# Chemical Characterization Of Aerosols Collected In Ariab Mining Area, Eastern Sudan

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## Abstract

The goal of this study was to determine the concentrations of elements (S, Cl, K, Fe, Ba, Ti, Cr, Cu, Pb, and Se) in aerosol collected at different sites in Araib mining area. An air sampler was constructed for sample collection. The samples were taken onto nucleopore membrane filter. The sampling time was two hours for each. Particle Induced X-ray Emission (PIXE) was used for the determination of the investigated elements. Quality control of data analysis was assessed using certified Micro-Matter® thin film standards. The average concentrations of S, Cl, K. Fe, and Ba in (%) found to be 0.27, 0.02, 0.03, 1.53, and 0.09 in location one, respectively; while the concentration of these elements in (%) found to be 0.09, 0..06, 0.08, 1.8 and 0.24 in location two, respectively. The average concentration of Ti, Cr, Cu, and Pb in (ppm) found to be 260.86, 27.38, 431.22, and 281.96 in location one, respectively; while the concentration of these elements in (ppm) found to be 435.4, 29.14, 99.36, and 315.56, respectively. The concentrations of elements (Cl, K, Fe, and Ba) were found higher in loc2 than their values recorded in loc1, however, the concentrations of Ti, Cr, and Pb were found lower in loc1 than the concentrations found at various sites in loc2.

The correlation between the various elements was determined. Also, clusters analysis was performed. The enrichment factor (EF) of elements was calculated using Fe as a reference element. Comparisons between this study and data from literature were done.

**Keywords:** Elements, aerosols samples, Ariab mining, PIXE

## Introduction

The mining activities disturb the natural settings mainly induced by machinery used in mining, transportation, blasting, soil and water erosions, etc. Air pollution is another causality of mining activities, blasting of land produces a lot of dust which invariably mixes with air and this reduces and disturbs the oxygen portion and the air carries many toxic matters which prisoners. The quality of ambient air depends upon the concentrations of specific contaminants, the emission sources, and meteorological conditions. Therefore, the study of the elemental composition of aerosol particulates in Araib is very important to assess the quality of the atmosphere. The pollutants such as trace elements and aerosols in the air are liable to affect adversely the atmosphere and ultimately cause health hazards [1].

The aerosols in the atmosphere are often divided into two groups: the anthropogenic aerosol and the natural aerosol. The major natural aerosols components are sea salt, soil dust, natural sulfates, volcanic aerosols, and those generated by natural forest fires [2]. Anthropogenic aerosols are formed because of human activity, and they are in the largest amount in the big cities. The major potential environmental impacts include soil contamination from treatment residues, spillage of chemicals, leaching of pollutants from

tailings and disposal areas and contaminated soils, air emissions from minerals processing operations, and dust emissions from sites close to living areas or habitats. While occupational health impacts include handling of chemicals, residues, and products, dust inhalation, fugitive emissions within the plant, air emissions in confined spaces from transport, exposure to asbestos, cyanide, mercury, or other toxic materials used on-site [3]. Atmospheric aerosols play many important roles in the environment. Consisting of microscopic particles suspended in the air, aerosols scatter and absorb sunlight, thereby exerting direct effects on climate and reducing visibility. Accumulation mode aerosols, which dominate impacts on visibility, also affect cloud formation, lifetime, and optical properties, resulting in indirect climate effects. Also, aerosols provide surface sites for heterogeneous chemical reactions and negatively impact human health [4].

However, the particulate pollutants also play a significant role in the environment as these represent the major transport form of material. The knowledge of the chemical composition of particulate matter helps to estimate the impact of various pollution sources on the ambient air quality. High concentrations and enrichments of Pb, Fe, Zn, Cu, Sb, As, and Se as well as other elements are generally found near the thickly populated areas and industrial centers. From these studies, it is quite evident that anthropogenic emissions are the dominant sources of the enriched elements. Long-term exposure to toxic trace metals such as As, Cd, Cr, Cu, Ni, Zn, Pb, and Hg even at low concentrations can be deleterious to human health as well as the ecosystem. These can lead to cardiovascular diseases and respiratory disorders [5].

Nuclear analytical techniques, such as Particle Induced X-ray Emission (PIXE) technique has shown itself well suited to precisely this type of broad range analysis, covering almost the entire spectrum of elements whilst requiring only micrograms of total samples. Studies of airborne contamination using PIXE and related techniques have been undertaken by several laboratories around the world and they demonstrate its value in environmental sciences [6].

In the present study, an attempt has been made to determine the concentration of elements (S, Cl, K, Fe, Ba, Ti, Cr, Cu, Pb, and Se), to identify the major sources of pollution, draw some correlations among the investigated elements, and compare the obtained data with the global similar studies.

## Materials and methods

## Sampling area

The sampling area was located in Ariab mining area, eastern Sudan. The sampling sites are subdivided into two locations. Location one which includes the mines, while location two places where the surrounding mines.

## Samples collection and samples preparation

An air sampler was constructed for sample collection. Air samples were collected at approximately 1.5 meters from the ground level. Sampling on filters is the most practical method currently available to characterize the particle sizes and chemical composition of airborne particulates [7]. Nuclepore membrane filters with a diameter of 47 µm and a pore size of 0.45 µm were used. 27 samples were collected for different locations. The time sampling was two hours for each sample. The filters were stored under sterile Petri dishes. Following an integrated procedure of identification of the particulate matter and determination of its concentrations using PIXE technique, each filter was cut into four quarters with ceramic scissors in a cleanroom. One quarter was used for PIXE analysis.

Table 1 shows sampling sites, volume, and sampling duration, and the number of samples.

Table 1 Sampling sites, volume, and sampling duration, and number of samples

| Locations | The volume of air sampled (l) | Sampling duration (h) | Number of samples |
|---|---|---|---|
| Loc1(mines) | 14392 | 26 | 13 |
| Loc2 (area surrounding) | 14720 | 28 | 14 |

## PIEX measurement

The elemental analysis of air samples was carried out using Particle-Induced X-ray Emission (PIXE) technique. PIXE provides a rapid and non-destructive method. For PIXE measurement, 3 Mev protons of ~3mm diameter delivered by the NEC 5SDH 1.7 MV Pelletron tandem accelerator of the Lebanese Atomic Energy Commission were used. The characteristic X-rays emitted from the sample were detected using Si(Li) detector with Full Width at Half Maximum intensity (FWHM) equal 170 eV at 5.9 keV positioned at 135° referring to the beam direction. The software QUPIX was used for specific treatment and elemental quantification [8].

To test the accuracy of PIXE setup, the certified Micro-Matter® thin film standards were used as a quality control sample throughout the measurement period to demonstrate the consistency of the analytical procedure. The mass fractions of elements in the standard reference material were determined and the certified values were compared with the measured values. The measured concentration values were found to be in good agreement with the certified values Table (2). The calculated minimum detection limits (MDL) of the elements were given in ng/m$^2$ Table (3).

Table 2 The accuracy of PIXE measurement by using Micro-Matter® thin film standards

| Micro matter® Standards | | Certified values ($\mu$g/cm$^2$) | Measured values ($\mu$g/cm$^2$) | Relative error % |
|---|---|---|---|---|
| ZnTe | Zn | $18.7 \pm 5\%$ | $19.17 \pm 0.6\%$ | -2.5 |
| | Te | $36.5 \pm 5\%$ | $37.5 \pm 0.8\%$ | -2.7 |
| CaF2 | Ca | $24.4\pm 5\%$ | $23.4\pm 2\%$ | 4.6 |
| SiO$_2$ | Si | $24.9 \pm 5\%$ | $23 \pm 2\%$ | 7.9 |
| Ni | Ni | $52.2\pm 5\%$ | $53.13\pm 2\%$ | -1.7 |
| Cu | Cu | $48\pm 5\%$ | $50.13\pm 2\%$ | -5.5 |

Table 3 Detection limits obtained for the elements in ng/m$^2$

| Elements | Detection limits |
|---|---|
| S | 46.1 |
| Cl | 28.1 |
| K | 18 |
| Ca | 15.9 |

| Ti | 13.4 |
|----|------|
| Cr | 9.23 |
| Fe | 3.3 |
| Zn | 2.27 |
| Pb | 13.5 |
| Ba | 64.5 |

## Results and Disscucion

The summary of the statistical data for aerosol samples concentrations are shown in Table (2) & (3) and average elemental concentration are plotted in Figure (1) & (2).

In location one, the concentration of S was found to vary from 0.016 to 1.98 % with a mean of 0.27%. Chloride concentration ranges from 0.007 to 0.027 % with an average value of 0.02 %. Potassium, concentration was found to vary from 0.01 to 0.12 % with a mean value of 0.03 %. The concentration of iron ranges from 0.28 to 3.54 % with an average value of 1.53 %. Barium concentration was found to vary from 0.01 to 0.298 % with a mean value of 0.09%. On the other hand, S concentration in location two ranges from 0.013 to 0.29 % with an average of 0.09 %. The concentration of Cl was found to vary from 0.014 to 0.55 % with a mean value of 0.06 %. K concentration was found to vary from 0.008 to 0.58 % with a mean value of 0.08 %. The concentrations of Fe ranges from 0.12 to 9.58 % with an average value of 1.8 %. Barium concentration ranges from 0.006 to 1.15 % with an average value of 0.24 %.

In location two, the concentration of Ti was found to vary from 76.16 to 1364.7 ppm with a mean value of 543.4 ppm. Cr concentration was found to vary from 9.23 to 96.54 ppm with a mean value of 29.14 ppm. The concentration of Cu was found to vary from 4.19 ppm to 231.5 ppm with a mean value of 99.36 ppm. Pb concentration ranges from 23.64 ppm to 1586.8 ppm with an average value of 315.56 ppm. On other hand, in location one the titanium concentration was found to vary from 59.3 ppm to 557.3 ppm with a mean value of 260.83 ppm. The concentration of Cr ranges from 0.01 ppm to 57.63 ppm with an average value of 27.38 ppm. Cupper concentration was found to vary from 9.69 ppm to 4248.3 ppm with a mean value of 431.22 ppm. The concentration of lead was found to vary from 12.7 to 1145.7 ppm with a mean of 281.96 ppm. The concentration of Se was detected only in three samples L16 (37.3 ppm), L19 (232.8 ppm), and L26 (577.2 ppm), respectively.

The comparison of mean elemental concentrations obtained in different locations showed that the mean elemental concentrations of Cl, K, Fe, and Ba were slightly very high in location two compared to values were found in location one except for S which was found higher in location one. On the other hand, the mean concentration of Ti and Pb were found higher in location two compared to their concentration in location one, while the mean concentration of copper was found to be higher in location one compared to its values found in location two. The mean concentration of Cr was found to be close in both locations, while the concentration of Se was found only in three samples L16, L19 and L26. The concentration of elements in different samples varies due to differences in the geology of the sites, also due to the different mining activities in each area under study.

## Correlation

The correlation matrix for the various elements from different locations is shown in Table (5). Significant positive correlations (r > 0.8) were observed between S-Cu, S-Pb, K-Ti, and Cu-Pb in location one, while, slightly positive correlations (r ≥ 0.8) were observed between S-Fe, S-Pb, Cl-K, and Fe-Pb in location two. A positive correlation between S-Cu, S-Pb, and S-Fe Suggest copper, lead, and iron, where Cu, Pb, and Fe are always present as sulphide deposits at the mining site.

## Cluster analysis

The results of cluster analysis of elements in air samples were obtained as dendograms displaying two main clusters. In the dendogram the first group containing Cl. Ti, K, Cr, Pb, Cu, Ba, and S were generally as elements in the soil like Cl, Ti, K, and Cr, while these elements were enriched in the air such as Pb, Cu, Ba, and S may due to the mining. The second group containing only Fe represents the element which highly enriched in an aerosol.

## Enrichment factor

Table 8 shows the concentration of the elements compared to crustal abundances from S. R. Tylor [9]. The enrichment factor (EF) is the enrichment of the element in the air compared to that in Earth's crust, using Fe as a reference element. An enrichment of unity indicates a soil-derived element, whereas elements derived from high-temperature combustion processes will be more volatile and have enrichment factors significantly above one. EF calculation showed that Cu, Cl, S, and Ba are significantly enriched, while the element Pb is extremely high enriched. Pb exhibited a high EF value due to its anthropogenic sources of emissions from the drilling and crushing machines, and diesel trucks used for transporting ores.

## Comparison between this study and data from the literature

Table 9 shows the comparison of elemental concentration between this study and data from the literature. The average concentrations of S and Cr were higher in this study than the values in Nigeria and Brazil. Cl concentrations in Brazil and Italy are less than the concentration in Nigeria and this study. The concentration of K in Italy. Nigeria and this study are higher compared to Brazil and China. The average concentrations of Fe and Ti were higher in Nigeria and this study than the values in Nigeria, China, and Brazil. The mean concentration of Cu and Pb in Italy and this study were higher compared to Nigeria and Brazil.

Table 4 Summary statistical of elements concentration (%) from a different location:

|  | Loc1 | | | | Loc2 | | | |
|---|---|---|---|---|---|---|---|---|
|  | Mean | SD | Min | Max | Mean | SD | Min | Max |
| S | 0.27 | 0.54 | 0.016 | 1.98 | 0.09 | 0.08 | 0.013 | 0.29 |
| Cl | 0.02 | 0.006 | 0.007 | 0.02 | 0.06 | 0.14 | 0.014 | 0.55 |
| K | 0.03 | 0.029 | 0.01 | 0.12 | 0.08 | 0.15 | 0.008 | 0.58 |
| Fe | 1.53 | 1.24 | 0.28 | 3.45 | 1.8 | 2.75 | 0.12 | 9.58 |
| Ba | 0.09 | 0.099 | 0.01 | 0.29 | 0.24 | 0.43 | 0.006 | 1.15 |

Table 5 Summary statistical of elements concentration (ppm) from a different location:

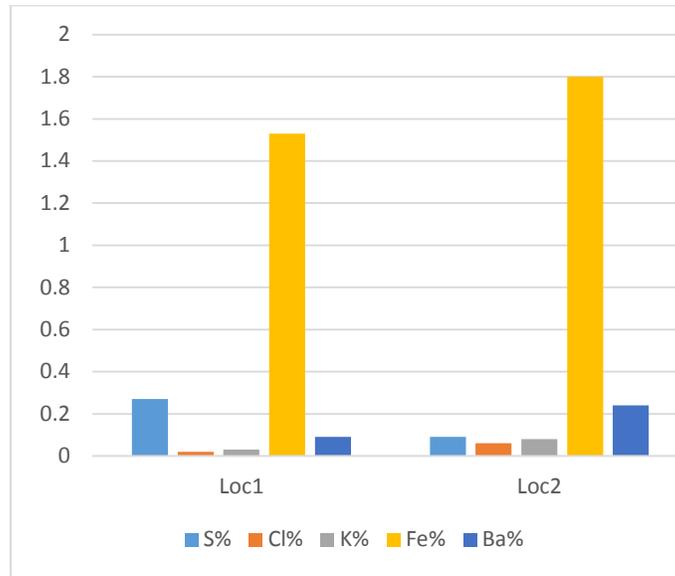|  | Loc1 | | | | Loc2 | | | |
|---|---|---|---|---|---|---|---|---|
|  | Mean | SD | Min | Max | Mean | SD | Min | Max |
| Ti | 260.8 | 168.5 | 59.3 | 557.3 | 453.4 | 398.4 | 79.1 | 1364 |
| Cr | 27.38 | 18.05 | 0.01 | 57.63 | 29.14 | 24.17 | 9.23 | 96.5 |
| Cu | 431.2 | 1153 | 9.69 | 4248. | 99.36 | 83.2 | 4.19 | 231. |
| Pb | 281.9 | 366.5 | 12.7 | 1145 | 315.5 | 484.9 | 23.6 | 1586 |



Figure 1 Mean elemental concentration (%) from a different location
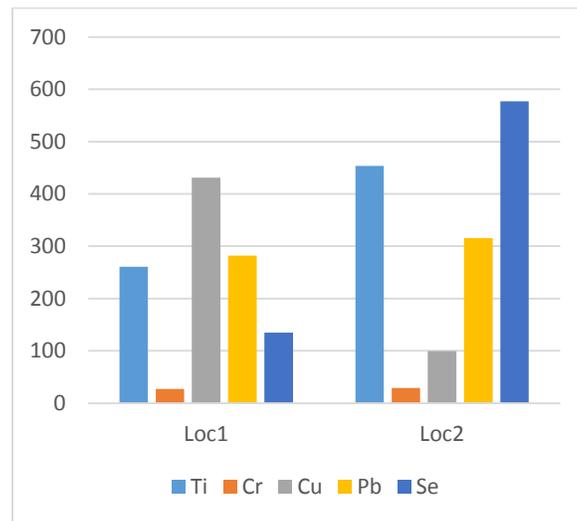


Figure 2 Mean elemental concentration (%) from a different location

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Table 6 correlation coefficients of investigated elements in location 1

|    | S | Cl    | K     | Fe   | Ba    | Ti    | Cr    | Cu    | Pb    |
|----|---|-------|-------|------|-------|-------|-------|-------|-------|
| S  | 1 | -.028 | -.179 | .331 | .131  | .285  | -.521 | **.970** | **.932** |
| Cl |   | 1     | .074  | .536 | .461  | .286  | .472  | -.062 | .038  |
| K  |   |       | 1     | .400 | -.313 | **.722** | .609  | -.111 | -.192 |
| Fe |   |       |       | 1    | .357  | .483  | .260  | .384  | .305  |
| Ba |   |       |       |      | 1     | .299  | -.359 | .146  | .433  |
| Ti |   |       |       |      |       | 1     | .491  | -.185 | -.115 |
| Ct |   |       |       |      |       |       | 1     | -.490 | -.571 |
| Cu |   |       |       |      |       |       |       | 1     | **.863** |
| Pb |   |       |       |      |       |       |       |       | 1     |

Table 7 correlation coefficients of investigated elements in location 2

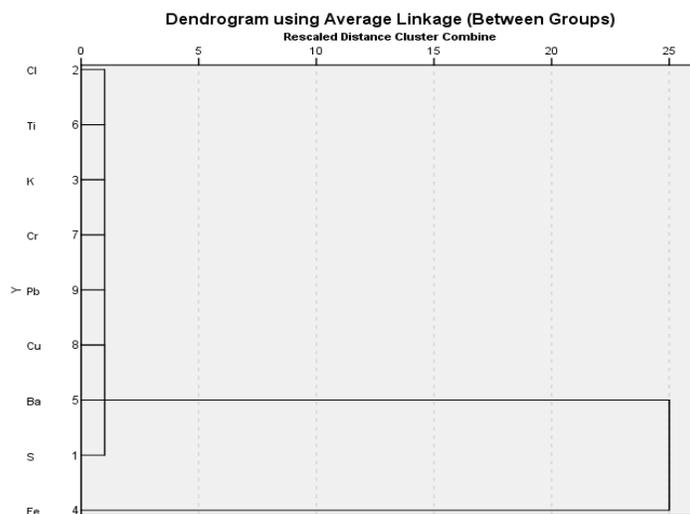|    | S | Cl    | K     | Fe    | Ba    | Ti    | Cr    | Cu    | Pb    |
|----|---|-------|-------|-------|-------|-------|-------|-------|-------|
| S  | 1 | .348  | .252  | **.800** | -.354 | .068  | .267  | .491  | **.836** |
| Cl |   | 1     | **.957** | -.140 | -.157 | -.122 | -.009 | .018  | -.123 |
| K  |   |       | 1     | -.149 | -.172 | .139  | .166  | -.024 | -.200 |
| Fe |   |       |       | 1     | -.221 | .367  | .335  | .419  | **.949** |
| Ba |   |       |       |       | 1     | -.435 | -.460 | -.520 | -.217 |
| Ti |   |       |       |       |       | 1     | .163  | .011  | .156  |
| Ct |   |       |       |       |       |       | 1     | .345  | .189  |
| Cu |   |       |       |       |       |       |       | 1     | .250  |
| Pb |   |       |       |       |       |       |       |       | 1     |



Figure 3 Hierarchical cluster analysis

Table 8 Enrichment factor for investigated elements

| Elements | Enrichment Factors |
|----------|--------------------|
| S        | 21.7               |
| Cl       | 9.26               |
| K        | 0.09               |
| Ba       | 12.46              |
| Ti       | 0.02               |
| Cr       | 0.9                |
| Cu       | 5.21               |
| Pb       | > 40               |

Table 9 Comparison between this study and data from the literature

|  | S | Cl | K | Fe | Ti | Cr | Cu | Pb |
|---|---|---|---|---|---|---|---|---|
| Nigeria [10] | 0.02 | 0.01 | 0.03 | 2.39 | 318 | 8 | 7 | 5 |
| Brazil [11] | 0.01 | 0.001 | 0.003 | 0.001 | 1.15 | 0.5 | 0.8 | 0.6 |
| Italy [12] | - | 0.01 | 0.01 | 0.01 | 55 | - | 100 | 75 |
| China [13] | - | - | 0.003 | 0.006 | 6.5 | - | - | - |
| This Study | 0.17 | 0.03 | 0.06 | 1.67 | 360 | 28 | 286 | 298 |

## Conclusion

In the present study, Particle Induced X-ray Emission (PIXE) was used to identify these elements (S, Cl, K, Ti, Cr, Fe, Cu, Pb, and Se) in aerosols samples collected from Ariab mining area, eastern Sudan.  The results showed that the mean concentrations of Cl, K, Fe, Ti, Pb, and Ba were slightly very high in location two, while the mean elemental concentrations of S, Cu was found higher in location one.

Based on E.F calculation, the K, Ti, and Cr are defined as crustal elements (non-enriched), while the S, Cl, Cu and were classified as non-crustal (enriched).  Pb is highly enriched.

It has been confirmed from the positive correlation between the elements Cu, Zn, and S, the presence of Cu and Zn as sulphide deposits at the mining site.

The mean elemental concentrations of all elements analyzed in this study were higher than the data from the literature.

## Recommendations

1. Awareness of dangers of toxic elements especially for miners.
2. The camp where most of the labor and engineer were settling must be constructed far away from the mining sites due to the strong emissions of some toxic elements like Pb.
3. Further research is needed to cover a new location such as the crushing and heap area.

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