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Characterization of Settleable Dust and Surface Dust Samples from the Old and Abandoned Asbestos Mine Dumps in the Limpopo Province, South Africa

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Abstract

Old and abandoned (D&O) mine dumps refer to the asbestos mine dumps which were operated when environmental management was not regulated in the country and owners of mining rights could no longer be traced. These mine dumps are not being maintained or rehabilitated and the associated impacts are not being mitigated and managed.

The aim of this research is to monitor, measure and characterize settleable dust and surface dust samples collected around local communities in the vicinity of old and abandoned asbestos mine dumps. The local standard method for collection and analysis of settleable dust (the South Africa National Dust Control Regulations 827 of 2013) was used in this research. Surface dust samples were collected using standard method in January, April and July 2016. Settleable dust samples were collected from January 2016 to July 2016 around five sampling sites in Limpopo Province. The samples were prepared for analyses.

The settleable dust rates are below the residential limit of 600 mg/m^2/day. The analytical measurements confirm the presence of silicates, minerals, amphibole and serpentine asbestos minerals. SEM-EDS results tested positive for amphibole and serpentine asbestos minerals. The continued presence of amphibole and serpentine asbestos mineral in Limpopo Province is cause of concern.

Keywords: Settleable dust; Surface dust; XRF; SEM; XRD; Limpopo province; South Africa

Introduction

Mining in South Africa is the leading force behind the history and development of the local economy [1]. Gold, diamond, coal, iron are the major contributors of the South Africa's mining economy. Local mining sectors contributed up to 65% to the Gross Domestic Products [2-4]. Mining in South Africa has resulted in environmental legacies such as acid mine drainage (AMD) and D&O mine dumps which contributes to environmental degradation and health challenges. The government has begun processes to mitigate and rehabilitate the AMD and D&O mine dumps in an attempt to reduce associated impacts.

Asbestos mining in South Africa started in 1800's and it has left major environmental and health problems [5]. Old and abandoned asbestos mines dumps which are not rehabilitated contribute to the asbestos contaminated dust pollution that is experienced in surrounding areas [1]. Historically, asbestos was mined to manufacture building materials (such as cheap asbestos roof sheets and material used for producing ceilings) which are now linked to health problems [6]. Despite the banning of asbestos mining, illegal asbestos mining operations continue to produce the deadly asbestos dust found everywhere on the ground [7]. The short asbestos fibres had no commercial value and were dumped and made heaps of mine waste.

South Africa has the highest mesothelioma conditions which occur after inhalation of short asbestos fibers [8]. After inhalation, the small needle-like fibres would pierce the lung membrane and remain lodged for a long time causing inflammation and eventually cancer. Health effects are associated with dust particles with diameters below 25 µm because they enter the mouth, nose and the gas exchange regions of lungs readily during inhalation. Dust with particle diameters greater than 25 µm is called nuisance or annoyance dust and is associated with public perceptions where exposed individuals would complain [9]. The purpose of the study was to measure long term settleable dust rates, the geochemistry, mineralogical, morphological composition and levels.

Experimental Design and Methodology

Study area, geology and sampling points

The study took place within the following five human settlements (Ga-Malemang Village, Ga-Mafefe- Mathabata Village, Penge and Taung Village) located in the northern province of Limpopo in South Africa. Site B is fully rehabiliated and Site A, C, D and E are partially rehabiliated. These human settlements are located near the old and abondoned asbestos mine dumps. The province has bushveld, majestic mountains, primeval indigenous forest, unspoilt wilderness and patchworks of farmland [10]. The geology of the region contains the Transvaal and Chuenespoort group; carbonate rock formation (contains iron and magnesium embedded in the rocks) form part of the dolomite series in succession near the top, which is followed by carbonate rock formation [11]. Most rocks in the province belong to the Malmani SubGroup and Penge formation. The most common rocks found in the province are shale, dolomite, chert, quartzite, conglomerate, breccia

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and diamictite [12]. Penge is a town situated approximately 80 km northwest of Burgersfort, in the Greater Tubatse Local Municipality and Greater Sekhukhune District Municipality. The asbestos mines were located south of the Pietersburg asbestos fields [13] and extend in an 80 km arc from Malisdrift in the northwest to the confluence of the Olifants and Steelpoort Rivers in the southeast (Hall, 1930). The Penge asbestos mine and village are located in the southeastern extremities of the Pietersburg asbestos field [14].

Figure 1 shows an aerial map of the location of sampling sites and Figure 2 shows some of the mine dumps which are covered by natural vegetation, while signs of rehabilitation activities are visble at Site B.

Figure 2 showing the location of the asbestos mine dumps in Limpopo Province.

The geological importance of the mineral composition

The calcite mineral composition identified occurs in sedimentary setting and is found in hydrothermal veins and hot spring deposits. It also occurs as limestone rock and as marble, which are metamorphosed rocks. It is associated with dolomite, gypsum, anhydrite, chert and halite pyrite, fluorite, galena and chalco pyrite [15]. Goethite/Hematite occurs as a variety of igneous and metamorphic rocks most abundant in sedimentary settings. They also form directly from direct precipitation and from marine waters. They are also found with other iron bearing minerals, especially magnetite, goethite and siderite. The layered deposits are known as banded iron formation. They also occur when the chemistry of the earth's atmosphere differs fundamentally with the present ocean [16]. K-feldspar, Plagioclase, Kaolinite and Smectite occur in igneous rocks especially and are intermediate to mafic rocks. They are often developed in pegmatite, coarsely crystalline, igneous rocks and formed during water-wet stages of the magma cooling. When weathered, they form clay minerals which are a resistant component of detrital sediments and sedimentary rocks. The calcium-rich and sodium-rich bond tends to be characterised by the intermediate formafic igneous rocks with high grade metamorphic and metamorphosed carbonate rocks. In contrast felsic igneous rocks with low-grade metamorphic rocks occur as overgrowths on feldspar grains in sedimentary sandstones [17]. Quartz mineral is a component of silica rich igneous rocks, forming up to 25% of the volume of granites and occurs in stones and detrital as a hydrothermal vein and very stable pegmatite. They are weathered by the surface temperatures, pressures and concentrates causing them to be even more abundant in sandstones and siltstones [18]. Amphibole occurs as intermediate felsic igneous rocks; alteration of pyrene occurs during late water wet stages of igneous activity. They are the most abundant in igneous rocks that form deep of the earth's surface, then in volcanic igneous rock. Titanium rich oxides also occur in basaltic rock. They are most commonly found in granite and abundant syenite and diorite rocks as well as metamorphic schists and gneisses and bulk make-up in metamorphic and dominant rocks in dark bands [19]. Mica mineral occurs in igneous, metamorphic and sedimentary regimes. Large crystals of mica used for various applications are typically mined from granitic pegmatites and I/S interstratification stratifications occur among or between other layers or strata [20].

Figure 1: An aerial map showing the location of sampling points within human settlelments.

Samples collection method

In this study, settleable dust samples were collected from January to July 2016 at sites that are within the human settlements situated near old and abandoned asbestos mine dumps. Individual units were installed within the yards of two private houses, two public clinics and a public hospital. An individual settleable dust collection unit is made of a single 5.0 L cylindrical bucket half filled with deionized water is placed on a 2.0 m high stand with a bird ring on top (Figure 2). The units are exposed on identified sites for a period of 30 ± 33 days before being replaced with clean ones. The exposed units containing settleable dust samples are transferred to the laboratory and filtered with a buchner filtration system. After filtration, dried samples on filter papers are placed in the incubator to allow mass to stabilize before being weighed to determine the exact amount of dust that settled using gravimetric calculations.

In order to measure the impact on nearby human settlements, dust monitoring units were placed within 5.0 km from the mine dump sources. Surface dust samples were collected using a brush, dust pan, sieve with 1.0 mm and stored in a zipper plastic and analysed for January, April and July 2016 and for the research purpose July 2016 data is presented for XRF, XRD and SEM. The surface dust samples were collected once after consecutive three months. Figure 3 shows location of the installed single dust bucket monitoring units [21].

Laboratory analysis method

The mass concentration of settleable dust rate (D in mg/m^2/day) was determined by calculating the total weight mass (W_m in mg) divided by cross-section area of the dust fall bucket diameter (A in m^2) and multiplied by the number of days (30 days) on site as shown below:

$$D = \frac{W_m}{A\ x\ number\ of\ days}$$

Settleable dust samples were studied further using an X-Ray Diffraction (XRD) analytical technique to evaluate the mineralogical composition. The intrument was conditioned according to the Council for Geoscience Mineralogy Laboratory Methods.

Geochemistry (XRF) analysis was used to identify major and trace elements in surface dust (that contained small rock) samples. Crushing, milling, splitting and roasting (at 1000°C for at least 3 hours) were required prior to the analysis for major element in the fine surface

Site A Site B Site C Site D Site E

Figure 2: Showing the location of the asbestos mine dumps in Limpopo Province.

Site A Site B Site C Site D Site E

Figure 3: Location of the installed single dust bucket monitoring units

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dust samples. Glass disks were prepared by fusing 1.0 g roasted sample and 10 g flux consisting of 49.5% $Li_2B_4O_7$, 49.5% $LiBO_2$ and 0.50% LiI at 1150°C. For control an in-house amphibolite reference material (sample 12/76) was used and 1 in every 10 samples was duplicated during sample preparation. For trace element analysis 12 g milled sample and 3 g Lico wax was mixed and pressed into a powder briquette by a hydraulic press with the applied pressure at 25 ton. The glass disks and wax pellets were analysed by a PANalytical wavelength dispersive Axios X-ray fluorescence spectrometer equipped with a 4 kW Rh tube.

Mineralogy (XRD) analysis was obtained on BRUKER D8 Advance diffractometer with Cu radiation. The system is equipped with a LynxEye detector and a Ni-filter. Tape samples were mounted on dedicated filter holders or powder mounts and run in step scan mode from 2 to 70° 2θ CuK (λ=1.54060) radiation at a speed of 0.05° 2θ steps size/1 sec and generator settings of 40 kV and 40 mA. Data processing, evaluation and reporting XRD: Phase identification is based on BRUKER DIFFRAC Plus-EVA evaluation program. Phase concentrations are determined as semi quantitative estimates (with accuracy ± 5%) using RIR (Reference intensity Ratio) method and relative peak heights/areas proportions.

Scanning Electron Microscopy-Energy Dispersive Spectrometry (SEM/EDS) analysis was performed on a Leica Stereo scan 440 SEM linked to an OXFORD INCA EDS. The system was equipped with an Oxford X-Max SDD detector with 20 mm^2 active area and resolution of ca. 128eV for Mn K-a (5895 eV) and has the capabilities for Secondary, Backscattered and Cathodoluminescence Electron Imaging, X-Ray EDS microanalysis and X-Ray element mapping. Mineral chemistry was determined by means of spot analyses at beam settings of 20 kV accelerating voltage, Probe current of 5.0 nA and counting time was set at 100 s.

Settleable dust standards and acceptable rates

The local acceptable settleable dust rates are shown in Table 1 [22].

Results and Discussions

Settleable dust rates

Tables 2 show the monthly settleable dust rates for Limpopo Province. All the settleable dust rates for all the sites are below the residential areas of 600 mg/m^2/day. Site D in January 2016 is the highest with 387 mg/m^2/day and the lowest is Site E with 24 mg/m^2/day in March 2016 and the sites are both partially rehabilitated and rehabilitation methods used needs improvement. The highest total average of the settleable dust rates is Site D with 1154 mg/m^2 day and the lowest is at Site A with 476 mg/m^2/day (Table 2).

Geochemistry results

An XRF instrument was used to generate the geochemistry data in Table 3. The results confirm the presence of the silicate minerals with dominant metal oxide concentrations such as SiO_2 (47.32 to 61.23%), Fe_2O_3 (10.02 to 31.91%) and Al_2O_3 (6.09 to 12.86%). The other oxides are of metal cations of Ca, Mg, Ti, Mn, K, Na, P and Cr.

The mineralogy results for July 2016

Table 4 shows the mineral composition data for samples collected in January 2016 and was characterized by an XRD instrument of analysis. The most dominant mineral is the Quartz with 32% m/m at Site A and 68% m/m at Site B. Other minerals of significant levels are K-feldspar with 4.0% m/m at Site C and 12% m/m at Site E; Plagioclase with 4% m/m at Site C and 23% m/m at Site A. Serpentine was detected at all four sites and with 2% m/m at Site B, 7% m/m at Site A and the site is rehabilitated it indicate improve with regard to the exposure of asbetsos

Restriction Areas	Dust fall rate (D) (mg/m^2/day)-averaged over 30 days	Permitted frequency of exceeding dust fall rate
Residential area	D<600	Two within a year, not sequential months
Non-residential area	D<1200	Two within a year, not sequential months

Table 1: Acceptable settleable dust rates.

Sampling Site	16-Jan	16-Feb	16-Mar	16-Apr	16-May	16-Jun	16-Jul	Total average
Site A	74	79	46	67	80	65	65	476
Site B	204	139	35	74	69	246	246	1013
Site C	78	129	48	50	126	115	115	661
Site D	387	57	115	132	141	161	161	1154
Site E	54	278	24	54	70	109	109	695

Table 2: Settleable dust rates (mg/m^2/day) from January to July 2016 for Limpopo Province.

Sampling Sites / Minerals	Site A	Site B	Site C	Site D	Site E
SiO_2	61.23	55.36	47.32	59.74	53.32
$Al2O_3$	12.86	6.09	7.70	10.51	10.08
Fe_2O_3	10.02	27.97	31.91	10.29	12.27
MnO	0.197	0.442	0.639	0.323	0.279
MgO	1.83	0.83	1.39	1.65	2.35
CaO	2.93	1.06	1.35	2.93	7.31
Na_2O	0.57	0.37	0.33	0.57	0.56
K2O	1.66	1.07	1.19	1.80	1.87
TiO_2	0.97	0.72	0.71	1.22	0.96
P_2O_5	0.148	0.205	0.225	0.362	0.310
Cr_2O_3	0.085	0.028	0.042	0.047	0.074
Total	**99.93**	**100.02**	**100.02**	**99.9**	**100.09**

Table 3: Geochemistry results for Limpopo Province for July 2016.

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Minerals detected	Chemical formular	Site A	Site B	Site C	Site D	Site E
Calcite	$CaCO_3$			2	18	7
Goethite	œ$Fe^{3+}O(OH)$			6		
Illite	$(K,H3O)(Al,Mg,Fe)_2(Si,Al)_4O_{10}[(OH)_2,(H_2O)]$			7		
K-feldspar	$KAISQ_3O_8$		5	4	5	12
Plagioclase	$NaAlSi_3O_8$	23	12	4	10	18
Quartz	SiO_2	32	68	59	38	35
Serpentine	$Mg_3(OH)_4(Si_3O_5)$	7	2		4	6
Amphibole	$NaCa_2(Mg,Fe,Al)_5(Al,Si)_8O_{22}(OH)_{22}$	12		11	3	5
Mica	$KAl_2(Si_3AlO_{13})(OH)_2$	20	6	7	15	10
Smectite	$A_{0.3}D_{2-3}[T_4O_{10}]Z_2.nH_2O$	6			5	5

Table 4: Mineralogy (in% m/m) results for Limpopo Province for July 2016.

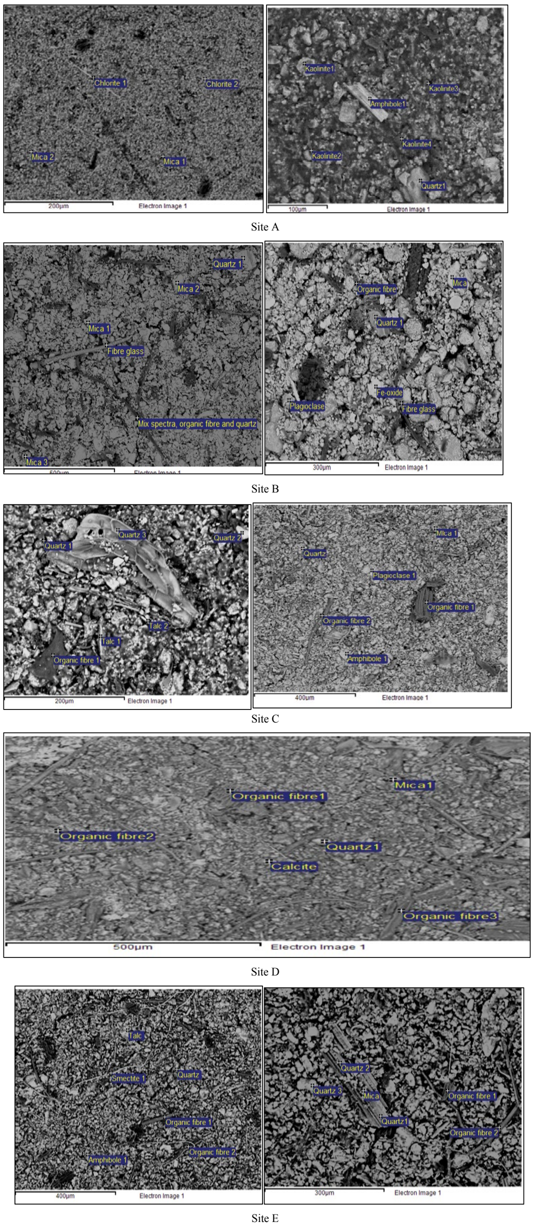

Figure 4: SEM results for Limpopo Province for July 2016.

dust. The amphibole was detected at four sites except Site B and with 3% at Site D and with 12% m/m at Site A both partially rehabilitated. Quartz, Plagioclase and Mica were detected at all the five sites and with 32% m/m and with 68% m/m, plagioclase with 4% m/m to 23% m/m and mica with 6% m/m at Site B and 20% m/m at Site A. Goethite and Illite were detected at Site C. The least common mineral detected was calcite with 2% m/m at Site C and with 18% m/m at Site D respectively.

The mineralogy results from Table 4 show that the presence of significant levels of the serpentine and amphibole asbestos minerals, which is a major concern. Other dominant minerals include the quartz, mica, plagioclase, Illite, K-feldspar, calcite, goethite and smectite.

SEM-EDS results

EM-EDS results for limpopo province for July 2016: Figure 4 shows the results confirm the presence amphibole [$NaCa_2(Mg,Fe,Al)_5(Al,Si)_8O_{22}(OH)_2$] mineral group and other silicate minerals is quartz (SiO_2), mica [$KAI_2(Si_3AlO_{10})(OH)_2$], and plagioclase[$NaAlSi_3O$]. The non-silicate mineral detected was kaolinite [$Al_2Si_2O_5(OH)_4$], feldspar [$KAISQ_3O_8$] and chlorite [$(Mg, Fe)_3(Si, Al)_4O_{10}$]. At all the sites the size particles is 100 µm for semi-rectangular, semi-triangular and the shape characterized by straw or bundle clustered together, organic fiber and fiber glass also detected. According to the research studies conducted in America in Vermont and Washington D.C. by Thompson et al. [23], there were determining the amphibole mineral from the soil content whereby their shows SEM photographs and EDS data of amphibole particles actinolite from Vermont; ferro-actinolite from Washington D.C; amphibole (either grunerite or gedrite) from southern Illinois; and tremolite from eastern Washington state.

Conclusion and Recommendations

All the monthly dust fall rates are below the residential level of 600 mg/m²/day. The most dominant mineral composition is the quartz and plagioclase. Significant levels of asbesti-form minerals such as the serpentine and amphibole mineral groups were detected and remain a concern. Based on current results, local residents are at risk due to environmental exposure to asbestos fibres. Permanent solution involves rehabilitation of the dumps, but the very high costs of rehabilitation delay the process.

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