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Full Length Research Paper

Elemental analysis of atmospheric aerosols in Gaborone

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Aerosols are mixture of solid and liquid particles and have considerable variation in terms of their chemical composition and size. In this study the elemental composition of aerosol particles in the atmosphere of a city, Gaborone, was carried out. The elemental analysis was done by environmental scanning electron microscope (ESEM). The results clearly show that the composition of the particles observed was very complex. It also showed the presence of elements Al, Si, Fe, K, Ca, Mg, Zn, Na, Cu, Pb, Ti, Ni, Pt, Au and Cr. The most frequently occurred element was silicon and the least frequently occurred element was platinum. Our measurements also revealed that the elements which had an amount more than 90% were copper, lead, nickel and gold.

Key words: Atmospheric particles, elements, minerals.

INTRODUCTION

Botswana, as shown in the map in Figure 1, is a land-locked country in southern Africa surrounded by Namibia to the west, South Africa to the east and south and Zambia and Zimbabwe to the north. The Country lies between longitudes 20 and 30 degrees east of Greenwich and between the latitudes 18 and 27 degrees approximately south of the equator. It is approximately 500 km from the nearest coast line; to the south west (Geographical info, 1996). It is one of the largest pro-ducers of diamond (George, 2000) and rich in minerals. The minerals cobalt, copper and nickel are found in Selebi-Phikwe area, gold and nickel in Francis town and soda ash in Sowa. Gaborone is the capital of Botswana with an estimated population of 208,411 (Gaborone, 2001). It is the fastest growing city in Africa (Branco et al.,

2001).The composition of particulate matter in the atmosphere of North American cities and rural areas was identified and was listed (Legge and Krupa., 1986). The presence of trace metal, its concentrations and sources in the Levantine basin of the eastern Mediterranean was also carried out during 1999 - 2000 (Koaak et al., 2004). The understanding of the composition of atmospheric particles also helps to know cloud condensation, cloud albedo and component deposition (Charlson et al., 1987; Lukkac, 1994; Facchini et al., 1999). It also helps to identify the impact of aerosols on human health (Chanft and Lippmann, 1980; Berico et al., 1997) and in visibility (Horvath et al., 1997; Tsai et al., 2003).

The number, surface and volume size distributions of aerosol particles could provide information of their sources. According to Whitby et al. (1975) the number size distributions are characterized by three modes. The fine size mode is less than 0.1 µm and is due to gas to particle conversion of combustion vapours from vehicle exhausts and industry. The accumulation mode is in between 0.1 and 2 µm and is due to heterogeneous nucleation. The third one, the coarse particle mode occurs at sizes larger than 2µm and caused by large nuclei. A study by Morawaska et al. (1999) on the number, surface and volume size distributions of aerosols due to vehicular exhausts, vegetation burning and marine sources concluded that the tri-modal number size distributions did not always translate into three modes in volume size distributions. In most cases the volume size distributions were bimodal and the three modes occurred within size ranges, characteristic of the source of the aerosols.

The number size distribution is generally linear when described by an expression of the form

$$\text{Log } [dN/d (\log D)] = \text{const.} - v \log D$$

Or

$$dN/d (\log D) = CD^{-v},$$

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Figure 1. Map of Botswana showing the experimental site.

Where C is a constant related to the number concentration and v is the slope of the number size distribution curve (Wallace and Hobbs, 1977). The value of v lies between 2 and 4. For continental aerosols larger than 0.2 µm this value is close to 3.

The present study was to measure the particle content in the atmosphere of Gaborone, Botswana to identify the types of elements and their concentration. The facilities for their measurement exist in the Department of Physics in University of Botswana.

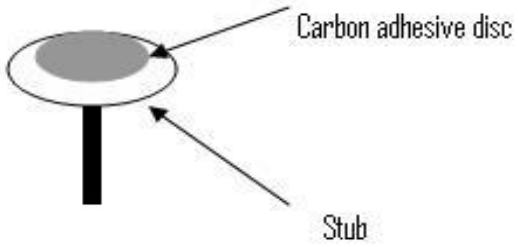

Figure 2. Environmental scanning electron microscope stub.

Methodology

Atmospheric samples were collected on small aluminium stubs which had high purity carbon discs about 12 mm in diameter attached to the top. Figure 2 below shows a stub used in this study.

The exposed side of the carbon disc was smoothed with adhesive to capture environmental particles to be later analyzed using an environmental scanning electron microscope (ESEM).

Each stub was placed in a beaker so that the wind effects could be minimized and only free falling particles could be captured. The beaker was placed at a height of about 2 m from the ground and about 5 m away from a busy road passing by the side of University of Botswana. From the preliminary study, it was decided to expose a stub three times a week with an exposure time of four hours. The exposed stubs were collected and kept safely in a box in the laboratory. The stubs were then carbon coated by resistive heating of shaped carbon rods to provide electrical conductivity. The carbon was heated in a vacuum to a temperature of approximately 2137°C until a vapour pressure of 1 x 10^{-4} mbar is achieved. In this condition, carbon would sublime and vapourisation would take place. As the atoms of evaporated carbon come into contact with the stub, they migrate along its surface, forming clusters and cause a continuous film to be produced.

The stubs were analyzed using environmental scanning electron microscope (ESEM) to detect the elements present and its concentration in the particles collected on each stub. The calibration of ESEM was done thrice a year using MRS-3 techniques with ISO-9000 standards (Magnification Calibration MRS-3.1996). Each particle in each stub was observed through ESEM and the weight percentage of each element in each particle was measured. The photographs of these particles were also taken using ESEM. Data were collected from the ESEM and the average weight percent of elements observed in each stub was calculated.

The particle counts during the experimental period was also done using HHPC-6 a portable particle counter. This instrument measures particles larger than 0.3 µm and separates them into five size ranges. The particle number, surface and volume size distributions were studied under the various conditions in order to identify similarities and characteristic differences in their shapes and modes.

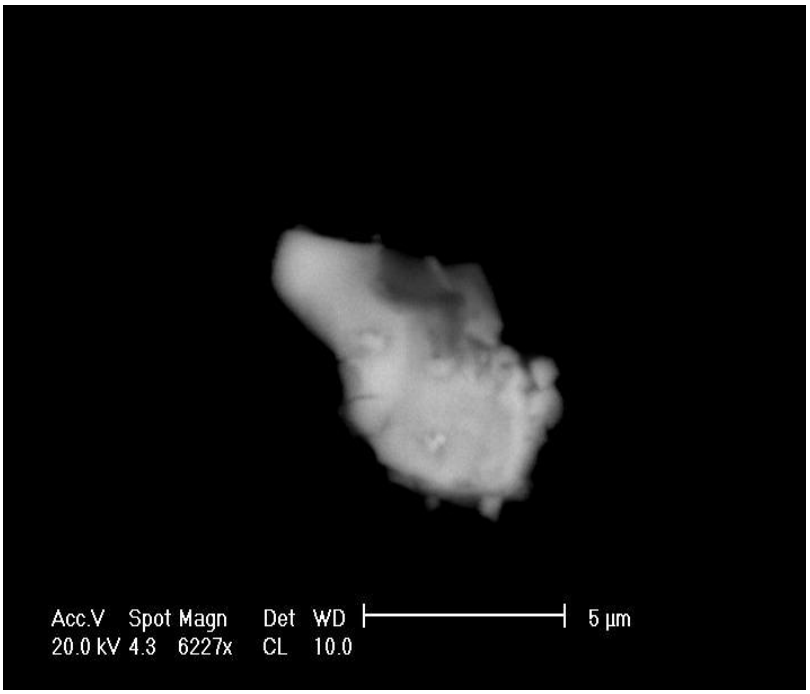

Figure 3. Stub 28, 28 May, 2006.

RESULTS AND DISCUSSION

Figure 3 shows the micro photograph of a particle in stub No. 28 taken by ESEM which was exposed on 28 May, 2006. The size of particle was about 5 µm in diameter and was one of the largest observed particles. The major elements present in this particle were lead and chromium.

Similarly, the elements present in other particles in different stubs were also analyzed. The number of occurrences of each element during the experimental period was found and a graph of number of occurrences of each element was plotted. As can be seen from Figure 4, the elements detected in the atmospheric particles of Gaborone were Al, Si, Fe, K, Ca, Mg, Zn, Na, Cu, Pb, Ti, Ni, Pt, Au and Cr. The elements that occurred more frequently were silicon, aluminium, iron, copper and lead. The most frequently occurred was silicon with a percentage of occurrence of 92 and the least frequently occurred was platinum with a percentage of occurrence of 4.

The maximum amount of each element in each stub was also found. Figure 5 shows a graph of maximum amount of each element in each stub. What could be observed from Figure 5 was that the elements which had an amount more than 90% were nickel, copper, lead, and gold. This is due to the fact that Botswana is rich in minerals such as nickel, gold, and copper. As stated earlier, copper and nickel are mined in Selebi-Phikwe and gold and nickel are in Francistown. Lead could be from the vehicle exhaust emissions or may be from other sources. Although, Government of Botswana has stopped the sale of leaded petrol via an ordinance dated 9th March, 2005 and implemented on 1st April, 2006, presence of lead may therefore be due to other reasons such as car batteries and toys coated with lead paints.

The size of particles and its concentration for each stub was calculated and a graph of total number concentration of particles larger than 0.3 µm for each stub was plotted and is shown in Figure 6. It shows that the concentration of particles in the atmosphere which was varying and the maximum number of particles ≥ 0.3 µm was observed on stub No. 8 which was exposed on 27th March, 2006 and the minimum was observed on stub No. 25 which was exposed on 21st May, 2006. The higher concentration of particles on stub No. 8 may be due to biomass burning related to low temperature occurred during night of that day, as the temperature recorded at 12 noon on that day is relatively low compared to other days. It should also be noted that there was high humidity of 70% and a busy morning heavy traffic on that day. The low count on stub No. 25 may be due to low humidity of 33% and wind effects.

The lead and zinc are present in the atmosphere in significant value of concentration. They may be originated from anthropogenic sources. The check on the sale of leaded petrol is existing, but the possibility of sporadic sale cannot be ruled out. The sources of lead and zinc may be car batteries, paints etc. The presence of potassium in significant amount is due to biomass burning. In suburb of Gaborone, there are localities where biomass is largely domestically used by inhabitants for cooking

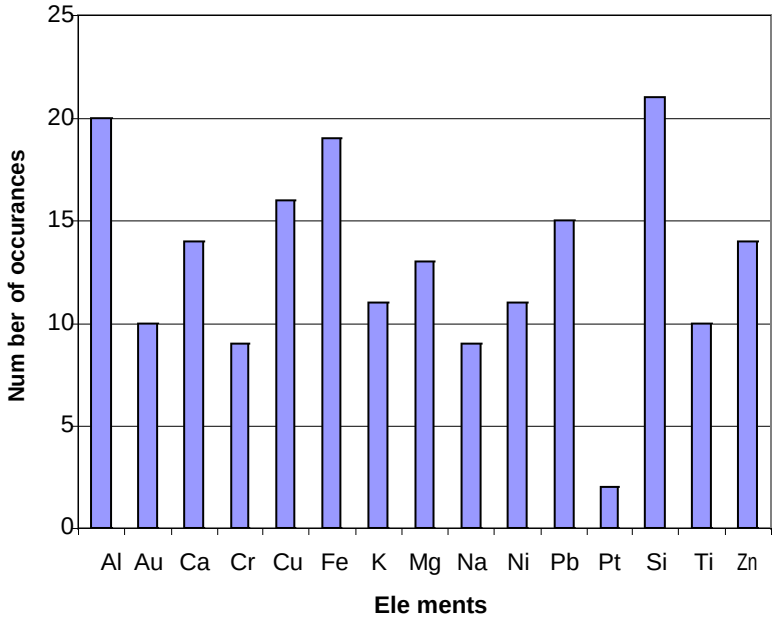

Figure 4. The graph showing the number of occurrences of elements.

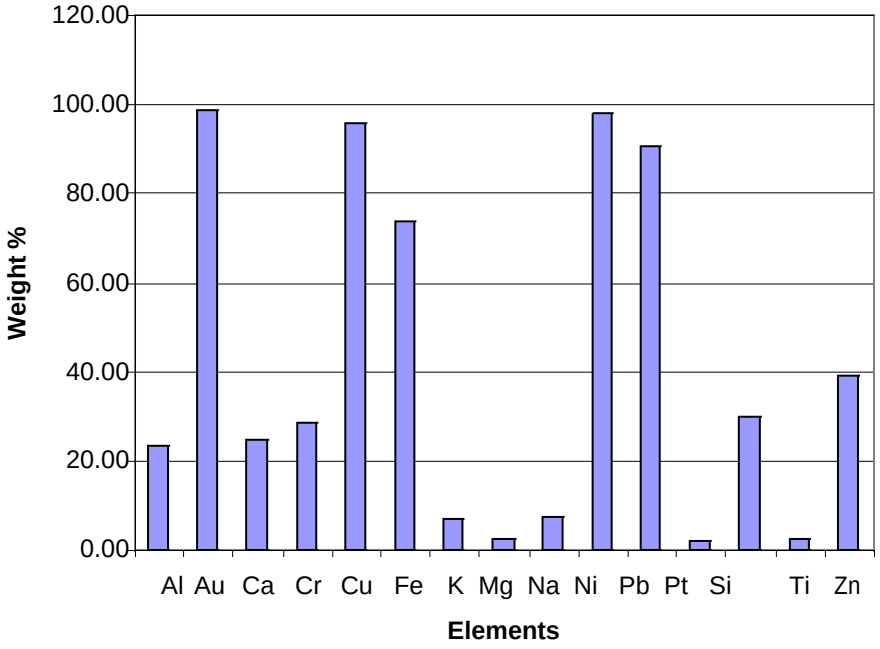

Figure 5. Thegraph showing the maximum amount of each element in the particles.

and room heating. Our previous studies (Jayaratne and Verma, 2001; Verma and Thomas, 2007) vividly indicate an enhancement of Thomas, 2007) vividly indicate an enhancement of particulate concentration in the winter season.

Figure 7 shows the graph of total number of particles of different sizes measured using HHPC-6 on 27th March, 2006. It shows that particle concentration is greatest around 0.3 µm and the lowest around 5 µm.

Figure 8a - c show the number, surface and volume size distributions for the highest concentration obtained on 27th March, 2006. The value for ‘v’ on that day was seen to be 2.88 ‘v’ is a measure of degree of pollution, and is determined from the slope of number distribution

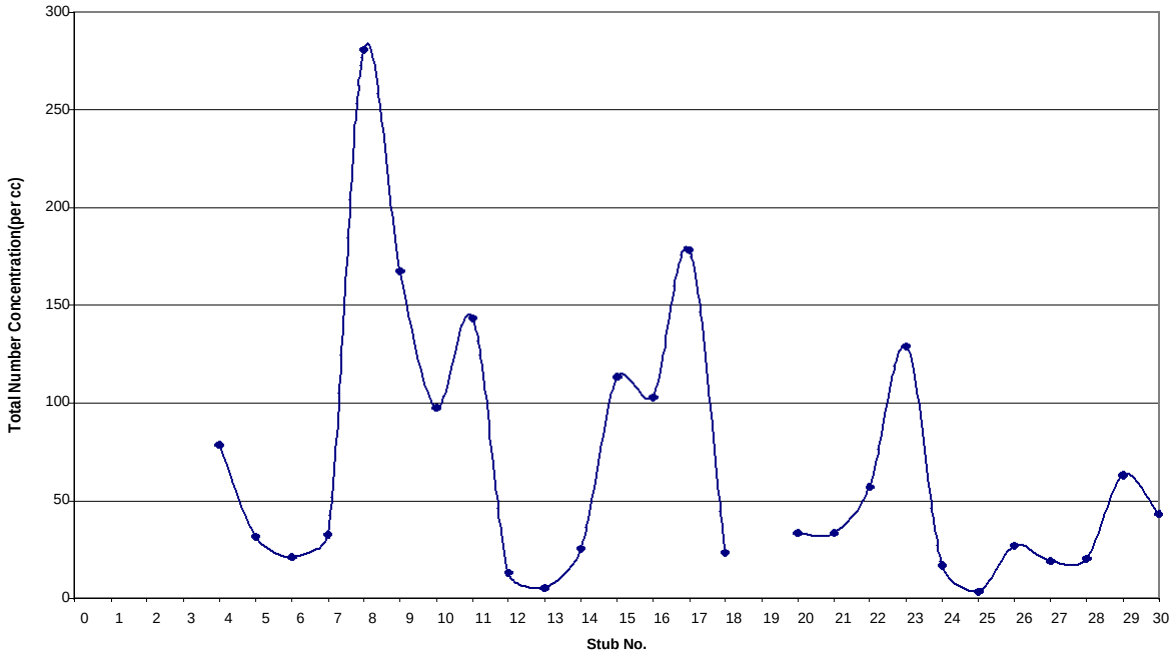

Figure 6. Variation of total number concentration of aerosols larger than 0.3µm in each stub observed.

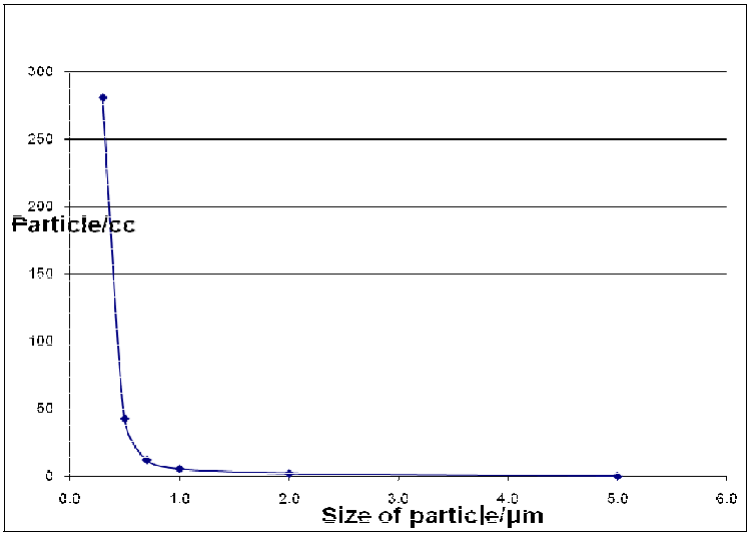

Figure 7. Particle concentration on 27 March, 2006.

curve; (drawn between log dN/dlogD versus logD). The value of 'v' generally lies between 2 and 4, (Wallace and Hobbs., 1977). Figure 8c shows that the volume size distribution is clearly bimodal.

Conclusion

The current study has produced the following findings The elements detected in the atmospheric particles of Gaborone were Al, Si, Fe, K, Ca, Mg, Zn, Na, Cu, Pb, Ti, Ni, Pt, Au and Cr. The frequently occurred elements were silicon, aluminium, iron, copper and lead. The most frequently occurred element was silicon and least frequently occurred element was platinum. The major percentage of elements present in the atmosphere of Gaborone was nickel, copper, lead and gold.

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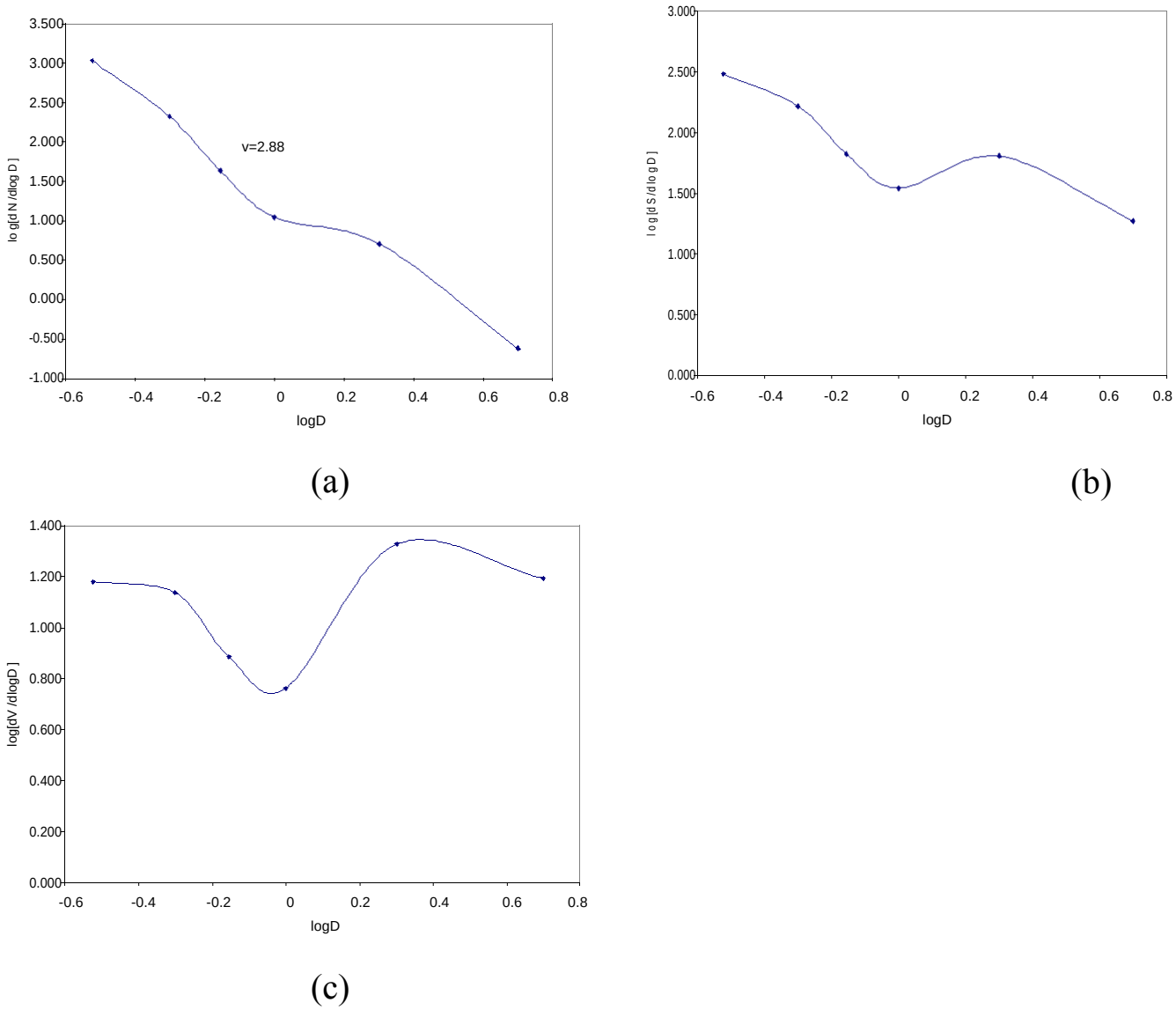

Figure 8. (a) A typical number size distribution spectrum of aerosol particles larger than 0.3 µm found in Gaborone on 27th March 2006. (b) and (c) show the corresponding surface and volume size distributions.

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