Determination of Trace Metal Composition in Ambient Air from Open Burning of Solid Waste in Aiyekale, Nigeria

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ABSTRACT

Open burning of solid municipal waste uncontrolledly presents an environmental menace, which exacerbate air pollution and poses considerable health risks in most developing countries. This study aims at investigating the seasonal deposition fluxes, trace metal concentrations and determination of scavenging ratios of the identified metals, resulting from such practice in Aiyekale, Kwara State, Nigeria. The particulate matter of both dry and wet samples was collected using deposition gauges. The elemental composition of particulates collected was analyzed using Energy-Dispersive X-ray Fluorescence Spectroscopy (EDX-RF). The deposition velocity and scavenging ratio were used to study the removal mechanics of trace metal composition of the ambient air in open burning of solid waste area. The average flux rate in the wet and dry seasons was evaluated to be 3.57×10^{-6} g/m^2.s, and 2.28×10^{-5} g/m^2.s, respectively. For the study area, the deposition velocities for the trace metals ranged from 5.288×10^{-5} to 4.818×10^{-3} m/s while the estimated scavenging ratio was between 0.61 – 3.96 in the study area. It was obtained from the result that Au, Mn, and Zn were better removed by gravitational particle settling while Fe, Ti, and Rh were scavenged by precipitation. The results show extremely high levels of trace metals above prescribed thresholds, highlighting the need for international cooperation in resolving air quality concerns and developing regulations targeted at lowering emissions from the burning of solid waste in the study environment.

Keywords: Aiyekale dumpsite, solid waste, open burning, Trace metals, particulate matter, deposition fluxes

1. INTRODUCTION

Globally, air pollution is one of the sources contributing to the deterioration of the environment. In many developing countries, the disposal of household or municipal solid waste frequently involves the uncontrolled open burning of waste (Wang *et al.,* 2017). Despite the importance of inhaling clean air and consuming healthy food, the human population is constrained to breathe contaminated air. The quality of air is determined by the degree of pollution it contains. Clean air, free from impurities, is considered good air quality. This can be assessed by measuring the concentration of pollutants present in the air (Zhang, 2005). Approximately one billion tonnes of waste are burned annually in uncontrolled fires, accounting for almost half of the municipal solid waste generated around the world (Lestari et al., 2020). The burning of such a large amount of solid waste can have severe significance for human health and the environment. It releases a harmful mixture of emissions into the atmosphere and onto land, posing risks to populations, workers, and the environment (Velis et al., 2021). The increasing human population, the constant generation, and the open burning of solid waste daily have a negative impact on the environment (Aderoju and Dias, 2020; Ramadan *et al.,* 2022), which is a common practice in Nigeria (Okafor *et al.,* 2022).This is usually carried out without any form of regulation to address its harmful effects such as green house gas (GHG) emissions (Adekola et al., 2021). Other associated gaseous air pollutants include

SOx, NOx, hydrogen floride, VOCs and particulate matter. These pollutants are carcinogenic and have been linked to variety of other diseases (Alexander,2016).

Researchers like Cheng *et al.,* (2021), Abdulaziz *et al.,* (2022), Ramadan *et al.,* (2022) and Charkiewicz *et al.,* (2023) have shown great interest in atmospheric deposition due to the effects of airborne particles settling in the environment and the subsequent health impacts. Atmospheric pollutants, including particulate matter containing heavy metals such as chromium, tin, and silver, are transported into the environment through atmospheric deposition (Jiang *et al.,* 2024). Atmospheric deposition refers to the process by which pollutants, in the form of particulates and gases, settle from the atmosphere like dust or precipitation. This allows pollutants to be deposited in distant locations far from their source. It is important to note that the elemental composition of particulate matter resulting from the open burning of solid waste can vary depending on the waste composition, combustion conditions, and other factors. Therefore, conducting comprehensive sampling and analysis is crucial to obtain accurate and representative results.

In most developed countries, wastes are considered as resources. However, with the government of developing countries like Nigeria, improper waste management is a challenge (Oladejo et al., 2018), with heaps of wastes deposited along road sides leading into a huge project with regards to collection and disposal, thereby constituting environmental risk, making solid waste unhealthy (Adeniran et al., 2017). There is an imminent need for building an effective waste management system in Nigeria, a critical fact towards sustainable metropolitan growth, which comprises the collection and disposal of wastes, to safeguard public health and environment (Okafor *et al.,* 2022; Popoola et al., 2023). Adeniran et al., (2023) reported that in Ilorin metropolis, particulates released into the environment from anthropogenic activites such as the open burning of solid wastes exceeded from 2500-17400 % and 312.5-4200 % respectively for $PM_{2.5}$ and PM_{10} WHO limits. Consequently, it is essential to investigate the effects of pollutants on the ambient air quality of the dump site. Smoke emanating from the burning of these MSW contributes to negative effects on this locality including human beings, animals, and the atmosphere. Thus, this study focuses on investigating the seasonal deposition fluxes, trace metal concentrations and determination of scavenging ratios of the identified metals, resulting from such practice in Aiyekale, Kwara State, Nigeria.

2. METHODOLOGY

2.1 Study Area

The study area is a 600-plot (390,000 sqm), government approved disposal site with 130 burning points, located at Aiyekale, Kwara State, Nigeria (Figure 1), (8° 30’N 4° 35’E). it is about 500 kilometres from Abuja, the Federal Capital of Nigeria and strategically located at the geographical and cultural confluence of the Northern and Southern part of Nigeria. The demographic growth of the city over the years is responsible for the continuous rise in MSW generation rate as well as its consequential effects.

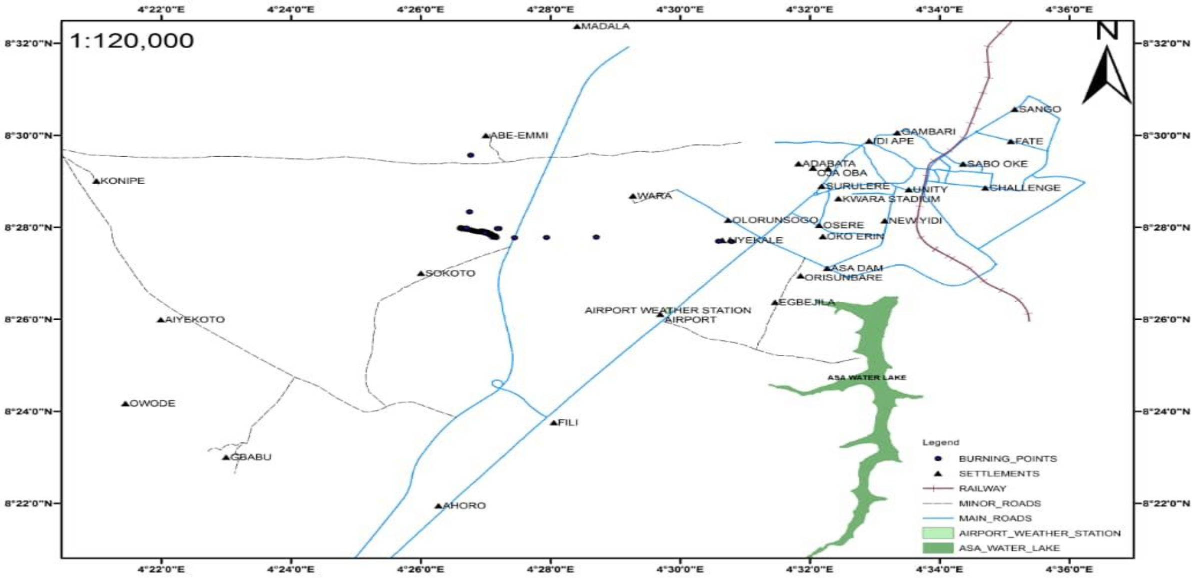

Fig. 1: Sokoto-Aiyekale dump site in Kwara State, Nigeria

2.2 Deposition Flux Measurements

Deposition flux measurements were conducted during wet and dry seasons using deposition gauges measuring 0.2 meters in diameter and 0.15 meters in depth. Ten locations within the study area were each equipped with gauges to quantify settleable particulate matter fluxes. The gauges remained in place permanently for one month during each sampling period of the wet and dry seasons. Wet deposition sampling occurred in June 2021 while dry deposition was sampled in December 2021. For wet deposition, rainfall and sediment were collected and passed through pre-weighed 125micron filter paper. The filter papers were then dried in a desiccator to avert further particle absorption until fully dried. The filter papers and particles were subsequently reweighed to determine the collected particle mass. Regarding dry deposition, gauges were left on site for 30 days to allow particulate matter deposition. The gauges were then harvested and rinsed with distilled water to eliminate all deposited material. The solution was drained through pre-weighed filter paper, which was subsequently dried in a desiccator and weighed again.

2.3 Wet and dry deposition flux measurement

The rates of wet and dry material deposition were calculated using the formula given in Equation 1 from the study by Jimoda et al. (2010).

$$Deposition\ Flux = \frac{M_p}{A.t} \qquad (1)$$

Where, M_p = Mass of particulate matter (g), A = Deposition gauges area (m^2), and t = Exposure duration (month). The heavy metal content present in the deposited matter was analyzed using energy-dispersive X-ray fluorescence Spectrometry (EDX-RF). The EDX-RF instrument was operated at 40kV and 18mA for the characterization.

2.4 Evaluation of deposition velocities and scavenging ratio of heavy metals

Equation 2 according to Jimoda et al. (2010) was used to calculate the heavy metal deposition velocities in the study area as the flux per concentration of the trace metals precipitated.

$$D_V = \frac{D_F}{C} \qquad (2)$$

Where, D_V = deposition velocity (ms^{-1}), D_F = Deposition flux, and C = concentration of the trace metals precipitated.

Understanding how deposition affects the lifetime of heavy metals in the environment depends on knowing the scavenging ratio of those metals. Assuming that the concentration of pollutants in precipitation (C_p) is dependent upon the concentration of pollutants (heavy metals) in the air (C_A) during precipitation formation, (Cheng et al., 2021). The scavenging ratio (SR) is represented by the relation in Equation. 3.

$$SR = \frac{C_p}{C_A} \qquad (3)$$

3. RESULTS AND DISCUSSION

3.1 Deposition flux

The particulate deposition fluxes collected at the study area in the wet season ranged from 7.32 to 11.46 g/m^2/month as shown in Table 1. The highest flux of 11.46 g/m^2/month was observed at sampling spot 4 (SS4). However, the lowest flux of 7.32 g/m^2/month was observed at sampling spot 5 (SS5). The deposition flux increased in the order of SS4>SS2>SS6>SS8>SS1>SS9>SS3>SS7>SS10>SS5. The deposition flux percentages from sampling spots SS1 to SS10 were 10.3%, 11.7%, 9.3%, 12.4%, 7.9%, 11%, 8.6%, 10.7%, 9.9% and 8.2% respectively. For the study area in the dry season, the particulate deposition fluxes ranged from 38.83 to 88.8 g/m^2/month as shown in Table 1. The highest flux (88.8 g/m^2/month) was obtained at SS9, while the lowest flux (38.83 g/m^2/month) was recorded at SS3. The flux increased in the order of SS9>SS10>SS6>SS4>SS5>SS7>SS2>SS8>SS1>SS3. The percentages of deposition fluxes from sampling spots SS1 to SS10 were 7%, 8.3%, 6.6%, 10.9%, 10.3%, 12.2%, 8.9%, 7.3%, 15% and 13.5%, respectively. It was observed that the deposition fluxes for the dry season are higher than that of the wet season. This may be due to meteorological factors such as high temperature, wind, and low humidity witnessed in the dry season which enhances the deposition of particulate matter (Mohan, 2016). The difference in the concentrations of the wet and dry deposition of the trace metals may be attributed to the different particle sizes of the metallic elements (Jiang *et al.,* 2024). Larger particles have shorter atmospheric residence time, as a result of their higher rates of deposition. Hence, the trace metals' dry deposition fluxes associated with larger particles are more than the wet deposition fluxes (Jiang *et al.,* 2024). While the deposition fluxes obtained in this study were lower than the values reported by Amodio et al. (2014), they were higher than some previous studies (Kufmaan et al., 2006; Uematsu et al., 2003; Cattle et al., 2002). The results obtained were comparable to those evaluated by Cao et al. (2011) and Zhang et al. (2004).

Table 1. Wet and dry deposition flux of selected sampling spots

Sampling Spot	Wet Season (g/m^2/month)	Dry Season (g/m^2/month)
SS 1	9.55	41.37

SS 2	10.82	48.70
SS 3	8.59	38.83
SS 4	11.46	64.61
SS 5	7.32	60.47
SS 6	10.18	71.93
SS 7	7.96	52.51
SS 8	9.87	42.97
SS 9	9.23	88.80
SS 10	7.64	79.89

3.2 Heavy Metal Concentration

An overview of the average heavy metal concentration from specific sampling locations during the wet and dry seasons is stated in Tables 2 and 3, respectively. During the wet season, the following concentration ranges were recorded: 30679-111650, 4615-4849, 11354–23200, 11554–16733, 19209–32407, 2,321–7667, 17710–33129, 17107–29497, 4292–8456, 4591–6111, 39830–81337, and 5705–11168 µg/m^3, respectively for gold, au, silver, lead (Pd), rhodium (Rh), cadmium (Cd), zinc (Zn), indium (In), manganese (Mn), tin (Sn), copper (Cu), manganese (Mn), and ruthenium (Ru). The range of concentration of Fe, Ag, Pd, Rh, Cd, Zn, In, Sn, Tungsten (W), Cu, Ti, Ru, Sulphur (S) in the dry season were 58841–117369, 10712-20912, 10055–16090, 39296–50420, 29326–40658, 7062–9575951–339964, 28356–38872, 3993 –45297, 4799–8456, 44101–85865, 8323–11510, and 7871–9903 µg/m^3, respectively. Iron had the highest mean concentration of 67512.8 µg/m^3 and Gold had the lowest concentration of 4732 µg/m^3 in the wet season (Figure 2), while Iron and Copper had the highest and lowest mean concentrations of 73846 µg/m^{3}and 6629 µg/m^3 respectively in the dry season as shown in Figure 3. The metal concentrations were higher in the dry season than in the wet season. This is believed to be because some metals are soluble in rainwater, thereby reducing their concentration captured on the filter paper. It could also be attributed to atmospheric conditions, such as high winds and temperatures during the dry season, which are thought to promote particulate deposition. A similar observation was reported by Fakinle et al. (2020).

All the characterized heavy metals were exponentially higher than the specified standard. Similar results were reported by Morakinyo et al. (2021). The findings revealed that heavy metals emanated through the burning of solid wastes in the open air and the emissions significantly affected the concentration of heavy metals in the particulate samples collected. This agrees with Kumar et al. (2018), who stated that the combustion of solid waste releases high quantities of heavy metals into the environment. Some of these heavy metals can trigger human poisoning (acute/chronic) after exposure through food or air. In the human body, accumulation of these heavy metals injurious to organs and tissues such as deoxyribonucleic acid (DNA) and membrane damage, neurotoxicity, skin toxicity, cancer, and cardiovascular toxicity, as reported by Balai-Mood et al. (2021) and Mitra et al. (2022). Globally, heavy metal contamination is gradually becoming a major issue of concern due to air emissions from human activities like open burning of solid waste, as discussed by Allen et al. (2018) and Masindi and Muedi (2018). The higher heavy metal concentrations in this study can be attributed to the proximity of sampling spots to the open burning emission source of municipal solid waste, as well as the large daily quantities of different waste compositions combusted on the 600 plots of land, which is the sole dump site in the state capital.

Table 2. Wet season heavy metal concentration from selected sampling spots

Elements	Heavy Metal Concentration $(\mu g/m^3) \times 10^3$										
	SS 1	**SS 2**	**SS 3**	**SS 4**	**SS 5**	**SS 6**	**SS 7**	**SS 8**	**SS 9**	**SS 10**	**Control**
Fe	72.57	111.65	59.91	54.44	81.1	59.54	77.94	69.06	30.68	58.24	44.63
Au	ND	ND	ND	ND	ND	4.85	ND	ND	4.62	ND	ND
Ag	15.19	11.5	15.19	16.73	16.64	16.65	13.61	18.02	23.2	17.67	14.76
Pd	13.81	11.87	13.22	16.27	13.14	15.09	13.12	14.55	15.11	14.09	12.03
Rh	40.93	34.13	37.08	54.14	36.37	41.81	33.38	39.85	51.08	45.58	38.84
Cd	27.48	19.53	23.69	28.08	19.21	23.89	21.48	25.91	32.41	31.18	22.68
Zn	4.22	6.65	2.32	5	7.17	4.07	7.67	6.51	3.13	5.53	1.97
In	23.38	18.55	21.25	29.58	24.07	25.28	17.71	27.05	33.13	30.21	24.92
Sn	25.22	17.11	22.24	24.22	18.84	22.74	15.78	24.83	29.5	21.25	6.37
Cu	4.29	ND	ND	ND	ND	ND	ND	8.46	ND	6.12	ND
Mn	ND	ND	ND	6.11	ND	ND	4.69	ND	ND	4.59	ND
Ti	59.97	39.83	77.15	61.72	57.69	66.64	61.72	56.23	81.34	68.71	30.26
Ru	7.62	5.89	6.29	9.13	6.62	7.55	5.71	7.91	8.99	11.17	6.73

SS: Sampling Spot and ND: Not Detected

Table 3: Dry season heavy metal concentration from selected sampling spots

Elements	Heavy Metal Concentration $(\mu g/m^3) \times 10^3$										
	SS 1	**SS 2**	**SS 3**	**SS 4**	**SS 5**	**SS 6**	**SS 7**	**SS 8**	**SS 9**	**SS 10**	**Control**
Fe	65.22	117.37	64.91	58.84	75.85	66.12	74.81	78.88	71.59	64.87	40.78
Ag	14.82	14.26	14.6	13.79	10.71	13.14	15.12	17.36	20.91	16.88	5.78
Pd	10.06	10.95	10.55	10.34	13.03	12.98	13.97	16.09	12.86	13.55	4.26
Rh	39.3	40.07	49.71	50.42	43.52	43.39	42.05	40.78	41.68	47.63	23.22
Cd	30.78	36.29	31.52	38	34.67	35.81	33.8	29.33	34.53	40.66	16.51
Zn	7.38	7.06	7.97	7.57	8.26	7.11	7.15	8.44	9.58	9.06	4.08
In	30.95	31.53	32.94	33.98	39.6	35.21	39.01	39.96	37.51	36.51	14.77
Sn	30.45	28.36	28.89	32.75	33.62	34.41	35.85	33.13	38.87	36.83	23.89
W	ND	39.94	ND	ND	ND	ND	ND	45.3	ND	ND	ND
Cu	4.8	ND	ND	7.55	ND	4.99	ND	8.46	7.35	ND	ND
Ti	66.24	59.11	85.87	79.97	74.12	50.45	44.1	82.03	66.37	59.15	38.83
Ru	10.64	8.71	7.99	10.64	7.43	9.74	11.51	8.32	10.38	10.76	3.78
S	9.9	8.92	ND	ND	9.56	ND	7.87	ND	8.14	7.54	ND

SS: Sampling Spot, ND: Not Detected

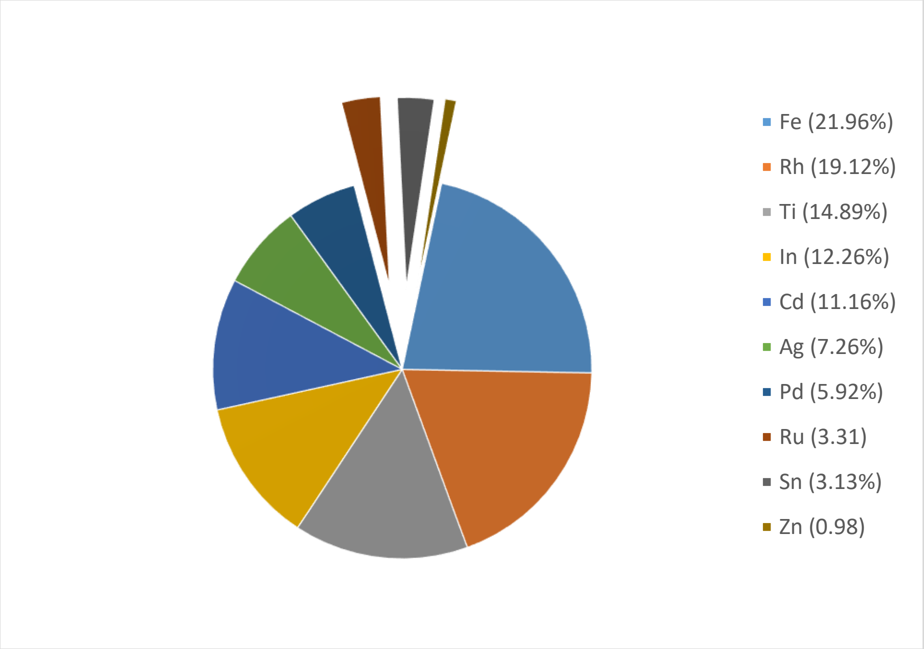

Fig. 2. Percentage of mean elemental composition in the wet season

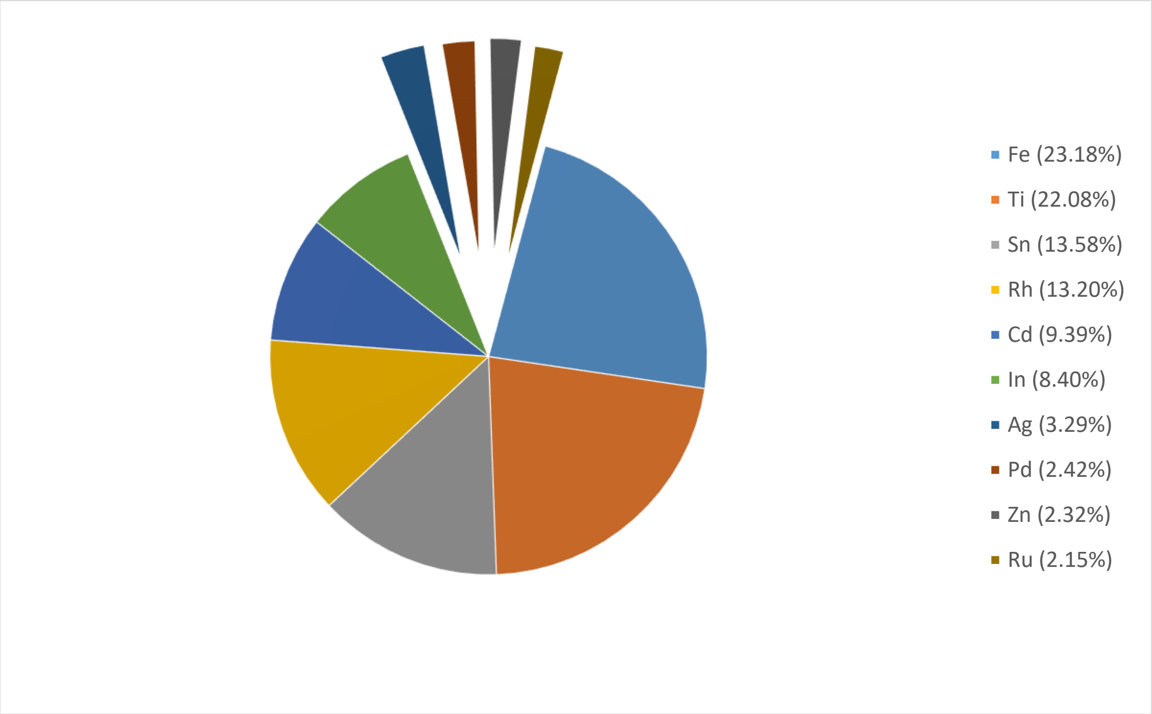

Fig. 3. Percentage of mean elemental composition in the dry season

3.3 Deposition Velocity

The deposition velocities of the heavy metals were evaluated as the flux per concentration of precipitated heavy metals. The evaluated deposition flux (g/m^2/sec) is shown in Table 4 while Table 5 gives the deposition velocities (m/s). In this study, the estimated deposition velocity of Au (0.0048183 m/s) was found to be the highest, which is less than the values reported by Yan et al. (2014), Zhang et al. (2012), and Qi et al. (2005), but greater than the result of Jimoda et al. (2010). The lowest value corresponded to Fe (0.0003377 m/s), which is lower than previous studies (Yan et al., 2014; Qi et al., 2005; Lestari et al., 2003). The deposition velocities throughout the seasonal measurement followed the order of Au>Mn>Zn>Cu>Ru>Pd>Ag>Sn>In>Cd>Rh>Ti>Fe. The highest deposition velocity from trace metal in Sokoto Aiyekale dump site, Ilorin was found to be almost the same when compared with the work of Yun et al. (2002), which obtained a deposition velocity of 0.004 m/s. The higher deposition velocity of Au implies it has the fastest settling/deposition speed to the surroundings, among all trace metals, following the aforementioned order, with Fe having the least.

Table 4. Deposition flux

Sampling Spot	Deposition flux			
	Wet Season		Dry Season	
	$(g/m^2\ /month)$	$(g/m^2/sec)10^{-6}$	$(g/m^2\ /month)$	$(g/m^2/sec)10^{-5}$
SS 1	9.55	3.68	41.37	1.60
SS 2	10.82	4.17	48.7	1.88
SS 3	8.59	3.31	38.83	1.50
SS 4	11.46	4.42	64.61	2.50
SS 5	7.32	2.82	60.47	2.33
SS 6	10.18	3.93	71.93	2.78
SS 7	7.96	3.07	52.51	2.03
SS 8	9.87	3.81	42.97	1.66
SS 9	9.23	3.56	88.80	3.43
SS 10	7.64	2.95	79.89	3.08
Control	0.95	0.37	33.74	1.30

Average flux (wet season) =$3.57 \times 10^{-6}(g/m^2/\ sec)$, Average flux (dry season) = $2.28 \times 10^{-5}(g/m^2/\ sec)$

Table 5. Deposition velocity of trace metals (m/s)

Trace Metals	Trace metal concentration in the precipitate ($\mu g/m^3$)	Deposition Velocity (m/s)	
		Wet season	Dry Season
Fe	67512.8	5.288×10^{-5}	33.77×10^{-5}
Au	4732	75.444×10^{-5}	481.83×10^{-5}
Ag	16445.9	21.708×10^{-5}	138.64×10^{-5}
Pd	14027.1	25.451×10^{-5}	162.54×10^{-5}
Rh	41434.1	8.616×10^{-5}	55.03×10^{-5}
Cd	25285.5	14.119×10^{-5}	90.17×10^{-5}
Zn	5227.5	68.293×10^{-5}	436.15×10^{-5}
In	25032.3	14.262×10^{-5}	91.08×10^{-5}
Sn	22171.4	16.102×10^{-5}	102.84×10^{-5}
Cu	6287.7	56.778×10^{-5}	362.61×10^{-5}
Mn	5131.3	69.573×10^{-5}	444.33×10^{-5}
Ti	63098.5	5.658×10^{-5}	36.13×10^{-5}
Ru	7685.9	46.449×10^{-5}	296.65×10^{-5}

3.4 Scavenging Ratio

Cu, Ti, Mn, and Fe had the highest scavenging ratios, SR, (3.96, 3.39, 1.89, and 1.46, respectively) during the wet season as shown in Table 6. In the meantime, the scavenging ratios for Zn, Ag, Sn, and Cd were found to be 0.66, 0.74, 0.77, and 0.95, respectively. Additionally, the scavenging ratios during the dry season indicate that Cu, Ti, Fe, and In had the highest ratios, estimated as 2.1, 1.57, 1.57, and 1.12, respectively. On the other hand, reduced scavenging ratios of 0.61, 0.75, 0.82, and 0.89 were observed for Ag, Pd, Zn, and Ru, respectively. Throughout the seasonal measurements, the scavenging ratios in the wet season were more than the dry season, which is comparable to those reported by Cheng *et al.* (2021); Sakata and Asakura (2009). This is possible because of the wind conditions in the wet season, which easily disperse particulates into the atmosphere resulting in their removal by in-cloud scavenging. It could also be due to the effective precipitation of particulates by rain (Wang *et al.,* 2014; Cheng *et al.,* 2021). Hence, these trace metals (Cu, Ti, Mn, and Fe) with high scavenging ratios may be efficiently removed from the atmosphere around solid waste combustion areas through deposition. Their lifetime in the environment could be influenced by wet deposition while that of Zn, Ag, Sn, Au, and Cd are governed by dry deposition. The contribution of scavenged trace metals to the deposition flux was evaluated using scavenging ratios, which is the concentration of trace metals in precipitation per their concentration in air. From the study area, the estimated scavenging ratio range for trace metals in the government-approved dump site in Ilorin was 0.61–3.96, while Cheng et al. (2021) evaluated ratios ranging from 1.3 - 7.8.

Table 6: Scavenging ratio of trace metals in wet and dry season

Trace Metals	Wet Season			Dry Season		
	Concentration (6h)	**Concentration (720h)**	**Scavenging Ratio**	**Concentration (6h)**	**Concentration (720h)**	**Scavenging Ratio**
Fe	46208	67512.80	1.46	47097	73845.5	1.57
Au	5107	4732.00	0.93	8440	ND	ND
Ag	22228	16445.90	0.74	24793	15158.8	0.61
Pd	14643	14027.10	0.96	16544	12436	0.75
Rh	38794	41434.10	1.07	44620	43854.4	0.98
Cd	26605	25285.50	0.95	32443	34538.1	1.06
Zn	7980	5227.50	0.66	9648	7957.6	0.82
In	26531	25032.30	0.94	31955	35721.2	1.12
Sn	28790	22171.40	0.77	35998	33314.7	0.93
Cu	1588	6287.70	3.96	2946	6172.3	2.1
Mn	2746	5131.30	1.89	3932	ND	ND
Ti	18672	63098.50	3.39	42641	66740.6	1.57
Ru	7190	7685.90	1.07	10775	9611.9	0.89
S	ND	ND	ND	ND	8638.5	ND
W	ND	ND	ND	ND	42618	ND

3.5 Health Risks of Heavy Metal Emissions from Waste Combustion in Sokoto Aiyekale

All the heavy metals characterized were exponentially higher than the stipulated standard the highest and lowest concentrations of Iron are 73845.5 and 67512.8 $\mu g/m^3$respectively. These concentrations are far above the 0.9-1.2 $\mu g/m^3$standard value (HSDB, 2010) (Table 7). According to Nagpure *et al.* (2016), open combustion of plastics, glass, metals, and organic wastes results in the emission of metals. Iron (Fe) was predominantly high in the study area, the results and observations were similar to the ones measured by Kumar *et al.* (2018). It has been reported that a higher concentration of Iron is responsible for Iron overload which can cause genetic disorders (Amin *et al.,* 2018), dehydration, lethargy, and liver disease named hemosiderosis (Chakraborty, 2023). Inhalation of Iron dust and fumes leads to pulmonary siderosis and irritation of the respiratory tract (Al-Abadleh *et al.,* 2023). Thus in this study, the concentration of Iron from the open burning of solid waste from Sokoto Aiyekale dump site is considerably higher than the recommended standard.

The wet and dry season concentrations of Cadmium are 25285.5 and 34538.12 $\mu g/m^3$) (Table 7), which is above the WHO and EPA permissible limits of 0.005-0.5 and 0.002 $\mu g/m^3$ respectively. Cd in the atmosphere may be from anthropogenic activities like the combustion of different types of wastes (Kumar *et al.,* 2023). It also affects the physico-chemical properties of the soil (Majumdar *et al.,* 2020). Wang *et al.* (2016) reported that in densely populated cities, open burning of municipal solid wastes leads to direct exposure to atmospheric Cd in the study area. In the study by Geiger and Cooper (2010), it was also discovered that Cd is emitted into the atmosphere through the incineration of municipal solid waste materials. Cd at higher concentrations has toxic effects on kidneys, which include kidney damage and impaired renal function, the obtained value for Cd in this study is exponentially higher than the recommended standard. Therefore, Prolonged exposure of workers and persons within the community to Cd in the study area may affect their organs and systems leading to toxicity in the form of diarrhea, infertility, cancer, cardiac abnormalities, bronchiectasis, emphysema, and osteoporosis in the human body (Chakraborty, 2023). Chronic, long-term exposure to cadmium in humans may contribute to the induction of carcinogenesis or the process by which normal cells are transformed into cancer cells (Charkiewicz *et al.,* 2023).

The concentrations of Zinc in wet and dry seasons are 5227.5 and 7957.6 $\mu g/m^3$, which is above the EPA permissible limit of 0.103 $\mu g/m^3$ $(\text{Table } 7)$. This result corroborates the study of Ramadan *et al.* (2022). The high concentration of Zinc observed in the depositions was attributed to the elevated concentration of the metal present in the atmosphere as a result of the solid waste combustion (Alamu *et al.,* 2020). The high concentrations of Zinc intake in the body can cause liver and kidney abnormal functioning, and gastrointestinal disorders such as nausea, vomiting, and diarrhea (Hao *et al.,* 2013).

The mean concentrations of Mn and Cu were 5131.3 and 6287.7 $\mu g/m^3$ in the wet season and 6172.3 $\mu g/m^3$ for Cu in the dry season. Mn was not detected in the dry season. These values exceeded the limits of WHO and EPA standard of 0.15 and 0.29 $\mu g/m^3$ respectively (Table 7). The high concentration of Mn and Cu could be as a result of the presence of metallic components in the solid waste being burnt resulting in hazardous fumes and metallic dusts (Geiger and Cooper, 2010). From this study, the average elemental concentrations were higher than in some previous works (Abdulaziz *et al.,* 2022; Ramadan *et al.,* 2022; Kumar *et al.,* 2018). A high concentration of manganese (Mn) causes a condition called Manganism which is characterized by symptoms resembling Parkinson's disease, including tremors, impaired motor function as well as cognitive function. It may also lead to neurologic and psychological problems (Saha and Zaman, 2013). Tin (Sn), Indium (In), Copper (Cu), Titanium (Ti), Ruthenium (Ru), Rhodium (Rh), and Palladium (Pd) all have limited information available as regards to their effects on human health in elemental forms at high concentrations.

Table 7. Concentration of trace metals with regulatory standards ($\mu g/m^3$)

Permissible Limit		Fe	Cd	Zn	Cu	Mn
WHO		-	0.005 - 0.5	-	-	0.15
EPA		-	0.006	0.103	0.29	-
HSDB		0.9 - 1.2	-	-	-	-
This	Wet	67512.8	25285.5	5227.5	6287.7	5131.3
Study	Dry	73845.5	34538.1	7957.6	6172.3	-

4. CONCLUSION AND RECOMMENDATIONS

This study assessed the elemental composition of wet and dry particulate matter deposition from open solid waste burning in Ilorin, Nigeria. Dry season deposition fluxes were higher than wet season due to particle re-suspension from burning activities. Also, element concentrations exceeded the recommended exposure limits of USEPA and WHO, posing risks to human life and the environment. Higher deposition velocities for Au, Mn, and Zn compared to Fe, Ti, and Rh indicate their lifetimes in the atmosphere are governed by dry deposition, while higher scavenging ratios for Fe, Ti, and Rh show their lifetimes are governed by wet deposition. Therefore, Au, Mn, and Zn are best removed from the study area atmosphere by dry deposition through gravitational particle settling, while Fe, Ti, and Rh are best removed by wet deposition through precipitation scavenging. Hence, the government should implement strict regulations against open waste burning and promote public awareness about its dangers. Investing in safe waste disposal facilities and establishing regular environmental monitoring programs are essential. Supporting research on alternative waste management technologies and enhancing community involvement in waste segregation can significantly reduce emissions. Additionally, the government should establish health monitoring programs for affected populations and collaborate with NGOs for effective pollution control. Finally, strengthening environmental policies within national development plans will ensure the prioritization of public health and environmental safety, ultimately improving community well-being.

Competing interests

The authors declare no potential conflict of interest in the article

AUTHORS' CONTRIBUTIONS

Popoola, Adewemimo Oluwakunmi: Conceptualization (equal); investigation (equal); methodology (equal); resources (equal); writing – original draft (equal); review and editing (equal); supervision (equal). **Jimoda, Lukuman Adekilekun:** Conceptualization (equal); supervision (equal); visualization (equal). **Alade, Abass Olanrewaju:** Writing, review, editing and methodology (equal) **Raji, Wuraola Abake:** Writing, review, editing and methodology (equal). **Oloyede, Christopher Tuni:** Conceptualization (equal); investigation (equal); resources (equal); writing – original draft (equal); review and editing (equal); supervision (equal). **Edun, Joseph Olaoluwa:** Resources and methodology (equal) and **Oyerinde, Kazeem Kolawole:** review and editing (equal).

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