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# Atmospheric Deposition of Pb, Zn, Cu, and Cd in Amman, Jordan

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## Abstract

Atmospheric samples were collected by high-volume air sampler and dustfall containers during the summer of 1995 at different sites in Amman city, Jordan. Heavy metal contents in settleable (dustfall) as well as in air particulates (suspended ) were analyzed by graphite furnace atomic absorption spectrophotometry. The atmospheric concentrations of Zn, Cu, Pb, and Cd were 344, 170, 291, and 3.8 ng/m$^3$, respectively. On the other hand, the levels of these elements in dustfall deposition were 505, 94, 74, and 3.1 µg/g, respectively. The fluxes and dry deposition velocities of these heavy metals were determined and compared with the findings of other investigators worldwide. Significant enrichment coefficients of heavy metals in dustfall were observed. The enrichment coefficients were 12.1, 6.1, 11.7, and 1.1 for Zn, Cu, Pb, and Cd, respectively.

**Keywords:** heavy metals, air particulates, dustfall, atmospheric deposition, Jordan.

## Introduction

Anthropogenic impact on natural environment and especially on atmospheric pollution is well known in many parts of the world[1-3]. These pollutants can be in many forms and toxicities and among them, are trace elements, which are known for their toxicity when existed above certain levels. These pollutants are emitted in the atmosphere continuously through various man activities, especially in large cities where inhabitants and industrial activities are concentrated. These aerosol pollutants are also depleted continuously from the atmosphere through two major pathways; dry, and/or wet deposition. The predominant path depends upon the type of chemical species and upon some meteorological factors such as intensity and distribution of rain fall.

The atmospheric particulates are usually of two types; suspended and settleable particles. However, the settling velocity depends upon the size of the particles. Differences can be expected in the physical and chemical properties between both types of particles. Studying such differences could be helpful in producing information about air quality and sources of pollutants. Heavy metal pollution of atmosphere could be estimated from determining the concentration of these heavy metals in the suspended and settleable particles. This is because the heavy metals are associated in many forms with the solid particulate matter.

Lead, is one of the most metals of interest in environmental samples. Many investigators were concentrated on the determination of lead alone in particulate matter[4,5]. Other heavy metals were also extensively studied[6-9].

Atmospheric pollution in Amman was scarcely studied, mostly, in the form of internal reports. In previous investigations, we studied cationic and anionic composition of air particulates in Amman[10,11]. This study aims to investigate heavy metal concentrations in settlealbe and suspended particulate matter as well as their deposition rates in the atmosphere of Amman. In fact, this is the first data published in the open literature on the levels of heavy metals on aerosol in Amman, Jordan.

**Experimental, Sites, and methods**

Setlleable and suspended particulates were collected from the atmosphere at different sites in great Amman (Figure 1), during the summer of 1995 to show the effects of different activities on the level of Pb, Zn, Cu, and Cd on the atmosphere.

Dustfall samples were collected from the same sites as those of suspended matter, at a height of 10 m, by using dry polyethylene cylindrical containers. The dimensions of these containers were 31 cm in height, 15.5 cm in diameter and mounted on 1.5 m high tripods to avoid collection of dust picked up by wind eddies. A bird ring was provided on each holder to avoid material gained by birds. The collectors were exposed to the atmosphere for a sampling period of 30 to 44 days. It is to be noted that measurements represent dry deposition only, as there was no rainfall during the sampling period.

The dry deposits (settleable particulates) was quantitatively transferred from the collectors to quartz crucible using milli-Q water. The content of the crucibles was dried at 105 °C to constant mass, weighed and the quantity of dustfall was computed in $\mu g/m^2$.month . About 0.10 g of the dried samples were accurately weighed and extracted with concentrated ultra pure nitric acid, sonicated for 30 min in a test tube heater for one hour, then left overnight. Blanks were treated in a similar way as the samples.

Suspended particulate matter was collected simultaneously from these sites by drawing air through weighed Whatman membrane filters ( 47 mm in diameter, 0.2 µm pore size). The suspended particles were collected for 12 hr periods using low volume air sampler ( Stuplex Air Division, Brooklyne, NY, USA), at a flow rate of 20 L/min. The sampler was mounted at 10 m above the ground to avoid dust collection from the ground in order to obtain only local airborne particulates. The Pb, Cu, Cd, and Zn were leached from air particulates samples by treating the filter samples with 5 ml concentrated nitric acid, 1 mL HCl (both acids are of ultra purity) and 19 mL Milli-Q water. The samples were left overnight after being treated in ultrasonic cleaner for 30 min, then filtered and the filtrate were evaporated to near dryness and filled up to 25 mL with 1% nitric acid (ultra pure). Blank filters were treated in a similar manner as the samples.

Analytical determination of Pb, Zn, Cu, and Cd in dustfall as well as in suspended particulate samples was carried out by using Graphite Furnace Atomic Absorption Spectrophotometry ( GF-AAS), varian model, GTA 100.

**Results and Discussion**

Heavy Metal Concentrations in Air

The average amount of particulate matter collected on filters was 0.417 $mg/cm^2$ with a range of 0.06 in site 11, which represents a suburban area, to 0.56 $mg/cm^2$ in site 9, which is an urban area of heavy traffic and a large automobile station.

The levels of Zn, Cu, Pb, and Cd in the atmosphere of Amman city are summarized in Table 1. Zinc shows the highest abundance, 21.6 - 1539 $ng/m^3$, while Cd has the lowest, 0.20 - 16.6 $ng/m^3$. Highest values of heavy metals were found in densely populated parts of the city with high traffic density, such as sites 7, 9, 12, and 14. The large variability in the concentration range and standard deviation is expected, since the samples were collected from different sampling sites that have different activities and different pollution sources.

The correlation coefficient ( r ) was calculated between the element concentrations in order to predict the possibility of a common source. The r values were low, except that between Pb and Cd ( $r = 0.76$ ), which could indicate a common source contributing to these metals; possibly automobile emissions.

Table 2 represents a comparison of the heavy metal concentrations in the atmosphere of Amman city with other places worldwide. The table illustrates that our results are generally greater than those of Cairo[3], Black sea[12], New-Zealand[14], Trombay[22], for lead and comparable to those found in Santiago[13] for zinc. However, our findings are much less than those of Riyadh[2] and Cartagena[23] for Cu and Pb and comparable to those of Bombay[8] for Cd, Cu, and Pb.

Dry Deposition

The average amount of settleable particulates deposited at the seventeen sampling sites was 163.6 $mg/m^2$.day, with a range of 80.4 in site 6 to 212.4 $mg/m^2$.day in site 7. The mean value, in this work, is less than that found in other places such as in Jamaica[6], 198.6 $mg/m^2$.day, and that in Cairo[3], 475 $mg/m^2$.day. These figures may indicate that Amman is less polluted than Jamaica and also significantly, less polluted than the crowded Cairo by settleable particulate matter.

The dry deposition was sampled and analyzed for zinc, copper, lead, and cadmium. The results are shown in Table 3. A large variation in the concentrations of these metals was observed. The table shows that zinc has the highest and cadmium has the lowest levels. This phenomena is similar to that found in the suspended particulates shown in Table 1. Comparison of the average concentrations of heavy metals in suspended and settleable particles, expressed in terms of µg/g, shows higher values in suspended particles; about 2, 8, 7.5, and 4.8 times higher for Zn, Cu, Pb, and Cd, respectively. This indicates that small portion of these heavy metals are removed from the atmosphere by gravitational settling, which may be due to small particle size of the suspended dust, that makes them suspended for long periods in air.

The enrichment coefficients of heavy metals were estimated and summarized in Table 4. The enrichment coefficient was computed as the ratio of the heavy metal concentration in the settleable particulates (dustfall) to the concentration in the soil collected and analyzed at the same time[6]. The values in the table indicate high enrichment of dustfall in Zn, Pb, and Cu. The high values of enrichment coefficients suggest the anthropogenic origin of these elements such as emission of motor vehicles. On the other hand, the enrichment coefficient for Cd was close to unity, which suggests that the origin of cadmium is mostly the local soil.

The dry deposition rates (fluxes) of heavy metals are represented in Table 5. Zinc has also the highest rate, while Cd has the lowest rate of deposition. This is consistent with what was concluded previously from Table 3. Zinc has the highest deposition rate as well as the lowest distribution ratio in suspended to settleable particles.

Evaluation of correlation relationships between fluxes of heavy metals revealed that some correlations exist, such as those between Cu and Zn ( $r = 0.66$), Cu and Cd ( $r = 0.65$), Zn and Cd ( $r = 0.48$ ). These values may indicate the possibility of a common source that contributing to these heavy metals.

A comparison between our results and with other data worldwide, Table 6, indicates that Zn and Cu levels are higher than those in Jamaica[6], and North sea[15], West Mediterranean[16], but they are less than that in Bombay[8]. The cadmium level is also higher than those other places, except that in Jamaica[5] and North Sea[15]. However, lead levels are comparable to other values worldwide.

Dividing the dry deposition fluxes by the atmospheric concentrations of metals gives the dry deposition velocities of these metals. Table 7 summarizes the mean dry deposition velocities of Zn, Cu, Pb, and Cd in Amman's atmosphere. Large variation in deposition velocities have been noticed. Zinc shows the highest deposition velocity while Pb has the lowest. Table 8 shows some values of deposition speeds found by other investigators. Generally our results show lower deposition speed than most of those found in the table. This can be due to local sources and meteorological factors. The low deposition speeds indicate that these elements may present in small particles , which will have low deposition velocities.

**Conclusions**

Based on our study of toxic heavy metals in Amman's atmosphere, the following conclusions could be drawn:

Zinc is the major heavy metals pollutant in settleable as well as in suspended particles. However, Cadmium is the minor in both types of particles.

The concentrations (μg/g) of Zn, Cu, Pb, and Cd are higher in suspended than in settleable particulate matter. This may indicate that these heavy metals are found as fine particles. The dry deposition velocities of the studied elements were generally found to be less than those found worldwide. The enrichment coefficients of heavy metals in dustfall were found to be greater than unity, which suggests anthropogenic sources.

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**Table 1.** Atmospheric concentrations of Zn , Cu, Pb, and Cd ($ng/m^3$) in Amman city (n = 51, 3 samples were taken from each site).

| Element | Mean ± SD | Min | Max |
|---|---|---|---|
| Zn | 344 ± 582 | 21.6 | 1539.0 |
| Cu | 170 ± 224 | 6.4 | 1139.0 |
| Pb | 291 ± 223 | 2.2 | 1091.2 |
| Cd | 3.8 ± 3.6 | 0.2 | 16.6 |

**Table 2.** Average atmospheric levels of Zn, Cu, Pb, and Cd ($ng/m^3$) compared with other results reported in the literature.

| Location | Zn | Cu | Pb | Cd | Reference |
|---|---|---|---|---|---|
| Bombay / India | 600 | 116 | 300 | 5 | 8 |
| Riyadh / Saudi Arabia | 207 | 1257 | 1850 | - | 2 |
| Black Sea | - | - | 51 | - | 12 |
| Santiago / Chile | 310 | 220 | - | - | 13 |
| Cairo / Egypt | 428 | 904 | 47.6 | - | 3 |
| New-Zealand | 34.9 | 10.4 | 112.6 | 0.41 | 14 |
| Amman | 344 | 170 | 291 | 3.8 | This study |

**Table 3.** Heavy metal concentrations (μg /g) in dustfall in Amman (n = 51, 3 samples were taken from each site).

| Element | Mean ± SD | Min | Max |
|---|---|---|---|
| **Zn** | 505 ± 476 | 65.1 | 1754.8 |
| **Cu** | 94 ± 202 | 7.1 | 882.2 |
| **Pb** | 74 ± 49 | 17.9 | 182.9 |
| **Cd** | 3.1 ± 3.3 | 0.3 | 12.0 |

**Table 4.** Enrichment factor of heavy metals deposited at the 17 sampling sites of Amman.

| Element | Enrichment factor | |
|---|---|---|
| | Average | Range |
| **Zn** | 12.14 | 1.78 - 35.88 |
| **Cu** | 6.06 | 0.59 - 54.46 |
| **Pb** | 11.74 | 3.14 - 25.76 |
| **Cd** | 1.11 | 0.45 - 3.75 |

**Table 5.** Fluxes of Zn, Cu, Pb and Cd (μg $m^{-2}$ $mon^{-1}$) in dry deposition at Amman city.

| Element | Mean ± SD | Min | Max |
|---|---|---|---|
| **Zn** | 2474.4 ± 2596 | 385.0 | 9262.8 |
| **Cu** | 462.8 ± 1057 | 20.1 | 4656.8 |
| **Pb** | 349.8 ± 245 | 64.9 | 990.1 |
| **Cd** | 12.5 ± 12.7 | 1.2 | 45.7 |

**Table 6.** Fluxes of heavy metals (μg $m^{-2}$ $mon^{-1}$) compared with other results reported in the literature.

| Location | Zn | Cu | Pb | Cd | Reference |
|---|---|---|---|---|---|
| **Bombay /India** | 3097.0 | 785.8 | 269.9 | 3.28 | 8 |
| **North sea** | 920.5 | 167.7 | 453.7 | 19.4 | 15 |
| **Jamaica** | 1525.5 | 332.1 | 450.4 | 184.8 | 6 |
| **W. Mediterranean** | 361.6 | 31.6 | 345.2 | 4.3 | 16 |
| **Amman** | 2474.4 | 462.8 | 349.8 | 12.5 | **This study** |

**Table 7**. Deposition velocities of Zn, Cu, Pb, and Cd ( cm $s^{-1}$) in Amman.

| Element | Mean | Min | Max |
|---|---|---|---|
| **Zn** | 0.274 | 0.023 | 0.564 |
| **Cu** | 0.104 | 0.030 | 0.401 |
| **Pb** | 0.046 | 0.010 | 0.110 |
| **Cd** | 0.125 | 0.023 | 0.431 |

**Table 8**. Deposition velocities (cm $s^{-1}$) of heavy metals compared with some results reported in the literature.

| Zn | Cu | Pb | Cd | Reference |
|---|---|---|---|---|
| 0.50 | - | < 0.50 | - | 17 |
| - | - | 0.30 | - | 18 |
| 0.40 | 0.29 | - | 0.20 | 19 |
| 0.50 | 0.81 | 0.28 | 0.10 | 8 |
| - | - | 0.25 - 1.80 | - | 4 |
| 0.35 | 0.48 | 0.25 | 0.39 | 15 |
| - | - | 0.04 | 0.05 | 20 |
| 0.22 | 0.22 | 0.22 | 0.22 | 21 |
| 0.27 | 0.10 | 0.05 | 0.12 | This work |

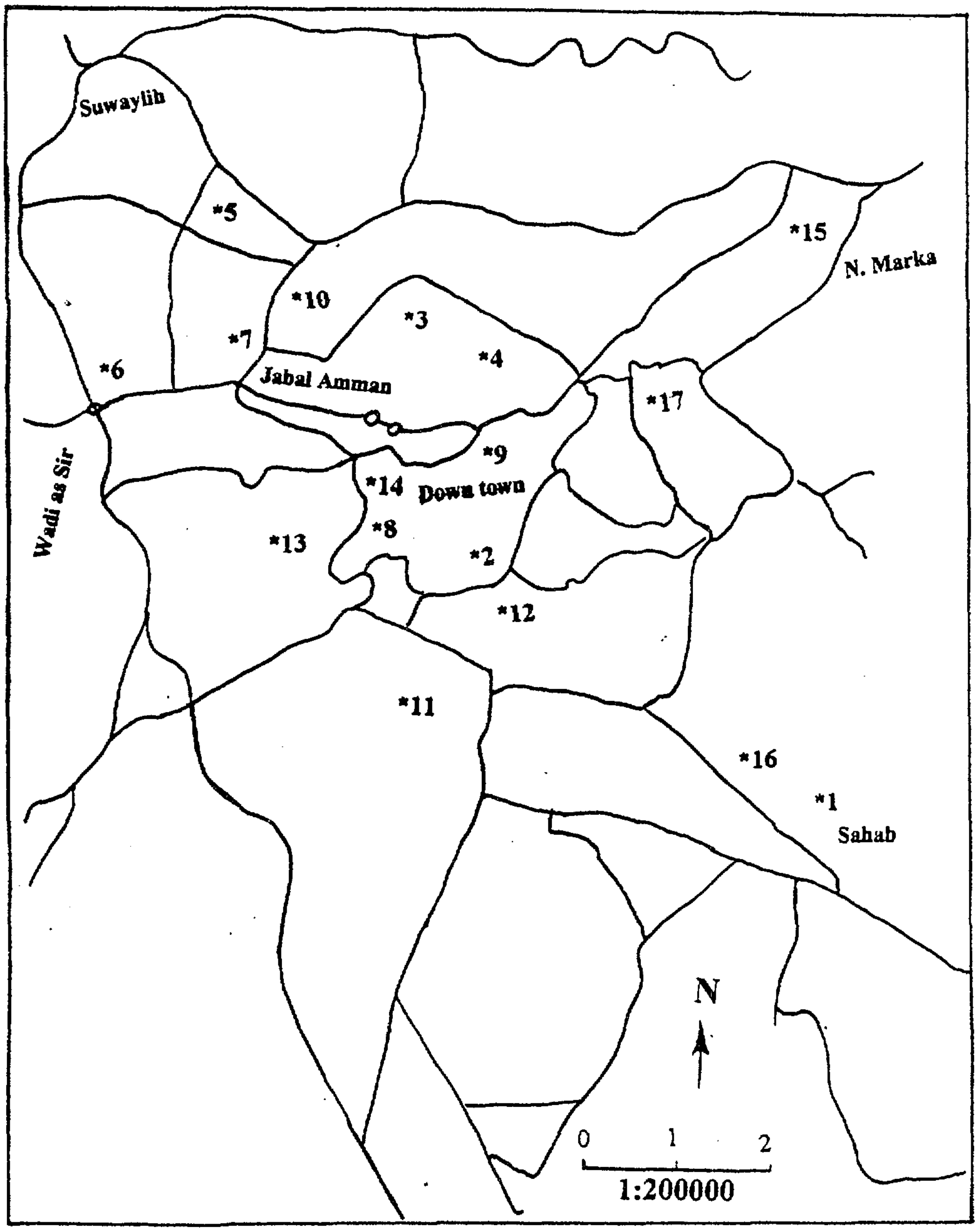


Figure 1. Location map of the sampling sites ( * )