Full Paper

# WET AND DRY DEPOSITION STUDIES OF AEROSOL HAZES AROUND A MAJOR SAWDUST OPEN BURNING AREA

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## ABSTRACT

The continuous generation of aerosol species from natural and anthropogenic sources around saw dust open burning sites necessitates extensive deposition study of such areas. This work used the concepts of deposition velocity and scavenging ratio to study the removal mechanisms of heavy metal constituents of the aerosol in a sawdust open burning area. The aerosol concentration of the area was determined using gravimetry method with a high volume sampler fitted with a two-filter holder and exposed filters. A sampling period of 6-hours was adopted. Twenty seven deposition gauges were deployed to the sampling site to measure the flux of settleable particulate matter. Aerosol samplings and deposition flux rates measurements were carried out in the area in the wet (July, 2008; May, 2009) and dry (October, 2008; February, 2009) seasons. The measured average deposition flux rates in wet were evaluated to be $1.092 \times 10^{-3}$ $\mu gm^{-2}s^{-1}$ in July, 2008; $1.388 \times 10^{-3}$ $\mu gm^{-2}s^{-1}$ in May, 2009 while that of dry season were evaluated to be $1.587 \times 10^{-3}$ $\mu gm^{-2}s^{-1}$ in October, 2008 and $1.933 \times 10^{-3}$ $\mu gm^{-2}s^{-1}$ in February, 2009. The calculated deposition velocities for the trace metals in the area had values between $3.87 \times 10^{-7}$ – $2.11 \times 10^{-4}$ m/s while the estimated scavenging ratios were found to be between 0.82 – 1224.31 in the study area. The results showed that Cd, Pb, and Sb are better removed through gravitational settling of particles while Fe, Mn, Cr and Ti are scavenged by precipitation.

**Keywords**: *Dry Deposition, Wet Deposition, Deposition Velocity, Scavenging Ratio*

## 1. INTRODUCTION

Some recent studies have been focused on air quality degradation caused by particulate matter. The presence of toxic elements in the atmosphere is now a great concern to scientists, engineers and policy-makers due to their adverse effects on human health and ecosystem. Particulate matter less than 10μm ($PM_{10}$) is easily transported through the upper respiratory tract into the bronchioles and alveoli of the lungs causing direct health effect. Attentions are being focused on $PM_{2.5}$ (particulate less than 2.5μm) because of its ability to penetrate deep into the respiratory system and its visibility degradation [1]. The toxic elements in the aerosol including (Al, Fe, Ca, Mg, K, Na. As, Pb, Cd, Sc and Hg) in the atmosphere are linked to various sources which include fossil fuel combustion[2]. Elements including Pb, and Zn are associated with wood combustion [3], while vehicular traffic releases Cd, Cr, Cu, Ni, Pb and Zn [4]. Electroplating activities contribute Cr to the atmosphere [5], but metal alloy industries emit Cd, Cr, Al, Fe, Ni, Zn, Pb and Cu [6].

These toxic elements in the aerosol are removed from the atmosphere through the mechanism of dry and wet deposition. Due to this, the concepts of deposition velocity and scavenging ratio are often used to parametize dry and wet deposition respectively [7]. A common practice to parameterize the dry deposition process is to use the concept of deposition velocity. [8] described dry deposition parameterization for surface boundary layer (SBL) in the form of dry deposition flux given in equation (1)

$$F = V_{d(z)}.[C_{(z)} - C_s] \tag{1}$$

Where $F$ =dry deposition flux

$V_{d(z)}$ = dry deposition velocity at height *z*

$C_{(z)}$ = concentration of pollutant at height *z*

$C_s$ = concentration of pollutant at the surface.

If the surface is covered by vegetation, a plane-displacement, d, is included resulting in eqn. (2).

$$F = V_{d(z-d)}.[C_{(z-d)} - C_s] \tag{2}$$

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For absorbing surface, $C_s$ = 0 and a zero-plane displacement gives eqn.(3).

$$F = V_d(z)C_{(z)} \tag{3}$$

For gases such as nitrogen dioxide ($NO_2$), sulphur dioxide ($SO_2$) and ammonia ($NH_3$), the resistance analogy that expressed the parameterization of the dry deposition velocity was reported by [9] as in eqn.(4).

$$V_d = (r_a + r_b + r_s)^{-1} \tag{4}$$

with $r_a$ = Surface area aerodynamic resistance ($sm^{-1}$)

$r_b$ = Quasi-laminar resistance ($sm^{-1}$)

$r_s$ = Surface resistance ($sm^{-1}$)

Also, for the surface covered by vegetation, surface resistance $r_s$ is estimated by [10] and [11] using eqn.(5).

$$r_s = [(r_{inc} + r_{soil})^{-1} + r_{ext}^{-1} + (r_m + r_{stom})^{-1}]^{-1} \tag{5}$$

where

$r_{inc}$ = In-canopy aerodynamic resistance

= The resistance against transport of air through vegetation towards the soil and lower plant parts.

$r_{soil}$ = Soil resistance

= The resistance against the destruction or absorption at the soil surface.

$r_{ext}$ = External surface resistance

= The resistance to the exterior plant parts against the uptake or destruction of the compound.

$r_m$ = The mesophyll resistance

= The resistance of the internal plant tissues against uptake or destruction (in terms of chemical reactions).

$r_{stom}$ = The stomata resistance

= The resistance against the transport through the stomata of leaves and needles.

For surfaces not covered by vegetation or those that are covered by snow, the total surface resistance is set to be equal to the soil resistance of the selected surface type [12]. [13]. estimated the average dry deposition for each compound in the dry and wet part of model grid cell using (eqn. 6).

$$\bar{V}_d = \varphi.\sum_{i=1}^{N} a_l.V_{d,l}^{wet} + (1-\varphi).\sum_{i=1}^{N} a_l.V_{d,l}^{dry} \tag{6}$$

where $\bar{V}_d$ = Average dry deposition velocity over the entire grid cell.

= The weighted sum of the dry deposition velocities for the wet and dry part of the grid.

$N$ = Number of land cover classes in the grid cell

$\phi$ = Wet fraction of the grid which is equal to zero when the grid cell has not been affected by precipitation in the last six hours.

$a_l$ = Fraction of the land covers in the grid cell

$V_{d,l}^{wet}$ = Dry deposition velocity in the wet part of the grid

$V_{d,l}^{dry}$ = Dry deposition velocity in the dry part of the grid

For in-cloud scavenging coefficient, [13] estimated it for gases and particles using eqn. (7).

$$S = \frac{P}{W.\Delta z} \tag{7}$$

where

$\Delta z$ is the height of the grid cell

$W$ is the cloud water (kg of water $m^{-3}$)

$P$ is the precipitation released from the individual grid cell.

Also, the concentration change caused by wet deposition is expressed as eqn. (8).

$$\frac{\partial C}{\partial t} = -S.f_{aq}.C \tag{8}$$

with $C$ being the total concentration of the gas and particles in aqueous phase of the pollutant.

$f_{aq}$ is the fraction of the pollutant dissolved in the droplets.

However, the sub-cloud deposition of gases is calculated by [8] using eqn. (9).

$$\frac{\partial C}{\partial t} = -C.\frac{\Delta.P}{\Delta z}.\frac{1}{\rho_W} \tag{9}$$

Where $\Delta$ is the sub-cloud scavenging coefficient which depends on the gas and $\rho_w$ is the density of water.

Also, wet deposition rate for particles was described by [13] with eqn. (10).

$$\frac{\partial C}{\partial t} = -A.M.E.C \tag{10}$$

$A$ = a constant given as $5.2 m^3 kg^{-1} s^{-1}$

$M$ = Mass of the precipitation

$E$ = Mean collection efficiency ( $E$ = 0.1).

[14] estimated dry deposition flux as the product of the atmospheric concentration and a suitable deposition velocity;

$$F = C_i V_d \tag{11}$$

Hence the gravitational settling velocity $V_d$ can be expressed as :

$$V_d = F/C_i \tag{12}$$

F = Dry deposition flux

$C_i$ = Trace element mean concentration.

Scavenging ratio (SR) is expressed by [15] as:

$$SR = \frac{C_p}{C_A} \tag{13}$$

where $C_p$ = Concentration of the Trace Element in the Precipitate and $C_A$ = Concentration of Trace Element in the Air.

Jarostz et al. [16] measured deposition velocity of pollen grain in a commercial farm in France during the summer of 2000. The deposition velocity was found to be of range 0.2ms$^{-1}$ – 1.8ms$^{-1}$ with that 95% of the pollen grains emitted being deposited at 10 metres from the source and 99% at 30 metres from the source. Geroza et al. [17] measured ozone, water and energy fluxes over Mediterranean maquis ecosystem from 9th of May till 31st of July using eddy covariance technique. It was concluded that the maquis ecosystem acted as a net sink for ozone. Ozone deposition was quiet high. Nevertheless, only a minor part of ozone (32.8%) was absorbed by vegetation through the stomata. The study area is not covered with vegetation, hence, equation 3 will be appropriate

## 2. MATERIALS AND METHOD

### 2.1. The Study Area/Sampling Site

Southeastern Lagos is in Lagos Mainland Local Government of Lagos state, Nigeria. It is characterized by towns and villages comprising of Yaba, Ebute-metta, Iddo-Otto, Akoka, Maroko, Ijero, Oko-baba, Abule-Ijesha and Olaleye. This site of interest located at the center of Okobaba is characterized by about 327 sawmills and 34 burning points of sawdust between Ebute-metta and Oyingbo on the edge of the Lagoon (Fig. 1). This study area is quite visible on the Third Mainland Bridge, a major link between the mainland and the island parts of the city [18].

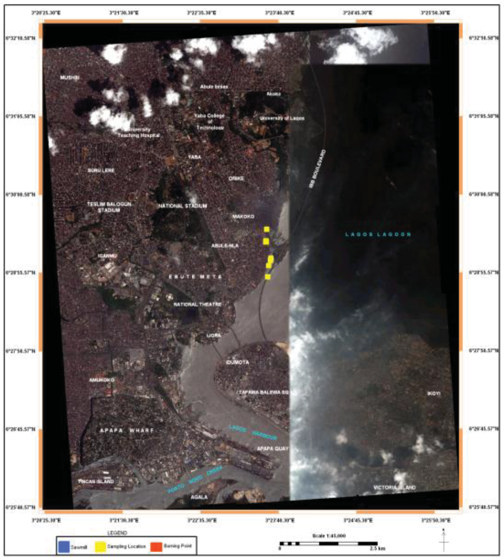

*Fig. 1: Study Area*

### 2.2. Atmospheric Deposition Measurements

Flux rates were evaluated for both the dry and wet seasons using deposition gauges. Twenty seven (27) deposition gauges each of dimension 20 cm diameter by 15 cm depth were deployed to the study area to measure the flux of settleable particulate matter. The gauges were left permanently for 1 month during the sampling period.For wet deposition, the rainwater in the gauges was collected and filtered through dry, pre-weighed filter. The filter was dried to a constant weight and then reweighed. For dry deposition analysis, the dry deposition gauges were rinsed with distilled water to remove all the deposited matter. The water was then drained and filtered through a dry pre-weighed filter. The filters were finally dried in a dessicator and then reweighed. The flux rate was thereafter calculated using eqn. (14).

$$\text{Flux rate} = \frac{W_p}{A.t} \qquad (14)$$

where $W_p$ = Weight of particulate matter

$A$ = Area of the deposition guage

$t$ = Duration of exposure

### 2.3. Aerosol Sampling And Measurement

Sampling and analysis of fine $(dp\angle 2.5\mu m)$ and coarse ( $2.5\mu m\angle dp\angle 10\mu m$ ) particulate matter was carried out using the gravimetric method with 6 hours and 24 hours averaging sampling period. The sampling inlet comprises of two-filter holder for collection of particles, designed and tested by [19]. The coarse particles were collected on 8.0µm pore size filter while fine particles $(dp\angle 2.5\mu m)$ were collected on 0.4µm pore size filter with a high volume air sampler.

The sampling location covered two sites. The first site was made up of 67 sawmills and 1 open burning point of sawdust while the second site was made up of 260 sawmills and 33 open burning points of sawdust. The mass and concentration of $PM_{2.5}$ and $PM_{10}$ was estimated using eqns. (15) and (16).

$$PM_{10}(\mu g) = PM_{2.5}(\mu g) + 2.5\mu m\angle dp\angle 10\mu m(\mu g) \qquad (15)$$

$$PM_{10}({}^{\mu g}\!/_{m^3}) = PM_{2.5}({}^{\mu g}\!/_{m^3}) + 2.5\mu m\angle dp\angle 10\mu m({}^{\mu g}\!/_{m^3}) \qquad (16)$$

After sampling, a micro-balance with 0.01 µg minimum resolution and the exposed filter papers were equilibrated for 24 h at a constant temperature corresponding to room temperature at zero ventilation. The filters are then re-weighed. For chemical composition analysis, the filters were digested in HCl / $HNO_3$ solution, filtered and then diluted to 25 ml with distilled water [20] and stored in a refrigerator. The digested samples were analyzed for trace metals content using Atomic Absorption Spectrometer (AAS). The deposition velocities of heavy metals in the study area were evaluated as the flux per concentration of the trace metals precipitated. The contribution of the scavenging of particulate trace metals to the deposition flux was evaluated using scavenging ratios for the trace metals which is the concentration of trace metals in the precipitation per its concentration in air.

## 3. RESULTS AND DISCUSSION

The deposition fluxes measured in July, 2008 (the first wet season) are summerized in Table 1. These ranged between 7.4169×10$^{-5}$g/m$^2$/day and 10.4576×10$^{-5}$ g/m$^2$/day with the minimum flux in sample 10 and the maximum flux in sample 13. Similarly in October, 2008 (the first dry season), the measured flux ranged between 1.2071×10$^{-4}$g/m$^2$/day and 1.6176×10$^{-4}$g/m$^2$/day with the minimum and maximum flux in samples 24 and 15 respectively. During second dry season (February, 2009), the measured deposition flux were of the range 1.5090 × 10$^{-4}$-1.8287×10$^{-4}$g/m$^2$/day with minimum and maximum obtained in samples 19 and 24 respectively. Also, in the second wet season (May, 2009), the deposition flux was found to vary between 1.0853 × 10$^{-4}$ and 1.3999 × 10$^{-4}$ g/m$^2$/day with minimum and maximum obtained in samples 18 and 5, respectively (Table 1).

The average concentrations of the heavy metals samples in site 1 and site 2 in wet season (July, 2008; May, 2009) were summarized in Table 2, while that of dry season (October, 2008; Feb., 2009) was in Table 3. Fe had the highest concentration of 2803.67µg/m$^3$ and

*Table 1: Deposition Flux Measurement around the Study Area in Wet and Dry Seasons.*

| Sample no | Deposition Flux × $10^{-5}$ ($g/m^2/day$) (Wet Season) | | Deposition Flux×$10^{-6}$ ($g/m^2/day$) (Dry Season) | |
|---|---|---|---|---|
| | July, 2008 | May, 2009 | Oct., 2008 | Feb., 2009. |
| 1 | 9.5641 | 1.1950 | 1.4682 | 1.7016 |
| 2 | 10.1795 | 1.2070 | 1.5300 | 1.6803 |
| 3 | 9.99108 | 1.1710 | 1.5939 | 1.8034 |
| 4 | 8.0596 | 1.1307 | 1.3615 | 1.7190 |
| 5 | 9.7786 | 1.0853 | 1.5934 | 1.6803 |
| 6 | 9.5217 | 1.3429 | 1.2116 | 1.6142 |
| 7 | 10.0328 | 1.1647 | 1.4045 | 1.6123 |
| 8 | 7.8432 | 1.2117 | 1.3388 | 1.5906 |
| 9 | 9.7358 | 1.1075 | 1.2128 | 1.8032 |
| 10 | 7.4169 | 1.2117 | 1.3827 | 1.6783 |
| 11 | 8.6115 | 1.1079 | 1.3407 | 1.6166 |
| 12 | 9.1440 | 1.3393 | 1.2354 | 1.6251 |
| 13 | 10.4576 | 1.2454 | 1.4088 | 1.6367 |
| 14 | 9.9448 | 1.1181 | 1.2751 | 1.5885 |
| 15 | 9.9932 | 1.1944 | 1.6176 | 1.6307 |
| 16 | 8.7347 | 1.1278 | 1.4293 | 1.6463 |
| 17 | 8.9344 | 1.1923 | 1.3195 | 1.6675 |
| 18 | 8.2970 | 1.3999 | 1.4025 | 1.8056 |
| 19 | 10.6866 | 1.1275 | 1.2767 | 1.5090 |
| 20 | 9.9480 | 1.1681 | 1.3195 | 1.6330 |
| 21 | 10.0140 | 1.1625 | 1.4087 | 1.6464 |
| 22 | 10.4379 | 1.1934 | 1.6121 | 1.6449 |
| 23 | 9.3768 | 1.2966 | 1.3180 | 1.5678 |
| 24 | 9.8162 | 1.1265 | 1.2071 | 1.8287 |
| 25 | 10.0331 | 1.1481 | 1.2749 | 1.6575 |
| 26 | 10.2102 | 1.1919 | 1.4116 | 1.6611 |
| 27 | 9.7362 | 1.1492 | 1.3399 | 1.6844 |

3247.79μg/m$^3$ in July 2008 at site 1 and site 2 respectively, while Cd had the lowest concentration of 9.81μg/m$^3$ and 13.76μg/m$^3$ at the two areas respectively. In the dry season (October, 2008) as reported in Table 3, Fe also had the highest concentrations of 1853.93μg/m$^3$ and 1888.08μg/m$^3$ at site 1 and site 2 respectively, while Cd still had the same lowest concentration of 9.18μg/m$^3$ at the two areas. Similarly, in February, 2009 (the second dry season) as shown in Table 3 and May, 2009 (the second wet season) as reported in Table 2, Fe concentrations were still the highest with concentration of 1834.69 μg/m$^3$ at site 1 and 1853.93μg/m$^3$ at site 2 in February, 2009 while the Fe concentrations measured at site 1 was 2616.24 μg/m$^3$ and 2817.43μg/m$^3$ at site 2 in May, 2009 (wet season). However, Cd concentrations remained the lowest at the two sites with concentration of 9.18μg/m$^3$ in both February, 2009 and May, 2009.

As reported in Table 1, the average deposition flux in the dry season was higher than that of wet season. This implies that deposition flux increases when the particle re-suspension from the open burning activities in the study area increases. Due to easy movement of sawdust in the dry season, it is easily resuspended by wind and other moving object on it. The lower deposition flux in wet season can be attributed to the surface soil in the area which though usually made up of sawdust is highly moistened, thus, become heavy and difficult to be suspended. Although, the overall deposition flux measurements in dry season are higher than that of wet season as earlier shown, the heavy metal composition were found to be higher in wet season than that of dry season for Ca, Mg, Fe, Al, Ti, V, Cr, Mn, Co, Ni, Cu, Zn, Ag, Pb, and Sb, except for Cd.

In July, 2008 (the first wet season), Ca concentration was the highest while the concentration of Vanadium was the lowest. In October, 2008; February, 2009 and May, 2009, Ca concentrations were the highest while the lowest heavy metal concentration was Ti in October, 2008; Cr in February, 2009 and May, 2009. At site 1, $Ca^{2+}$ concentrations were the highest in all the seasons of the year while the lowest trace metal concentration was Ti in July, 2008; Cr in October, 2008; Ti in February, 2009 and May, 2009.

*Table 2: Concentration of Trace Elements in the Deposition Flux of the Study Area in Wet Season.*

| Trace Elements | Ca | Mg | Fe | Al | Ti | V | Cr | Mn | Co | Ni | Cu | Zn | Ag | Pb | Sb | Cd |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| July, 2008(Site 1) | 1730.61 | 558.37 | 2803.67 | 90.37 | 207.24 | 78.95 | 248.33 | 277.00 | 112.99 | 155.74 | 438.02 | 621.97 | 83.68 | 17.37 | 24.86 | 9.18 |
| May, 2009(Site 1) | 1619.26 | 526.23 | 2616.24 | 82.76 | 184.27 | 70.24 | 220.75 | 243.92 | 91.64 | 126.46 | 392.34 | 582.31 | 74.35 | 17.37 | 22.82 | 9.18 |
| July, 2008(Site 2) | 1779.59 | 597.55 | 3247.79 | 102.49 | 222.88 | 91.41 | 269.55 | 1124.89 | 122.61 | 170.11 | 484.67 | 605.95 | 92.49 | 21.71 | 29.83 | 13.76 |
| May, 2009(Site 2) | 1656.34 | 541.79 | 2817.43 | 92.68 | 202.76 | 79.94 | 248.33 | 992.46 | 982.44 | 150.78 | 406.12 | 540.28 | 78.24 | 17.37 | 26.34 | 9.18 |

*Table 3: Concentration of Trace Elements in the Deposition Flux of the Study Area in Dry Season.*

| Trace Element | Ca | Mg | Fe | Al | Ti | V | Cr | Mn | Co | Ni | Cu | Zn | Ag | Pb | Sb | Cd |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Oct.,2008 (Site 1) | 1227.76 | 430.04 | 1853.93 | 67.22 | 1419.40 | 54.02 | 171.92 | 833.58 | 81.74 | 98.23 | 256.59 | 464.47 | 61.66 | 13.03 | 13.03 | 9.18 |
| Feb.,2009 (Site 1) | 1210.24 | 410.29 | 1834.69 | 60.52 | 1392.44 | 49.28 | 156.29 | 743.42 | 75.26 | 87.13 | 241.24 | 431.63 | 58.24 | 13.03 | 13.03 | 9.18 |
| Oct., 2008(Site 2) | 1337.14 | 407.51 | 1888.08 | 89.27 | 1546.49 | 72.71 | 167.67 | 882.88 | 88.95 | 124.59 | 313.61 | 451.13 | 74.87 | 13.03 | 13.03 | 9.18 |
| Feb., 2009(Site 2) | 1316.18 | 400.04 | 1853.93 | 77.46 | 1419.40 | 60.91 | 144.37 | 779.21 | 78.41 | 110.48 | 286.12 | 421.39 | 71.12 | 13.03 | 13.03 | 9.18 |

### 3.1. Deposition Velocity And Scavenging Ratio

The calculated deposition velocities and scavenging ratios for the study area (Tables 4 and 5) showed that Cd had the highest deposition velocity in wet season (July, 2008) while Fe had the lowest. The deposition velocities of Cd as shown in Tables 4 and 5 are 1.79 x $10^{-4}$ m/s and 1.19 x $10^{-4}$ m/s at site 1 and site 2 respectively, while that of Fe are 0.034 x $10^{-4}$ m/s and 0.0039 x $10^{-4}$ m/s respectively. In the dry season (October, 2008) Cd had also the highest deposition velocity while Fe was the lowest at the two sites in the same period. Similarly, in February, 2009 (dry season) and May, 2009 (wet season), Cd recorded highest deposition flux velocity while Fe values remained the lowest. The higher deposition velocity of Cd and its lower value for Fe show that the lifetime of Cd in the aerosol particles in the two areas is governed by dry deposition while that of Fe is governed by wet deposition. Hence, scavenging ratio will be a better factor for Fe to parameterize its removal mechanism in the atmosphere.

The scavenging ratios (Tables 4 and 5) show that Fe, Mn, Cr and Ti had highest scavenging ratio of 61.69 – 1124.31 at the two sites, in the two seasons, while Cd, Pb and Sb were characterized with low scavenging ratio of 1.00 – 6.00. Hence, Fe, Mn, Cr and Ti may be better removed in the atmosphere around sawdust open burning area through wet deposition. The lifetime of Fe, Mn, Cr and Ti in the environment could be influenced by wet deposition while that of Cd, Pb and Sb are governed by dry deposition.

*Table 4: Scavenging Ratio and Deposition Velocity of Trace Metals at Site 1 in Wet and Dry Seasons*

| Trace Metals | Trace Metals Concentration in Air (6hours) (μg/m$^3$) | | | | Trace Metals Concentration in Precipitate (720hours) (μg/m$^3$) | | | | Scavenging Ratio | | | | Deposition Velocity × $10^{-4}$ (m/s) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | July, 08 | Oct., 08 | Feb., 09 | May, 09 | July, 08 | Oct., 08 | Feb., 09 | May, 09 | July, 08 | Oct., 08 | Feb., 09 | May, 09 | July, 08 | Oct., 08 | Feb., 09 | May, 09 |
| Ca | 39.18 | 29.44 | 15.50 | 19.50 | 1730.61 | 1337.14 | 1210.24 | 1619.26 | 44.17 | 45.42 | 78.08 | 83.04 | 0.006 | 0.013 | 0.015 | 0.008 |
| Mg | 13.82 | 9.78 | 9.16 | 11.26 | 558.37 | 407.51 | 410.29 | 526.23 | 40.40 | 41.67 | 44.79 | 46.73 | 0.018 | 0.037 | 0.048 | 0.026 |
| Mn | 4.49 | 3.93 | 3.54 | 3.83 | 277.00 | 882.88 | 743.42 | 243.92 | 61.69 | 224.65 | 210.01 | 63.69 | 0.010 | 0.019 | 0.025 | 0.014 |
| Fe | 2.29 | 3.89 | 2.84 | 3.11 | 2803.67 | 1888.08 | 1834.69 | 2616.24 | 1221.31 | 485.37 | 646.02 | 841.23 | 0.034 | 0.009 | 0.01 | 0.005 |
| Zn | 11.19 | 14.43 | 11.66 | 12.55 | 621.97 | 451.13 | 431.63 | 582.31 | 55.58 | 3.26 | 37.02 | 46.81 | 0.018 | 0.034 | 0.046 | 0.023 |
| Cu | 5.23 | 3.79 | 2.04 | 2.31 | 438.02 | 313.61 | 241.32 | 392.34 | 83.75 | 82.75 | 118.25 | 169.84 | 0.03 | 0.065 | 0.068 | 0. 034 |
| Pb | 8.46 | 8.56 | 8.56 | 8.56 | 17.37 | 13.03 | 13.03 | 17.37 | 2.05 | 1.52 | 1.52 | 2.03 | 0.503 | 1.22 | 1.48 | 0.800 |
| Cr | 2.12 | 2.01 | 2.01 | 2.01 | 248.33 | 167.67 | 156.29 | 220.75 | 117.14 | 83.42 | 77.76 | 109.83 | 0.041 | 0.092 | 0. 134 | 0.056 |
| Co | 2.40 | 4.72 | 2.40 | 2.40 | 112.99 | 88.95 | 75.26 | 91.64 | 47.08 | 18.85 | 31.36 | 38.18 | 0.089 | 0.19 | 0.247 | 0.041 |
| Ni | 2.40 | 2.40 | 4.80 | 4.80 | 155.74 | 124.59 | 87.13 | 126.46 | 64.89 | 51.91 | 18.15 | 26.35 | 0.064 | 0.16 | 0.175 | 0.092 |
| V | 3.12 | 2.08 | 4.16 | 4.16 | 78.95 | 72.71 | 49.28 | 70.24 | 25.30 | 34.96 | 11.85 | 16.88 | 0.120 | 0. 29 | 0. 317 | 0.092 |
| Ti | 1.96 | 2.94 | 1.96 | 1.96 | 207.24 | 1546.49 | 1392.44 | 184.27 | 105.73 | 526.02 | 710.43 | 94.02 | 0.049 | 0.011 | 0.014 | 0.174 |
| Sb | 7.46 | 4.97 | 9.96 | 9.94 | 24.86 | 13.03 | 13.03 | 22.82 | 3.33 | 2.56 | 1.31 | 2.30 | 0.37 | 1.22 | 1.48 | 0.069 |
| Cd | 9.16 | 4.59 | 4.59 | 6.87 | 9.18 | 9.18 | 9.18 | 9.18 | 1.00 | 2.00 | 2.00 | 1.34 | 1.79 | 1.73 | 2.11 | 1.51 |

*Table 5: Scavenging Ratio and Deposition Velocity of Trace Metals at Site 2 in Wet and Dry Seasons.*

| Trace Metals | Trace Metals Concentration in Air (6hours) (μg/m$^3$) | | | | Trace Metals Concentration in Precipitate (720hours) (μg/m$^3$) | | | | Scavenging Ratio | | | | Deposition Velocity × $10^{-4}$ (m/s) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | July, 08 | Oct., 08 | Feb., 09 | May, 09 | July, 08, | Oct., 08. | Feb., 09 | May, 09. | July, 08, | Oct., 08. | Feb. 09 | May, 09 | July, 08, | Oct., 08. | Feb., 09 | May, 09. |
| Ca | 39.21 | 22.93 | 23.77 | 26.46 | 1779.59 | 1227.76 | 1316.18 | 1656.34 | 45.39 | 53.54 | 55.37 | 62.60 | 0.006 | 0.012 | 0.016 | 0.0086 |
| Mg | 10.78 | 9.09 | 8.28 | 8.70 | 597.55 | 430.04 | 400.04 | 541.79 | 55.43 | 47.31 | 48.31 | 62.27 | 0.020 | 0.039 | 0.047 | 0.026 |
| Mn | 6.74 | 3.90 | 3.71 | 3.86 | 1124.89 | 833.58 | 779.21 | 992.46 | 166.90 | 212.11 | 210.03 | 257.11 | 0.046 | 0.018 | 0.026 | 0.006 |
| Fe | 4.57 | 3.43 | 3.25 | 3.74 | 3247.79 | 1853.93 | 1853.93 | 2817.43 | 710.68 | 540.50 | 570.44 | 753.32 | 0.004 | 0.008 | 0.011 | 0.005 |
| Zn | 17.29 | 14.43 | 12.39 | 13.55 | 605.95 | 464.47 | 421.39 | 540.28 | 35.05 | 32.19 | 34.01 | 39.87 | 0.02 | 0.035 | 0.045 | 0.024 |
| Cu | 5.23 | 2.61 | 3.32 | 3.71 | 484.67 | 256.59 | 286.12 | 406.12 | 92.67 | 98.31 | 86.18 | 109.47 | 0.02 | 0.05 | 0.0801 | 0.035 |
| Pb | 8.46 | 8.56 | 8.56 | 8.56 | 21.71 | 13.03 | 13.03 | 17.36 | 2.57 | 1.52 | 1.52 | 2.03 | 0.63 | 1.22 | 1.48 | 0.799 |
| Cr | 2.16 | 2.01 | 2.01 | 2.01 | 269.55 | 171.92 | 144.37 | 248.33 | 124.79 | 85.50 | 71.83 | 123.55 | 0.04 | 0.095 | 0.12 | 0.063 |
| Co | 4.81 | 3.02 | 4.81 | 4.81 | 122.61 | 81.74 | 78.44 | 982.44 | 25.49 | 27.07 | 16.30 | 204.25 | 0.10 | 0.18 | 0.26 | 0.0151 |
| Ni | 2.40 | 2.40 | 7.19 | 7.19 | 170.11 | 98.23 | 110.48 | 150.78 | 70.88 | 40.93 | 15.37 | 20.97 | 0.07 | 0.13 | 0.22 | 0.011 |
| V | 2.08 | 2.08 | 4.16 | 4.16 | 91.41 | 54.02 | 60.91 | 79.94 | 43.95 | 25.97 | 14.64 | 19.22 | 0.14 | 0.22 | 0.39 | 0. 20 |
| Ti | 2.94 | 1.96 | 2.94 | 2.94 | 222.88 | 1419.40 | 1419.40 | 202.76 | 75.81 | 724.18 | 482.79 | 68.97 | 0.05 | 0.01 | 0.014 | 0.075 |
| Sb | 4.97 | 9.94 | 9.94 | 9.94 | 29.83 | 13.03 | 13.03 | 26.34 | 6.00 | 1.31 | 1.31 | 2.65 | 0.4 | 1.22 | 1.48 | 0.06 |
| Cd | 8.93 | 4.59 | 4.59 | 11.22 | 13.76 | 9.18 | 9.18 | 9.18 | 1.54 | 2.00 | 2.00 | 0.82 | 1.19 | 1.73 | 2.11 | 1.51 |

The estimated values of the highest deposition velocities of this study was found to be that of Cd (about $2.1x\ 10^{-4}$ m/s) which is 10 times lower than the reported value by [21], [22] and [23]. Similarly, the lowest value which corresponds to that of Fe (about $0.00336 \times 10^{-4}$ m/s) is 10,000 times lower than those of other studies. However, the highest deposition velocity of trace metals in the study area was found to be almost the same value when compared with the work of [24] who obtained deposition velocity of $1.8 \times 10^{-4}$ m/s. The estimated scavenging ratios for the trace metals in the study area was in the range of 0.82 – 1224.31, while those of urban cities of Japan were evaluated by [25] to be 112-170.

Throughout the seasonal measurements, Fe has the highest scavenging ratio (1124.31) while Cd has the least (0.82). The results in both wet season and dry seasons show that over 40% of the particulate matter scavenged by precipitation originated from Fe while the contribution from Cd is significantly low. The higher scavenging ratio at site 2 when compared with site 1 could be attributed to the higher burning points and other anthropogenic emissions in site 2.

## 4. CONCLUSION

This study has investigated the aerosol hazes around a major sawdust open burning area. There were higher deposition fluxes in the dry season, attributed to higher particle re-suspensions from sawmilling activities in the area. Higher concentrations of heavy metals in wet season in the deposition measurement were as a result of higher emission from domestic cooking and other anthropogenic activities in the area. Higher deposition velocities obtained for Cd, Pb and Sb (about $2.1 \times 10^{-4}$ m/s) when compared with Fe, Mn, Cr and Ti show that the lifetimes of these trace elements in the atmosphere are governed by dry deposition while higher scavenging ratio of Fe, Mn, Cr and Ti (about 61.69 – 1224.31) shows that their lifetimes are governed by wet deposition. Hence, Cd, Pb and Sb are best removed from the atmosphere of the study area by dry deposition (gravitational setlling of particles) while Fe, Mn, Cr and Ti are best removed from the atmosphere by wet deposition (i.e. scavenged by precipitation).

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