaiman, M., Usman, U. L., Mudassir, B., & Salisu, A. A. (2026). Assessment of Microplastic Pollution, Seasonal Dynamic and Polymer Composition in Water, Sediment, and Fish from Mairuwa Reservoir, Funtua, Katsina Northwestern Nigeria. FUDMA JOURNAL OF SCIENCES, 10(12), 109-119. https://doi.org/10.33003/fjs-2026-1012-5639

Urrutia-Pereira, M., Rizzo, L.V., Staffeld, P.L., Chong-Neto, H.J., Viegi, G., and Sole, D. (2021). Dust from the Sahara to the American Continent: Health impacts, Allergol. Immunopath., 49, 187–194

Villeneuve, D.L., Khim, J.S., Kannan, K., Giesy J.P.(2002). Relative potencies of individual polycyclic aromatic hydrocarbons to induce dioxin-like and estrogenic responses in three cell lines. *Environmental Toxicology.* 2002;17(2):128–137. doi: https://doi.org/10.1002/tox.10041

Wani, A.L., Ara, A., Usmani, J.A. (2015). Lead toxicity*:* a review. *Interdisciplinary Toxicology.* 2015;8(2):55–64.

Wang, G., Liu, H., Gong, Y., Wei, Y., Miso, A., Yang, L. and Zhang, H. (2017). Risk assessment of metals in Urban Soils from a typical Industrial City, Suzhou, Eastern China. *International Journal of Environmental Research and Public Health.* 14(1025):1-7

World Health Organization (WHO) (2019). Exposure to Cadmium: A major health concern. Chemical Safety and Health Unit (CHE), https://www.who.int/publications/i/item/WHO-CED-PHE-EPE-19-4-3 (Accessed 24 July 2025).

Zhuo, S., Shen, G., Zhu, Y., Du, W., Pan, X., Li, T., Hau, Y., Lin, J., Cheng, H., Xing, B., Tao, S. (2017). Source-orientation risk assessment of inhalation exposure to ambient polycyclic aromatic hydrocarbons and contributions to non-priority isomers in urban Najig, a megacity located in Yangtze River, China. *Environmental pollution* 224(10): 796-809.