The Closing of a Mine: A Case Study of the Effectiveness of Rehabilitation Works at the Moshaneng Asbestos Mine, Botswana

E.M. Shemang[*1], K. Mickus[2], P.T. Odirile[3], M.B.S. Atanga[4], C.E. Suh[5], A.P. Tsheboeng[6]

[1]Department of Earth and Environmental Sciences, Botswana International University of Science and Technology, Private Bag 16, Palapye, Botswana

[2]Department of Geography, Geology and Planning, Missouri State University Springfield, MO 65897 Missouri, USA

[3]Department of Civil Engineering, University of Botswana, Gaborone, Botswana

[4]Department of Nursing, Faculty of Health Sciences, University of Buea, P.O. Box 63, Buea, Cameroon

[5]Department of Geology, University of Buea, P.O. Box 63, Buea, Cameroon

[6]EIA Projects (Pty) Ltd Gaborone, Botswana

[*1]shemange@biust.ac.bw; [2]KevinMickus@missouristate.edu; [3]odirilep@mopipi.ub.bw; [4]mbisuh@yahoo.com; [5]chuhma@yahoo.com; [6]alfred.tsheboeng@eiaproject.co.bw

***Abstract*-A preliminary analysis of the reclamation efforts at the Moshaneng asbestos mining area in Botswana was undertaken. The study was performed in order to determine a benchmark for more detailed studies on the environmental hazard potential due to the potential presence of asbestos minerals within and outside of the former mining region. The analysis included the physical examination of the closed mining shafts, the chemical and mineralogical analysis of surface water, asbestos tailing dumps and air samples. The closing of the inclined and vertical shafts was incomplete as the potential for collapse of several of the old shafts was found. The chemical and mineralogical analysis indicated that asbestos minerals were present in the sampled surface waters, tailing dumps and air samples. Leached products (e.g., Mg and Ca) were present in the surface water, but the source of these may have been leached from non asbestiform amphiboles. The most dominant asbestos mineral found at all sites was chrysotile. A variety of minerals associated with the mining (quartz, calcite and sillimanite) were found in the tailings dumps but these minerals were not abundant in the nearby stream sediments or soils, suggesting that the vegetation surrounding the tailings dumps prevented their transport. Analysis of surface waters found high concentrations of heavy metals (Cd, Fe and Mn) that were also found in the tailings dumps. The leaching of these minerals is downgrading the water quality of nearby ponds used by domestic livestock. Analysis of air samples determined that all samples contained small amounts of asbestos fibers which are probably the greatest health risk to the local community due to the abandoned asbestos mining. Future studies should expand the number of sampled sites as well as number of locations for air, water and tailing samples analysed to further clarify the results of this study.**

Keywords- Botswana; Asbestos; Mining; Reclamation

I. INTRODUCTION

A steady increase in living standards in emerging economies of countries such as Botswana has increased the demand for minerals and it is forecast to remain strong in the future [1]. With this increased demand for minerals come enormous environmental concerns including erosion, ecological damages, groundwater and stream contamination, air pollution and sinkhole formation due to shaft and tunnel collapse [2, 3]. While there are major environmental concerns during the operation of a mine, there is also an increasing concern about the environmental problems that occur when a mine is closed. The problems include mine rehabilitation and closing procedures which are evident in the operation of social licenses held by various companies [1, 4, 5]. Good practices in mining operations require that mine closure be an integral part of pre-project planning. In most countries, mine closure procedures are governed by strict codes of environmental monitoring [4].

In this article, *a* cleanup at a former asbestos mining area in the Moshaneng region of Botswana is *investigated*. Asbestos is a general term that is used to describe a group of silicate minerals that are capable of developing long, thin fibers [6-9]. Despite many minerals being capable of producing fibrous minerals [6], most definitions of asbestos minerals include the amphibole minerals that form asbestiform (fibers with length to width ratio of at least 5:1 and be less than 10 micrometers in length [6, 7]) minerals. These include actinolite, tremolite, anthophylite, amosite and crocidoite. In addition, the asbestiform of the serpentine group mineral, chyrsotile is included as a asbestos mineral. While there is no consensus on a formal definition of asbestos, many U.S. federal and state government as well as international agencies include the above fibrous forms of these six minerals in their definition of asbestos from a regulatory sense [8-12]. The above asbestos minerals all contain magnesium, silica and water, and some asbestos minerals contain significant amounts of iron and calcium [13].

The amphibole group minerals are common in igneous and metamorphic rocks, but most asbestos ore deposits are formed by the metasomatic replacement of magnesium rich rocks [13]. These metasomatic processes may include regional metamorphism, contact metamorphism and magmatic hydrothermal systems [13]. The most commonly rock types that include

DOI: 10.5963/IJEP0408001

asbestos minerals are serpentinites, altered ultramafic and mafic rocks, metamorphosed dolomites and alkali intrusions [7, 13].

All of the above minerals while mainly found in a nonfibrous habitat, can exist in an asbestiform- habits. These asbestiform structures of these minerals have many useful characteristics such as flexibility, high tensile strength, resistance to heat, and physical durability. These features have made some of these are useful in many industrial and home applications [14]. However, the fibers can easily become airborne and be inhaled when the material containing them is friable and/or disturbed. The amphibole and chrysotile asbestos in some instances cannot be broken down in the lungs, and if retained in the lungs for long periods they would become a constant irritant which the body will eventually expel by producing cancerous cells [15]. However, the asbestos minerals may be broken down into smaller pieces and this process may increase the potential toxicity of the structures [6, 7, 15, 16]. There is some evidence that Fe-rich asbestos minerals may be more toxic when the iron is leached out in the body [7, 15], however the evidence is mainly related to higher levels of mesothelioma in regions where Fe-rich asbestos were mined and not from detailed chemical and biological studies. In this *paper*, a first-order study to determine the effectiveness of mine rehabilitation after the closure of the Moshaneng asbestos mine in Botswana *is provided*. Moshaneng Village is an old mine settlement located in the south-eastern section of Botswana (Fig. 1) that came into existence to mined asbestos minerals (chrysotile) which were discovered in the early 1920's. The study of how the mining area was rehabilitated is particularly important, considering the health effects of asbestos on humans who live between 200 and 1600 meters from the mines [17, 18]. First, an overview of the geology, mining history and previous rehabilitation efforts at the Moshaneng mine *is presented*. Then the results of our evaluation of the environmental conditions at the mining village several years after the rehabilitation procedures were implemented are presented. *Field* examination of rehabilitated shafts and analysis of air and water quality in the mine area six years after they were reclaimed *were used* to determine if the rehabilitation efforts were successful. We intend that this study will provide the background for more indepth studies to determine if the Moshaneng mining area poses a health risk to the surrounding village.

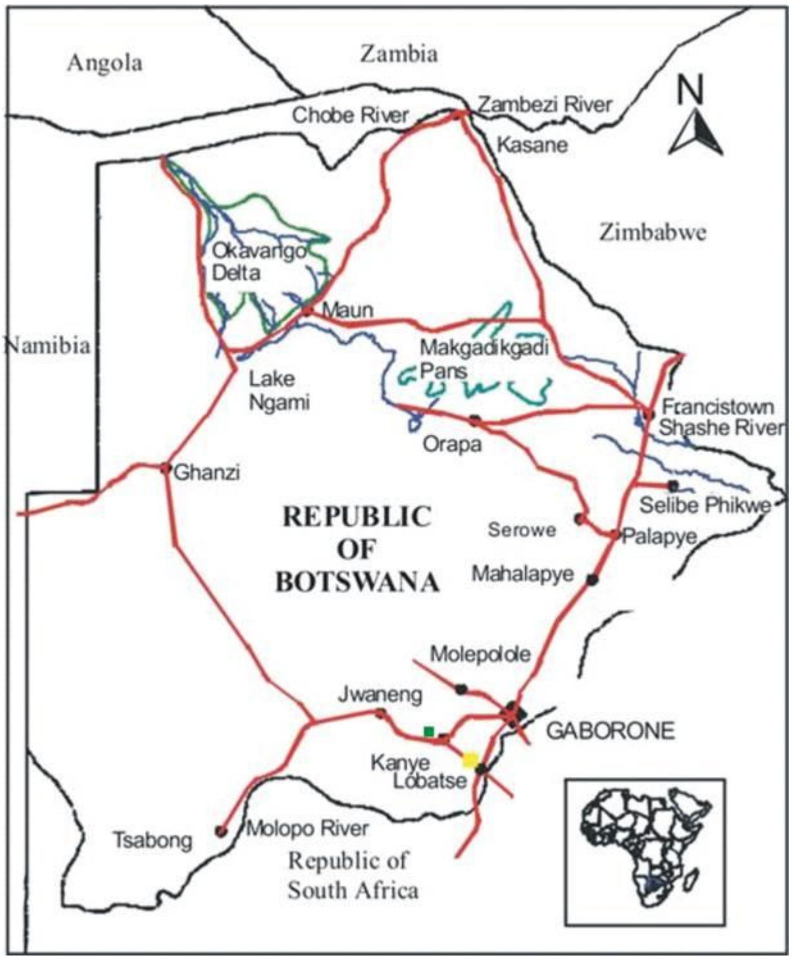


Fig. 1 Location of the Moshaneng mining area (green rectangle) in southern Botswana. Red lines represent major roads, green lines outline major wetland regions, blue lines represents rivers

II. GEOLOGY AND MINING HISTORY AT THE MOSHANENG ASBESTOS MINE

Asbestos minerals around Moshaneng village were emplaced in altered siliceous Proterozoic dolomite that was subjected to low-grade metamorphism along the upper margin a large Proterozoic dolerite intrusion [18-20] (Fig. 2). The asbestos minerals occur as seams of cross-fiber chrysotile with small amounts of tremolite and actinolite (Fig. 3) and are associated with

DOI: 10.5963/IJEP0408001

serpentine. The asbestos minerals occur in seams between 10 and 30 m in thickness along the 4.2 km strike-length of the dolomite/dolerite contact [17]. In some areas, the dolerite is discordant to the dolomite/dolerite boundary cutting across the bedding of the dolomite and rising to the surface. Where the dolomite/dolerite contact is discordant, the asbestos fibers developed along the bedding planes at a number of horizons and extended upwards for some 15 m from the intrusive contact. Asbestos minerals (chrysolite and tremolite) are also found in seams in fractured rocks lying approximately parallel to microfault zones within the dolomite. Typical fiber lengths are approximately 1.5 cm. Boreholes drilled to investigate the lower contact of the dolerite showed no evidence of chemical alteration or metasomatism. There was also no development of asbestos minerals at the contact between the Moshaneng Complex (Proterozoic gabbros, granites and diorites) [17] and the dolomite.

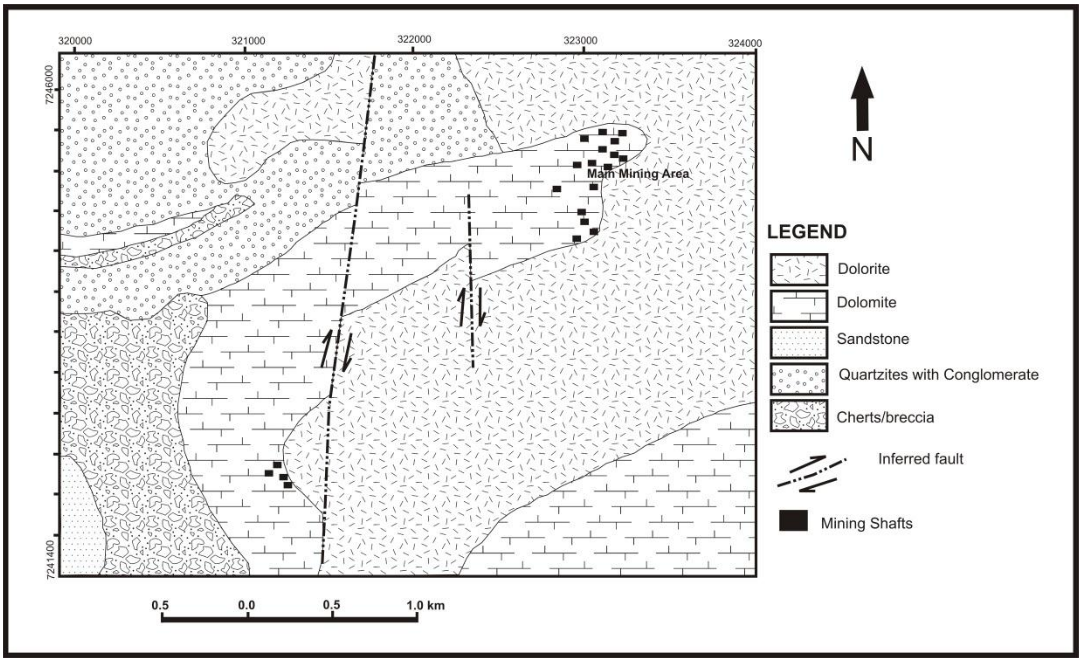


Fig. 2 Geologic map of the area around Moshaneng showing the locations of the mining shafts within the asbestos minerals mining area

Fig. 3 Typical appearance of asbestos minerals at the Moshaneng mine

Mining of the asbestos minerals (chrysotile) at Moshaneng took place between 1927 and 1965 by a number of companies [19]. However, there are no mining reports available to the public on the mining operations and asbestos treatment on site, although interviews with people who worked at the mine provided insights that are presented here. During the early stages of mining, work proceeded on three persistent asbestos horizons parallel to the concordant igneous contact and separated from one another by serpentinized dolomite (Fig. 2). The underground mine was accessed by westerly inclined shafts with cross-cuts established from these shafts. The cross-cuts led into stopes. Selective mining was done where only thick (greater than 15 meters) asbestos mineralization could be extracted [17]. Mining was performed using drilling and blasting, and the drills were powered by compressed air from the surface provided via pipes installed along the inclined shafts. Hand shovels were used to load blasted material onto ore-passes that led to boxes below the stopes. Hoppers were used to transport these materials to the inclined shafts, and a rail track was installed along the inclined shaft upon which hoppers were pulled to the surface using winches. On the surface the material was transported by train to the crusher plant after which the ore was placed on conveyor

DOI: 10.5963/IJEP0408001

belts.

Asbestos minerals were then handpicked from the moving conveyor belt and bagged to be transported to Lobatse. The rejected material was stockpiled and subsequently moved to a permanent dump site. The rejected material which contained a significant amount of asbestos minerals was also used to support the underground workings together with timber packs (gum poles). Ventilation of the underground workings was provided through vertical shafts using extraction fans. When mining stopped, the mine site was abandoned and left to waste [21]. The shafts, trenches and waste dumps from the mining activities were left without any protection, and therefore became a great source of concern to the people around Moshaneng village who lived between 100 and 1600 meters from the old mine [17].

III. REHABILITATION WORK DONE IN THE AREA

In 2003, the Department of Mines of the Government of Botswana commissioned a company [21] to assess the environmental status of the Moshaneng asbestos mining area, to determine if there were any harmful substances within the environs of the mine shafts and dumps, and to develop a rehabilitation plan for the area. The objective of the rehabilitation works was to leave the area in a condition that is chemically and physically stable and in a safe condition. NMA Consulting (Pty) Ltd recommended that the shafts, waste dumps, and old structures be rehabilitated [21]. They recommended that all shaft entrances be sealed, and excavations to be filled in order to prevent animals and humans from entering or falling, and that all vertical and inclined shafts be backfilled.

To help control the spread of asbestos into the environment, the company recommended that the waste dumps materials be isolated in such a way that there was no significant movement of asbestos fibers into the local water and air. All the dumps were to be graded into a slope not exceeding 1:3 and soil was used to cover the dumps. Old buildings and ruins were to be demolished and all rubble to be disposed of in an appropriate manner so that the asbestos minerals would not enter the environment. Table 1 shows the recommended rehabilitations at the Moshaneng mining area. Figs. 4 and 5 show how the recommendations from NMA Consulting were implemented.

TABLE 1 REHABILITATION ALTERNATIVES FOR THE MOSHANENG ASBESTOS MINE [21]

Item	**Recommendation**	**Recommendation for further action to be taken**
Inclined Shafts	A concrete retaining wall was to be built within the shaft and some material was to be hand packed against the wall. The box cut was to be backfilled with loosely placed waste rock.	To cap shaft as recommended
Vertical Shafts	The shaft was to be backfilled with waste rock. The shaft collar and adjacent spoil was to be excavated down to competent rock, a concrete cap placed on the shaft at the competent rock contact. The excavated collar be backfilled with un-compacted soil from spoil.	To cap shaft as recommended
Dumps	Grade all the dumps to slopes not exceeding 1:3, cover with soil to establish re-vegetation.	To grade and cover dumps as recommended
Old Workings, ruins and scattered waste piles	Demolition of the remains of old buildings and ruins, rip up and demolish foundations and disposal of rubble and pick up scattered waste piles. Ripping of denuded area to allow natural vegetation.	To demolish works as recommended

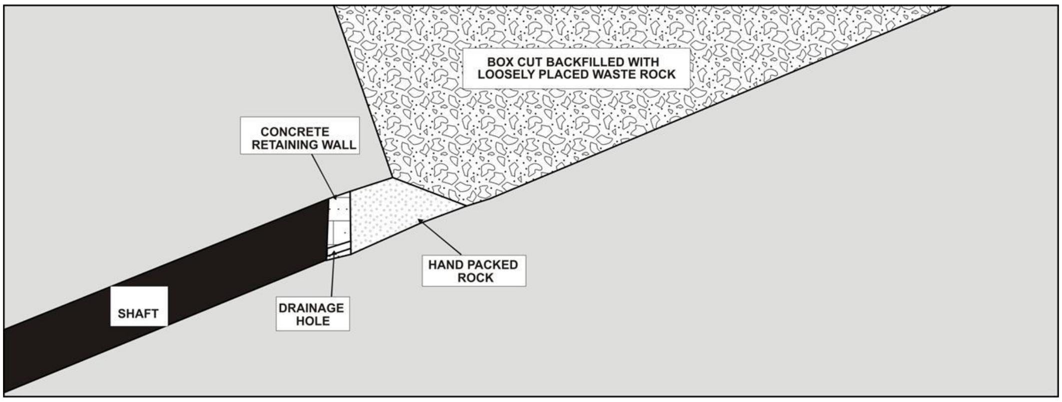


Fig. 4 Schematic diagram showing the rehabilitation of an inclined shaft at the Moshaneng mine following the recommendations of NMA Consulting [14]

DOI: 10.5963/IJEP0408001

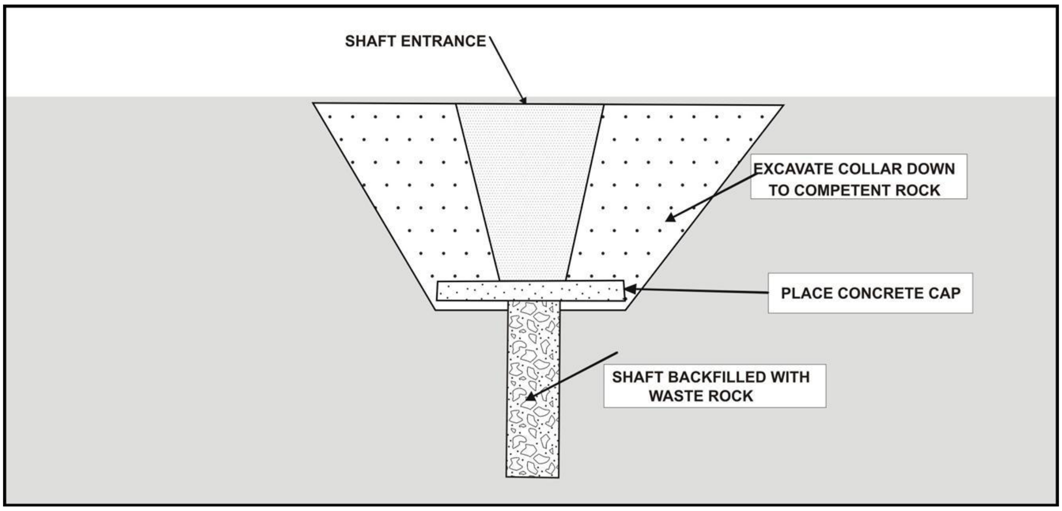


Fig. 5 Schematic diagram showing the rehabilitation of a vertical shaft at the Moshaneng mine following the recommendations of NMA Consulting [14]

IV. EVALUATION OF THE REHABILATION WORKS

The present study was carried out to determine how safe the area is for human and animals six years after all of the recommended rehabilitation procedures (Table 1). In order to achieve this, an assessment of the stability of rehabilitated inclined and vertical shafts, as well as analyses of water and air quality in the area were performed. The rehabilitated mine tailings dams were also assessed to determine their stability as well as the effectiveness of the cover soil placed over the tailings to prevent erosion, and any associated pollution of water and soils in the area.

A. Assessment of the Vertical Shafts and Inclined Shafts

The assessment of these shafts consisted of visual inspecting of the closed shafts to determine if they were intact or not. The visual inspection indicated that all the rehabilitated vertical shafts remained intact, while six rehabilitated inclined shafts have collapsed (Fig. 6).

Fig. 6 Pictures showing the collapsed rehabilitated shafts

B. Assessment of Rehabilitated Tailing Dumps

Mine waste dumps were observed to have been graded, with top soil that was collected from a nearby area and placed on top of the graded tailing dumps. However, there was not enough top soil placed on top of the dumps, leaving sections of the tailing dumps without soil cover. Also, where soil cover was provided, the layer was thin and proved to be insufficient. There were sections of the tailing dump sites that had eroded. As a result of this erosion, there was no vegetative cover on the mine waste tailings dump material (Fig. 7). Additionally, a pond had formed on the southern side of the tailings dump marking the

DOI: 10.5963/IJEP0408001

area where soil material had been removed to be placed on top of the graded mine waste dumps.

Fig. 7 Photograph showing erosion of the rehabilitated waste dump materials

V. ASSESSMENT OF WATER, AIR AND SOIL MINERALOGY IN THE MOSHANENG MINE AREA

A. Water Quality

The shafts in the Moshaneng mining area had either collapsed or were sealed during the preliminary rehabilitation works [21]. Therefore, it was not possible to collect water from these shafts for laboratory testing. Only water from the pond (Fig. 8) could be collected to determine the impacts of tailings on surface waters. Thirteen elements (Na, Ca, Mg, K, Cu, Mn, Cd, Fe, Pb, As, Hg, Si, Ti and Zn) and physical/chemical parameters (pH, conductivity (EC), turbidity and total dissolved salts (TDS)) were measured using standard methods and equipment including atomic absorption spectrophotometer (AAS) for the thirteen elements, a conductivity pocket meter (Model: WTW Cond 330i) and a pH-meter (Model pH 340i) for conductivity, pH and TDS respectively. The results for the most common elements, EC, TDS and alkalinity are summarized in Table 2, and indicate that the pH of the pond water and decant from the asbestos mineral tailings sites (DS1 and DS2) ranged between 8.1 and 8.6.

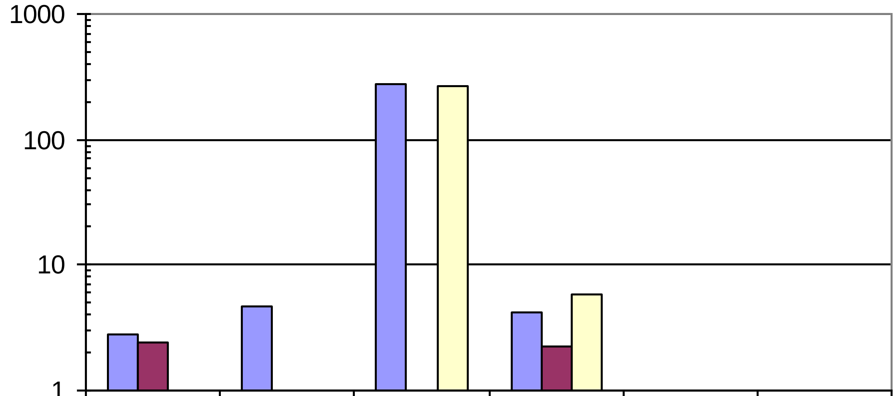
Fig. 8 Water collecting at a pond at the Moshaneng mining area. Note the cattle drinking from the pond

TABLE 2 PHYSICAL AND CHEMICAL PARAMETERS IN SURFACE AND POND WATERS IN THE MOSHANENG MINE AREA

Sample Point	**EC**	**pH**	**Na**	**K**	**Ca**	**Mg**	**TDS**	**Alkalinity**
	mhos		**ppb**		**mg/l**			
Pond Water	653	8.15	40.4	7.08	31.5	12.9	398	106.44
DS1	573	8.59	43.6	1.88	19.2	14.1	349.5	56.02
DS2	215	8.34	33.1	1.09	8.62	4.93	131.15	100.79

DOI: 10.5963/IJEP0408001

The concentration of heavy metals including Fe, Cd, Cu, Mn, Pd and Zn were determined from the surface water sources to determine whether there is possibility of metals leaching from tailings during rainy season into the surrounding streams. The results in Fig. 9 show high concentrations of Fe which may have been leached from the asbestos minerals. However, Since leaching of Fe from chrysotile usually only occurs in acidic waters and in neutral or slightly acidic pH waters, the leaching of Fe is more likely to be from the other amphiboles within the dolerites [22].



	Cd	Cu	Fe	Mn	Pb	Zn
Pond	2.83	4.62	278	4.16	0	0
DS1	2.43	0	0	2.28	0	0
DS1 & DS2	0	0	265	5.88	0	0

Fig. 9 Concentration of heavy metals (ppb) in the surface water and leachate

B. Analyses of Composition and Morphology of Asbestos Fibers

Asbestos fibers can be dangerous when inhaled, so it is important to assess the particle sizes to see if they can reach the alveolar region of the lungs [23, 24] as well as the mineralogy. Some studies have shown that certain asbestos minerals may be more toxic than others [14, 15]. *The x-ray diffraction technique (XRD) was used to determine the composition of the fibers*. A typical XRD pattern from the samples is shown in Fig. 10. Fig. 10 shows a small amount of quartz and a large component of calcite is associated with the asbestos. Part of the calcite can be explained by the presence of low-grade metamorphised dolomite. Table 3 shows the mineralogical compositions of the tailings and stream sediments from the mining. The samples were selected randomly from just below the surface on the tailing piles. Both fine and coarse grain samples were collected. The amount and type of minerals varies greatly as expected, given the wide compositional range of the Moshaneng Complex [18].

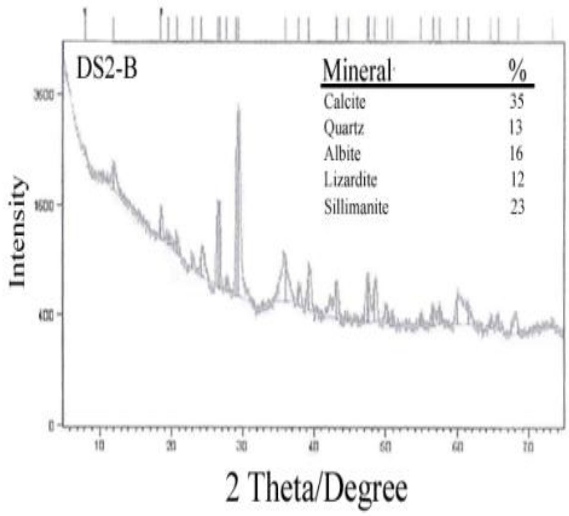


Fig: 10 An XRD spectrum of a waste dump sample showing its mineralogical composition

DOI: 10.5963/IJEP0408001

TABLE 3 MINERALOGICAL COMPOSITION OF TAILINGS SAMPLES AND STREAM SEDIMENTS

	Mineral content of samples (%vol)																				
	Quartz	**Bytownite**	**Lizardite**	**Sillimanite**	**Lepidolite**	**Albite**	**Spessartine**	**Albite Low**	**Calcite**	**Bavenite**	**Enstatite**	**Orthoclasee**	**Diopside**	**Muscovite**	**Albite high**	**Augite aluminian**	**Clino enstatite**	**Anortite 0rdered**	**Sericite**	**Sanidine**	**Microcline**
Sample	TAILING DUMPS SAMPLE POINTS																				
DS1-A	11	22	-	18	-	-	-	-	-	-	-	-	-	-	14	-	-	35	-	-	-
DS1-B	28	-	-	-	-	-	-	-	2	-	18	12	3	37	-	-	-	-	-	-	-
DS1-D	35	-	8	-	-	-	-	-	1	-	-	24	7	11	-	-	14	-	-	-	-
DS1-E	3	-	16	-	22	-	-	-	39	-	-	-	-	-	-	20	-	-	-	-	-
DS2-A	11	-	7	16	-	-	-	-	15	3	-	-	-	-	-	-	-	-	-	-	-
DS2-B	13	-	12	23	-	-	-	-	35	-	-	-	-	-	18	-	-	-	-	-	-
DS1&DS2	22	-	-		-	-	-	-	5	-	21	-	-	-	7	9	-	-	-	35	-
	STREAM SOIL SAMPLE POINTS																				
SPA	29	-	-	-	-	35	-	-	5	-	-	31	-	-	-	-	-	-	-	-	-
SPC	16	-	-	-	-	14	-	-	-	-	-	-	-	-	-	-	-	23	32	-	15
SPD	21	-	-	-	11	-	-	10	-	-	-	-	-	32	-	-	-	-	-	-	-

The morphology and particle sizes were determined using a scanning electron microscope (SEM) and the elemental composition of the fibers was estimated using energy dispersive x-ray spectrometry (EDS) on the SEM. The asbestos particles were found to be predominantly fibrous in shape and ranging in size from 0.35mm to less than 1 µm (Figs. 11-13) with approximately 15% of these particles fine enough to be inhaled (Fig. 12).

Asbestos mineral samples collected from the tailings dumps that were analysed for elemental composition using the EDS, yielded a variety of spectra for the elements (Fig. 14). The spectra showed a wide range in the compositional variation between the different samples. Using two samples to illustrate these variations, one sample (se001) contained Mg, Si, Ca and Fe while sample se002 contained Mg, Si, Ca, Fe Na, Al, K, Ti and Mn (Fig. 14 and Table 4). Table 4 shows the EDS results on various locations (particle number) on the two samples. Results show that Mg and Fe are present in both samples. This analysis did not show that the analyzed minerals were chrysotile but were asbestos minerals that contained Fe, and the elemental composition of the asbestos minerals in the dumps have a wide range of elements in them.

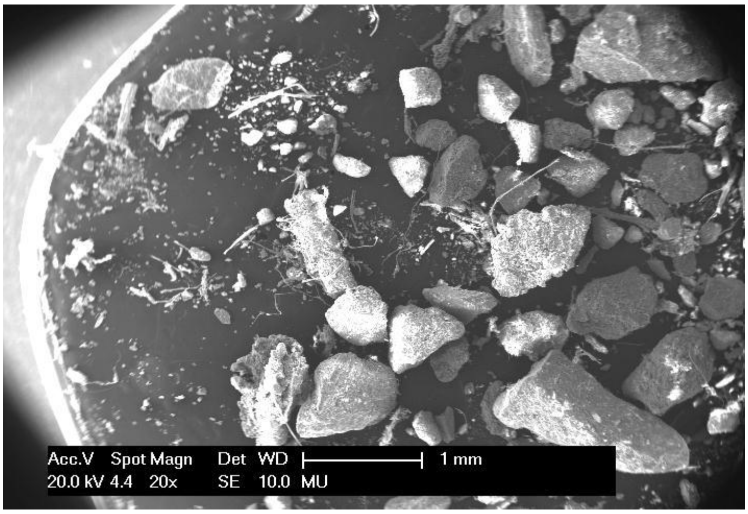


Fig. 11 Asbestos mineral particles from the tailings dumps as seen using scanning electron microscopy

DOI: 10.5963/IJEP0408001

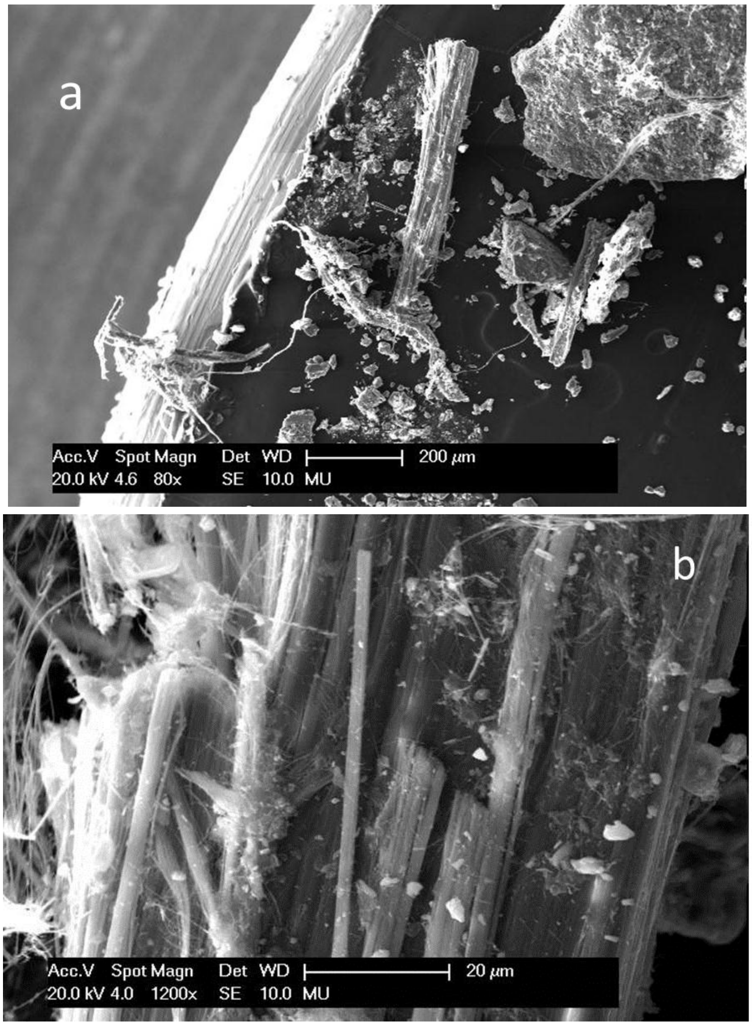
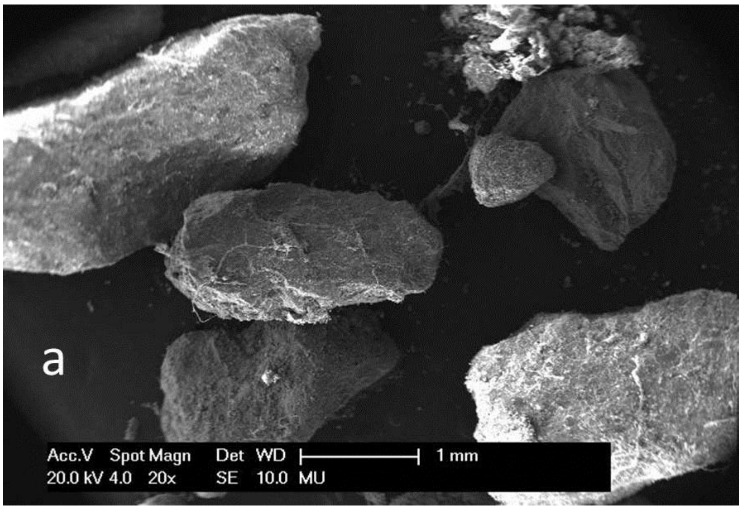


Fig. 12 Example of bundles of fine asbestos mineral fibers dust seen using scanning electron microscopy on tailings dump samples



DOI: 10.5963/IJEP0408001

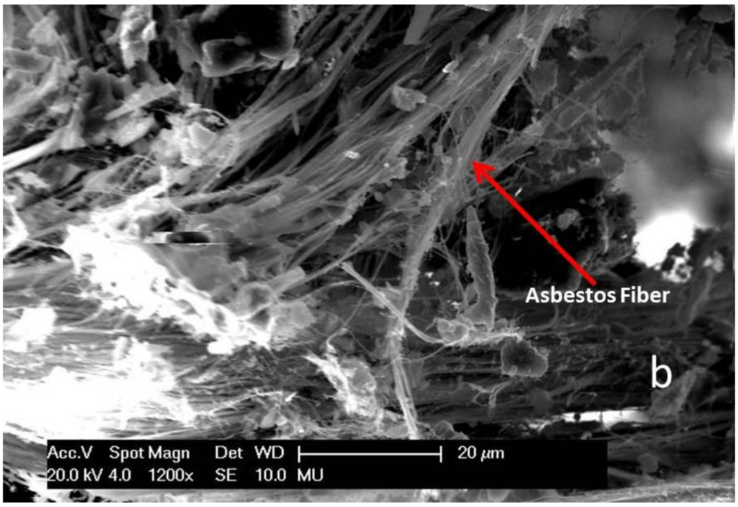


Fig. 13 Identification of fibers from coarse asbestos particles in the tailings dump samples using scanning electron microscopy

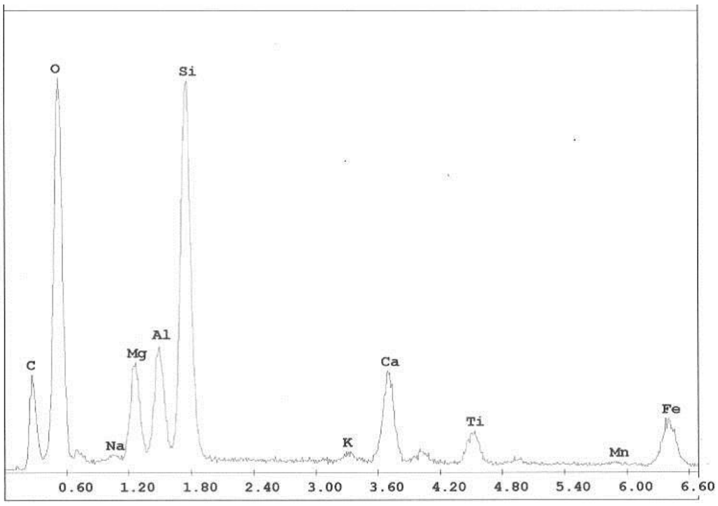


Fig. 14 Example of the electron microscope spectrum of elements of an asbestos tailings particle

TABLE 4 ELEMENTAL ANALYSIS OF ASBESTOS FIBERS IN WT%

Sample ID	Particle #	C	O	Na	Mg	Al	Si	K	Ca	Ti	Mn	Fe	S	Cl	Total %
se001	1	17.14	46.61	0	16.44	1.73	9.36	0	7.19	0	0	1.13	0.18	0.23	100
	2	21.7	44.57	0	14.02	0.45	8.86	0	9.59	0	0	0.81	0	0	100
	4	19.22	45.95	0	17.53	0	12.04	0	5.27	0	0	0	0	0	100
	5	47.18	0	0	28.03	0	0	0	0.84	0	0	0.77	0	0	100
	6	18.32	50.25	0	14.64	0.24	5.92	0	10.1	0	0	0.53	0	0	100
	7	54.56	0	0	22.83	1.11	16.36	0	4.34	0	0	0.82	0	0	100
\se002	1	18.38	46.21	0	13.44	0.34	9.28	0	12.35	0	0	0	0	0	100
	2	13.81	49.59	0	16.32	0	11.24	0	9.03	0	0	0	0	0	100
	3	23.62	42.42	0.45	4.04	3.84	12.68	0.4	4.25	2.13	0.29	5.89	0	0	100
	4	20.05	44.69	0	11.75	0.56	8.38	0	13.64	0	0	0.92	0	0	100

C. Assessment of Air Quality – Particulate Matter in Air Samples

For the analysis for the occurrence of asbestos mineral fibers in the air 100 meters from the Moshaneng mine, passive air samples were drawn through a filter by a vacuum pump (at a flow-rate of around 1–2 L/minute), and the fibers retained on the filters were examined microscopically. After a mild ultrasound treatment to disperse the fibers uniformly into a known volume of the water, the sample was filtered through a 0.1 um pore size Nuclepore® polycarbonate filter. A carbon coating was then applied in vacuum to the active surface of the filter. The carbon layer coats and retains in position the material which has been collected on the filter surface. A small portion of the carbon-coated filter was placed on an electron microscope grid, and the polycarbonate filter material was removed by dissolution in an organic solvent. The carbon film containing the original particulate, supported on the electron microscope grid, was then examined in a SEM at a magnification of 20,000.

DOI: 10.5963/IJEP0408001

There was a large variation in sizes of the chrysotile fibrils. Particles of larger size than the single fibril were almost impossible to define by any single parameter as strands composed of large numbers of fibrils often branched at their ends and intertwined with other strands to become irregular aggregates. Fig. 15 a and b show the SEM image of the air sample. Both images show that chrysotile fibrils are present in the air surrounding the Moshaneng mine. The small diameter (the majority of the fibers were < 5 μm and most were < 1 μm) and longer size (100-200 μm) of the fibrils are considered potentially dangerous as particles less than 5 μm in length are safer [25, 26]. However, there is considerable disagreement on what fiber length represents a potential health hazard [26]. Some researchers consider 1 μm to be the smallest length, while others consider 5 μm to be the smallest length.

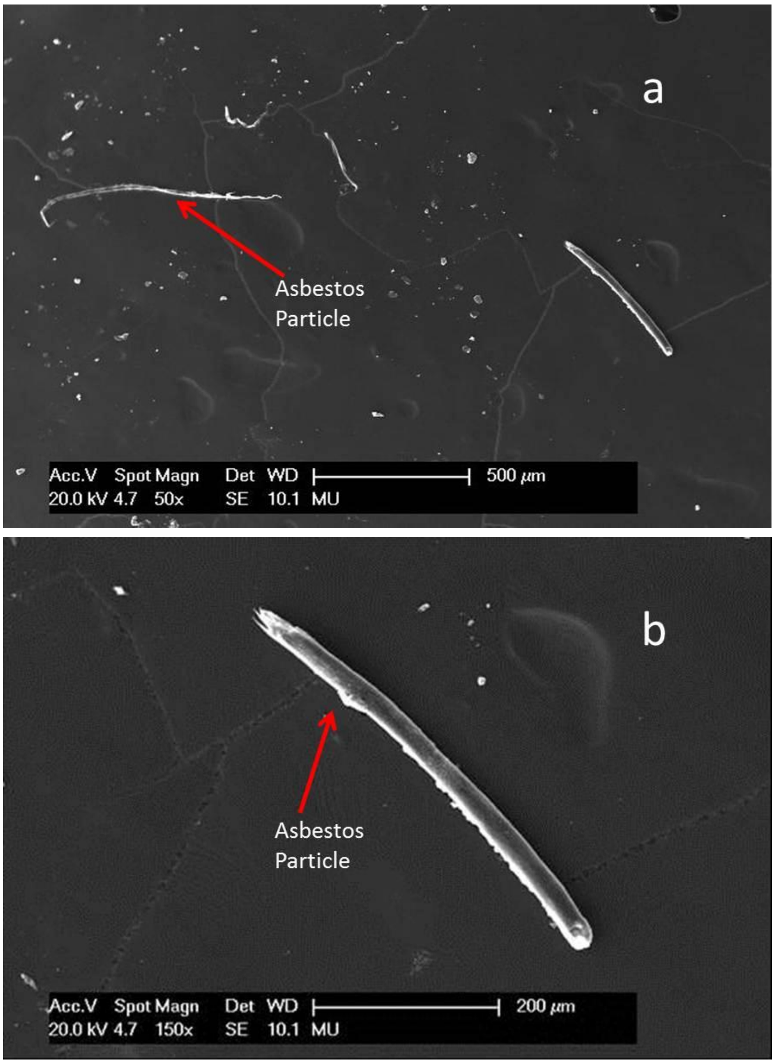


Fig. 15 SEM images of asbestos mineral particles captured from the air surrounding the Moshaneng mine

The characteristics of chrysotile dust varied with the method of production of the particle as the length of fiber depends not only upon the severity of the mechanical action imposed on the sample, but also upon the brittleness or harshness of the mineral [27]. The shape of the asbestos fibers also contributes to the effect caused by their inhalation, as asbestosis is related to the number of shorter, thicker fibers, whereas mesothelioma and lung cancer are related to longer thinner fibers [27, 28, 29]. The chrysotile fibers in our samples were generally between 100 and 200 μm in length.

VI. DISCUSSION AND CONCLUSIONS

The above analysis of the reclamation at the Moshaneng asbestos mining region indicates that the applied reclamation processes after closing of the mine did not completely rehabilitate the area. While all reclamation procedures were applied at Moshaneng mining area as prescribed by the consulting company [21], it appears that the recommended rehabilitation methodology for the inclined shafts was inadequate. As seen in Fig. 4, loose rubble was placed at the entrance of the inclined shafts that did not completely solve the potential problem of shaft collapse. The concrete slab was then covered with another layer of loose rubble. The surface water has now eroded the sides of the concrete slab, and the loose rubble has fallen into the inclined shafts (Fig. 6). The movement of the material into the shafts around the slabs will continue every rainy season until the shafts are open again.

DOI: 10.5963/IJEP0408001

At the Moshaneng mining area, tailings from the mining process were piled on the ground as dumps with some steep slopes (Fig. 7). During the rain events, the asbestos mineral tailings are washed away to the streams and ponds in the vicinity of the mine (Fig. 8). Our analysis showed that the surface water was alkaline and contained high levels of Mg. *However, since samples were not obtained we before the reclamation (to establish as baseline),* one cannot conclude that leaching of the asbestos minerals was the cause of the high levels of Mg. High levels of Mg and alkaline surface waters have been noted at other asbestos mineral mining regions [21]. Reference [29] analyzed samples from 12 different sites along the Becancour River in Quebec, Canada, found that the asbestos mineral pollution was high (>107 fibers/l) and the amount of fibers decreased downstream. They associated higher levels of Ca with the presence of actinolite and tremolite, while higher levels of Fe were associated with actinolite and anthophyllite. They also found high levels of Mg were common to all forms of asbestos minerals. Our results show that high levels of Mg and Ca (Table 2) were associated with mostly chrysotile and lesser amounts of tremolite and actinolite.

Surface water used as drinking water source may also become contaminated with asbestos fibers. Surveys of asbestos concentrations in raw and treated water in the United Kingdom have been reported in some drinking water containing asbestos fibers, at concentrations from none detectable to 1 million fibers/L [30]. While the amount of fibers were not measured at the Moshaneng mining area, the presence of leached metals in the surface waters suggest that fibers may be present in the water. Future studies of the Moshaneng mining area must include a fiber analysis within the surface waters, as there is inconclusive evidence that asbestiform minerals may increase the risk of intestinal cancer [31].

Air samples taken at the Moshaneng mining area showed that samples contained fine-grained asbestos minerals. The size of the asbestos indicated that they pose a threat to human health.

The detection of asbestos fibers in the air samples around the Moshaneng mines likely represents the most serious environmental problem. Exposure to asbestos fibers does not produce immediate acute effects other than some irritancy of skin, eyes and lungs with high concentrations [32]. Temporary breathing difficulties have been reported in individuals exposed to high concentrations of asbestos dust [28]. *Most health problems related to airborne asbestos fibers occur due to long term exposure to asbestos. This long term exposures will lead development of health problems (e.g., mesothelioma) inside and outside of the lungs* [32].

Within the Moshaneng mining area, a major concern is the weathering of the tailing piles due to fibers that can become airborne if asbestos-bearing rocks within the tailings piles are disturbed by natural erosion or human activities. The air samples collected at the Moshaneng mining region did contain asbestos fibers, more samples are necessary to determine the extent of the airborne asbestos fiber problem.

In conclusion, from the analysis of the reclamation efforts at the Moshaneng asbestos mining area, specific areas of concerns were determined. The closing of the inclined and vertical shafts was incomplete. Additional efforts are needed to ensure that the shafts will not collapse. The chemical and mineralogical analysis of surface water, tailing and air samples indicated that asbestos minerals or its leached product are present in all three sites. The mineralogical analysis showed that the dominant type of asbestos mineral at the Moshaneng mining area is chrysotile even though tremolite and actinolite asbestiforms do also occur in small amounts in the mining area. The most dominant minerals found in the asbestos tailings are quartz, calcites and sillimanite. Most of the minerals found in the tailings dumps were however, not found in the stream sediments/soils which may indicate that the eroded soils only extend to the bottom of the tailings dumps and are being stopped by the vegetation surrounding the dumps. The experimental results show that heavy metals (Cd, Fe and Mn) and other metals found in the ore (Mg, Ca and K) are leaching from the tailings into to the nearby pond, affecting the quality of water used by domestic livestock.

Lastly, air samples contained asbestos fibers. This poses a risk to the local community in Moshaneng. A risk analysis is beyond the scope of this project especially since only one air sample was obtained. However based on the US EPA guidelines [32], the risk to humans is low, since the activities that usually increase the possibility of asbestiforms in becoming airborne *are* not occurring at the site. These include motocycle riding, all terrain vehicle (ATV) riding and off-road truck riding. However, there is some human foot traffic which will increase the amount of asbestiforms in the air. But, studies have shown that hiking does not increase the asbestiform concentrations to levels high enough to be a hazard to humans [32].

REFERENCES

[1] D. Franks, "Management of social impacts of mining," in SME Mining Engineering Handbook, Society of Mining Engineering, 3rd ed., pp. 1817-1825, 2011.

[2] M. C. Betournay, "Underground mining and its surface effects," in Interstate Technical Group on Abandoned Mines, Fourth Biennial Abandoned Underground Mine Workshop, Davenport, Iowa, USA, 2002.

[3] A. Altun, I. Yilmaz, and M. Yildirim, "A short review on the surficial impacts of underground mining," *Scientific Res. and Essays*, vol. 5, pp. 3206-3212, 2010.

[4] A. Fourie and A. Brent, "A project-based mine closure model (MCM) for sustainable asset life cycle management," *Journal of Cleaner Production*, vol. 14, pp. 1085-1095, 2006.

[5] P. McCarthy, "Rehabilation of old mines," Australian Mining Consultants (Pty) Ltd., Melbourne, Australia, 2004.

DOI: 10.5963/IJEP0408001

[6] C. Skinner, M. Ross, and C. Frondel, "Asbestos and Other Fibrous Materials: Mineralogy, Crystal Chemistry and Health Effects," Oxford University Press, 1988.

[7] C. Skinner, "Mineralogy of asbestos minerals," *Indoor and Built Environment*, vol. 1, pp. 1-5, 2003.

[8] B. Case, J. Abraham, G. Meeker, F. Dooley, and K. Pinkerton, "Applying definitions of "asbestos" to environmental and "low-dose" exposure levels and health effects, particularly malignant mesothelioma," *Journal of Toxicology and Environmental Health*, vol. 14, pp. 3-39, 2011.

[9] http://health.usgs.gov/inhalation/asbestiform.html.

[10] R. Perkins and B. Harvey, "Method for the determination of asbestos in bulk materials," EPA Report 600/R-93-116, pp. 98, 1993.

[11] R. Brownson, K. Warner, and J. Rosenthal, "Current and historical American asbestos regulations," Report by Brownson and Ballou, PLLP, pp. 23, 2012.

[12] New Jersey Department of Environmental Protection, "Guidance document for the management of asbestos-containing material (ACM)," http://www.nj.gov/dep/dshw/rrtp/asbestos.htm, 2013.

[13] B. Van Gosen, "The Geology of asbestos in the United States and its practical applications," *Environmental and Engineering Geosciences*, vol. 13, pp. 55-68, 2007.

[14] Agency for Toxic Substances and Disease Registry (ATSDR), "Case studies in environmental medicine: Asbestos toxicity," US Department of Health and Human Services, Atlanta, US, 1997.

[15] J. Hodgson and A. Darnton, "The quantitative risks of mesothelioma and lung cancer in relation to asbestos exposure," A*nnals of Occupational Hygiene*, vol. 44(8), pp. 565-601, 2000.

[16] D. Bernstein and J. Hoskins, "The health effects of chrysotile: current perspective based upon recent data," *Regulatory Toxicology and Pharmacology*, vol. 45, pp. 252-264, 2006.

[17] D. Cullen, "Preliminary report on the geology in the vicinity of the Moshaneng asbestos mine," *Internal Report of the Geological Survey of Botswana*, 1955.

[18] R. Mapeo, A. Kampunzu, L. Ramokate, F. Corfu, and R. Key, "Bushveld-age magmatism in southeastern Botswana: evidence from U-Pb zircon and titanite geochronology of the Moshaneng Complex," *South African Journal of Geology*, vol. 107, pp. 219-232, 2004.

[19] D. Aldiss, A. Tombale, R. Mapeo, and M. Chipe, "The Geology of the Kanye Area" Bulletin 33, Geological Survey Department, Lobatse, Botswana, 1989.

[20] A. Walker, R. Key, G. Pouliquen, G. Gunn, J. Sharrock, I. McGeorge, M. Koketso, and J. Faff, "Geophysical modelling of the Molopo Farms Complex in southern Botswana; Implications for its emplacement with in the ~ 2 Ga large igneous provinces of southern and central Africa," *South African Journal of Geology*, vol. 113, pp. 381-400, 2009.

[21] NMA Consulting (Pty) Ltd., The Moshana Old Asbestos Mine Rehabilitation Study. Draft Report. Department of Mines, Ministry of Minerals, Energy and Water Affairs, Botswana, 2003.

[22] H. Shreier, "Asbestos in the Natural Environment" Studies in Environmental Sciences 37, Elsevier Science Publishing, 1989.

[23] M. Kadiiska, A. Ghio, and R. Mason, "ESR investigation of the oxidative damage in lungs caused by asbestos and air pollution particles," *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, vol. 60, pp. 1371-1377, 2004.

[24] C. Manning, V. Vallyathan, and B. Mossman, "Diseases caused by asbestos: mechanisms of injury and disease development," *International Immunopharmacology*, vol. 2, pp. 191-200, 2002.

[25] R. Dodson, S. Hammar, and L. Poye, "A technical comparison of evaluating asbestos concentration by phase-contrast microscopy (PCM), scanning electron microscopy (SEM), and analytical transmission electron microscopy (ATEM) as illustrated from data generated from a case report," *Inhalation Toxicology*, vol. 20, pp. 723-732, 2008.

[26] Eastern Research Group, Inc., "Report on the expert panel on health effects of asbestos and synthetic vitreous fibers: The influence of fiber length," Report prepared for the Agency for Toxic Substances and Disease Registry, Division of Health Assessment and Consultation, Atlanta, GA, 2003.

[27] S. Speil and J. Leineweber, "Asbestos minerals in modern technology," *Environmental Research*, vol. 2, pp. 166-208, 1969.

[28] Risk Assessment Information System (RAIS), "Toxicity summary for asbestos," Chemical Hazard Evaluation and Communication Group, Biomedical and Environmental Information Analysis Section, Health and Safety Research Division, Oak Ridge National Lab, Oak Ridge Tennessee, 1997.

[29] International Programme on Chemical Safety (IPCS), "Chrysotile asbestos," Environmental Health Criteria 203, WHO. Geneva, 1998.

[30] S. Monaro, R. Landsberger, R. Lacomte, and P. Paradis, "Asbestos pollution levels in river water measured by proton-induced X-ray emission (PIXE) techniques," *Environmental Pollution*, vol. 5, pp. 83-90, 1983.

[31] K. Cantor, "Drinking water and cancer," *Cancer Causes and Control*, vol. 8, pp. 293-308, 1997.

[32] World Health Organisation (WHO), "Air quality guidelines for Europe," WHO Regional Publications, European Series, No. 91, 2nd ed., WHO Regional Office for Europe, 2000.

DOI: 10.5963/IJEP0408001