Spatial epidemiology risk assessment for rehabilitated former asbestos mining areas in Limpopo Province, South Africa, using remote sensing and conventional analytical methods

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The aim of this study was to conduct a comparative analysis using remote sensing and conventional sample analysis to assess asbestos pollution in rehabilitated former asbestos mining areas. The study focused on the Mafefe and Mathabatha areas of Limpopo Province, South Africa. Field-based remote sensing techniques were used to spectrally differentiate various types of asbestos minerals in order to determine their efficacy in assessing asbestos pollution. X-ray diffraction and scanning electron microscopy were employed for the identification and characterisation of traces of asbestos minerals in soil and water samples collected from the rehabilitated areas. The samples were also examined using in situ remote sensing. An Analytical Spectral Devices field spectrometer was used for spectral analysis of asbestos minerals and that of soil and water samples to compare and validate reflectance spectroscopy findings with laboratory results. Results show that in situ remote sensing techniques are able to reveal traces of asbestos minerals on rehabilitated dry surface areas, suggesting that they can play a significant role in monitoring the distribution of the asbestos minerals for epidemiological risk assessment. However, the spectral characteristics of asbestos minerals in the water medium were not as distinct as compared to laboratory methods. Overall, the results show potential for using remote sensing techniques in spatial epidemiology studies.

Introduction

Epidemiology study factors affect the health and illness of people and provides the starting point for the necessary interventions for the purposes of public health and preventive measures. The focus is on the determinants and distribution of disease frequency, in the interests of public health management. Spatial epidemiology assesses the distribution of the disease, thereby providing analysis and description of the geographic variations in the disease in line with the socioeconomic, environmental, demographic and infectious behaviour, among others. It, most importantly, helps in determining the relationship between the disease and potential environmental hazards.

Asbestos exposes people to chronic lung diseases, due to the inhalation of asbestos fibres, and is characterised by diffuse interstitial fibrosis, frequently associated with pleural fibrosis or pleural calcification. The pulmonary fibrotic changes develop slowly over the years. Asbestos causes cancer of the lung, malignant mesothelioma of the pleura and peritoneum, cancer of the larynx and certain gastrointestinal cancers. The risk of these diseases increases in time with cumulative exposure to asbestos fibres. Epidemiological evidence helps in defining and measuring the risks of asbestos exposure. Further epidemiological studies are necessary to determine the relationship between asbestos exposure, particularly the low level exposure, and its potential carcinogenic role with other carcinogens in the evolution of the wide spectrum of human malignancy. This is important also to the postexposure environment to monitor progress and potential risks. This study examined the usefulness of remote sensing in comparison with conventional sample analysis in monitoring postexposure asbestos pollution in the Mafefe and Mathabatha areas of Limpopo Province, South Africa (Figure 1).

Asbestos mining used to be one of the main economic activities in South Africa. The asbestos minerals that used to be mined include amosite (grunerite), crocidolite (riebeckite), chrysotile, anthophyllite and tremolite. The common asbestos minerals which are found in the study area are amosite, crocidolite and chrysotile. The first recorded large-scale asbestos mining in the country started in the Prieska area of the Northern Cape in the 1890s. The mines were owned and operated by a British company known as the Cape Asbestos Company (now Cape Plc). By the 1920s, the company extended its operations into the Limpopo Province at Penge, and later into the Mafefe and Mathabatha areas (Figure 1). As early as the 1930s, the dangers posed by asbestos emerged and, in 1931, the first restrictions regarding asbestos were introduced in Britain. Although such dangers of asbestos became well documented in the 1950s, environmental legislation remained extremely lax and Cape Plc continued to mine in Prieska, Penge and Mafefe and Mathabatha until the company withdrew its investments from South Africa in 1979.

Pollution resulting from former asbestos mines is a serious health concern in South Africa. Mine rehabilitation has been undertaken in Mafefe and Mathabatha as a way of reversing the negative impacts caused by asbestos mining to the environment and rural communities. Despite the Government having invested millions of rands for the implementation of the rehabilitation programme, no monitoring.
and evaluation strategy and protocol have been developed and implemented. As in other parts of South Africa, asbestos rehabilitation has not been monitored in the study area. Rehabilitated former asbestos mining areas tend to have a significant amount of exposed fibres of different asbestos minerals that contaminate water, soil and air. This makes the areas more prone to resurfacing of asbestos fibres and, hence, an epidemiological risk. Ideally, rehabilitation should be able to reduce the exposure of the trace asbestos mineral fibres. The need for monitoring is to detect and determine whether rehabilitation succeeds in reducing such exposure. The conventional monitoring process would involve field spot checks, collection of samples in the field and subsequent analysis of the samples in a laboratory. It would be difficult to follow this process on a regular basis in the Mafefe and Mathabatha areas as the terrain is very rugged and difficult to access for normal field-based monitoring methods. Therefore, lower contact techniques, such as remote sensing, become attractive only if they are able to provide the necessary information. The question that the study reported in this paper sought to answer is whether or not remote sensing techniques could actually provide such necessary information.

The study investigated the feasibility of using remote sensing to spectrally differentiate various types of asbestos minerals through reflectance spectroscopy. As traces of asbestos minerals are considered point sources of pollution, this study will make a contribution towards asbestos monitoring. In this respect, the specific objective was to determine whether traces of asbestos minerals from the soil and water samples of the rehabilitated environments could be identified using spectral signature analysis. Furthermore, the study aims to establish to what extent these results can be used for the purpose of pollution monitoring and spatial epidemiology risk assessment. Conventional laboratory investigations (X-ray diffraction and scanning electron microscopy) were conducted for the identification and characterisation of asbestos minerals in the rehabilitated sites, and also to verify the reflectance spectroscopy findings.

Overview of remote sensing techniques

Remote sensing techniques provide information about objects by recording radiation reflected and/or emitted from such objects. They are based on the understanding that each object reflects or emits radiation in a more or less unique way, and that different objects could be distinguished through their ‘spectral signatures’. The techniques use ‘sensors’ that are normally mounted on satellites and aircrafts. There is also in situ remote sensing under which the sensors could be mounted on some other devices close to the ground, or even hand-held. Reflectance spectroscopy is a form of in situ remote sensing which is normally used in the laboratories or on the ground to record the reflectance properties of the targets/objects. It has traditionally been used to validate data obtained from satellite and airborne sensors. Reflectance and emittance spectroscopy of natural surfaces are sensitive to specific chemical bonds in materials, whether solid, liquid or gas. Spectroscopy has
the advantage of being sensitive to both crystalline and amorphous materials, unlike X-ray diffraction. The advantage of spectroscopy is that it is very sensitive to small changes in the chemistry and/or structure of a material. Variations in material composition often cause shifts in the position and shape of absorption bands in the spectrum. Spectrometry is derived from spectrophotometry, the measure of photons as a function of wavelength. Data acquired by air-borne or spaceborne sensors cannot be considered in isolation, since effective data interpretation requires a detailed understanding of the processes and interactions occurring at the Earth’s surface. In this respect, a fundamental component of understanding hyperspectral sensors is the laboratory and field measurement of the spectral reflectance of different surfaces. Spectroscopy is an excellent tool, not only for detecting certain chemistries, but also at abundance levels unmatched by other tools. For example, each layer of a layered silicate absorbs radiation almost independently from its neighbours. The absorption of photons does not depend on the longer range crystallographic order, as is required to give distinctive X-ray diffraction patterns.

Reflectance and imaging spectrometry have been developed largely for use in geological applications, partly due to the recognition that a wide range of rock-forming minerals has distinct spectral signatures. Numerous publications have provided detailed laboratory spectra of rocks and minerals and their mixtures, as well as accurate analyses of absorption features, many of which have been obtained from laboratory measurements. These serve as spectral references to those measured by ground radiometers or air-borne/space-borne sensors, with spectroscopic criteria applied to identify and map minerals and alteration zones.

Significant advances have been made in the development and application of geographic information systems (GIS) and remote sensing (RS) in the public health discipline. They are used to study the spatial and temporal patterns of diseases. GIS and RS offer powerful means for disease mapping, ecological analysis and epidemiological surveillance. They also significantly assist with the assessment of the distribution of health-relevant environmental factors via interpolation and modelling. They therefore complement conventional ecological monitoring and modelling techniques, making it possible to understand complex relationships in the ecology of diseases. RS provides a unique source of data that can be exploited to characterise climate and land surface variables at different spatial resolutions. It permits the calculation of vegetation indices, land surface temperatures, atmospheric and soil moisture together with rainfall indices. This provides an opportunity to characterise the bioclimatic parameters and other environmental parameters that makes the area prone to diseases. A combination of satellite-derived indices and field-based measurements are often used to characterise factors that make the environment suitable for the spread of diseases. Because disease vectors have specific requirements regarding climate, vegetation, soil and other edaphic factors, and are sensitive to changes in these factors, remote sensing can be used to determine their present and future spread and thereby predicting their distribution. Ecological analysis is targeted on the description of relations existing between the geographic distribution of diseases and environmental risk factors.

With the increase in availability of satellite images (low cost environmental and meteorological data sets), it is becoming more practical for epidemiologists to routinely utilise this information. However, most spatial epidemiology studies use multispectral satellite data, as opposed to hyperspectral sensors. Most regional remote sensing studies on health frequently use data available at local scale to extrapolate at a regional scale.

Several approaches are used in remote sensing to study spatial epidemiology. Inclusive approaches have been described by Herbreteau et al. The vector approach focuses on the analysis of ecological description of the environment, relating it to the risk of the presence of vector-borne diseases. The second is a pathogen approach where remote sensing helps in finding ecological conditions contributing to its survival and dispersion. This applies mostly to water-borne diseases. In these cases, climatic data and the delimitation of water extent or flooding areas will allow identifying hazardous areas. A human vulnerability approach is also used where socioeconomic data and cultural and behavioural information becomes a prerequisite. Satellite information cannot estimate human vulnerability to disease infection if it has no environmental origin or linkage. However, high spatial resolution images can show residential areas and allow calculating distances, for example between houses and hazardous areas. A public health approach can also be utilised to determine the prevalence of certain diseases in relation to the environments to which the patients are exposed. This helps to explain the cause of certain diseases if it becomes a common factor for most members of the population residing or working in a particular area.

Foresti et al used infrared and Raman spectroscopic analysis to investigate the preferred Si and Mg ions replacement by Fe ions, as a function of Fe doping extent in a geoinspired synthetic chrysotile. However, the purpose was to obtain a clear correlation between cytotoxicity and chemical-physical properties of chrysotile fibres with Fe-doped chrysotile modifications. The focus is on the impurities, ion substitutions and structural disorder in mineral chrysotile fibres that affect its chemical-physical properties and its biological-mineral fibre interaction. This investigated the role of these substances in altering the chrysotile fibre and potentially making it more toxic. Results show that the infrared absorption band characteristic of stoichometric chrysotile nanocrystals change frequency for Fe-doped chrysotile. The change is also confirmed using Raman spectroscopic analysis. The structural modification allows hypothesising electrostatic interactions affecting the interlayer bonding and chrysotile fibre stability. The stability is associated to biopersistence closely related to asbestos health hazard. The results showed that Fe can replace both Mg and Si, differently modifying the chrysotile structure as a function of the Fe doping extent.

Materials and methods

Research design and field data collection

The purpose of this research was to investigate the use of remote sensing comparatively with conventional sample analysis to assess the spatial epidemiology risk of the former asbestos mining area. This guided the sampling procedure for selection of long-term monitoring
sites. A systematic random sampling procedure was used to select sample sites for the areas within former mining sites, which covered fully rehabilitated, partially rehabilitated and water bodies in the study area. Within this design, sampling purposely covered significant research sites determined from the field surveys for long-term assessments. All sample sites are within reach of the local population, making it a public health hazard. The same samples were used for both remote sensing techniques (reflectance spectroscopy) and conventional sample analysis. This study did not require prior approval from an ethics committee, as there were no animal and human samples used.

Field surveys were carried out for physical observation of study sites and collection of samples. Forty-eight survey points were randomly selected for the whole project (Figure 2) for physical observations of rehabilitated, unrehabilitated, partially rehabilitated and natural sites. Location of the sample sites was recorded using Garmin V Global Positioning System (GPS) at a resolution of below 20 m. The surveys assessed the extent of degradation and the extent to which mine rehabilitation improves the environment. Samples used in this study are presented in Table 1. Ten soil samples were collected at the rehabilitated areas at a depth of 30 cm using a soil auger. Eight water samples were collected from the river flowing across the rehabilitated sites. Also, six wet soil samples were collected from the riverbed.

**Reflectance spectroscopy**

The collection, detection and recording of spectral reflectance of different asbestos minerals, soil and water samples were conducted using the Analytical Spectral Devices (ASD) FieldSpecFR spectroradiometer. This instrument records the reflectance within the range 350 nm to 2,500 nm. The sampling interval for the FieldSpecFR is 1.4 nm for the region 350-1,000 nm, and 2 nm for the region 1,000-2,500 nm. The full-width-half-maximum (FWHM) spectral resolution of the FieldSpecFR spectroradiometer is 3 nm for the region 350-1,000 nm and 10 nm for the region 1,000-2,500 nm. Spectral reflectance was recorded for each asbestos rock type collected from the rock library of the Council for Geoscience and the soil and water samples that were collected from the study area for laboratory analysis.

On recording the spectral signatures, the ASD field spectroradiometer was first calibrated with a calibration panel before measurements were recorded. The procedure was repeated continually every 15 minutes after taking the readings. This procedure involves optimising the instrument in order to adjust it to the sensitivity of various conditions of illumination. The instrument is then calibrated using a white reference. The spectral reflectance of the targets was then recorded. The analysis of the spectral profiles was conducted using the ASD Viewspec pro software and the output, in the form of spectral reflectance averages and graphs, was exported in an ASCII format for further analysis. The data were then imported to a Microsoft Excel spreadsheet for detailed analysis and interpretation. These included converting the nanometers to micrometers, plotting the graphs and computing the difference spectra. The output showed the presence, distribution and extent of asbestos fibres in the environment.

**Conventional sample analysis**

Sample analyses were conducted using X-ray diffraction (XRD) and scanning electron microscopy (SEM) with energy dispersive microanalysis system (EDS). Major and trace element compositions of the soil samples were determined with the use of X-ray fluorescence spectrometry (XRF). Identification and characterisation of asbestos minerals were done by combination of structural, morphological and chemical information. The structural information of asbestos minerals was obtained as XRD patterns, followed by the identification of the main mineral groups, i.e. serpentine and amphibole. The morphological

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**Table 1: Sample sites**

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<th>Sample</th>
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measurements, which include grain size, shape and habit (e.g. fibrous nature and aspect ratio - L/D, given as length: diameter measurement), were evaluated on an SEM. The chemical composition of individual asbestos particles was determined by EDS attached to the SEM. Sample preparation was applied, appropriate to the nature and state of the material and the various tests assigned for analyses. Samples were submitted in the form of dry soil (10 samples), wet soil (six samples) and eight water samples with visible solid residue. The wet soils (mud) were dried in an oven at 40ºC prior to processing. All soil samples were split; thereafter, a representative portion of each sample was milled and homogenised to a fine powder at approximately 10-15 μm in size for XRD and XRF analyses. The solid component of the water samples was settled by centrifuging and, as quantities allowed, used for XRD and SEM analyses.

XRD was employed to determine the bulk mineral compositions, for which a Siemens D500 diffractometer was used. The samples were run as a random powder preparation, in step scan mode from 2 to 65º 2θ with CuKα(λ = 1.54060) radiation at a speed of 0.02º 2θ steps size/1 min in size for m wavelengths. They can both be separated spectrally at 1.9 m because anthophyllite does not saturate in this region.

SEM was used to determine the amphibole and serpentine polytypes and study their physical appearance. The study also aimed at establishing if asbestiform varieties of these minerals are present based on their crystal morphology and elemental composition. Detailed searches for fibrous mineral occurrences and their chemical characterisation were performed on a Leica 440 Stereoscan SEM with INCA (OXFORD) EDS. The search was done at ~800-1,000 times magnification and the brightness/contrast settings adjusted to emphasise the silicate minerals. The results are presented in form of backscattered electron images for each sample. The BE image contrast is generated by the different average atomic mass of the phases, resulting in different backscatter intensities, e.g. the higher the average atomic mass, the brighter the image of a phase. Mineral chemistry was determined by means of spot analyses with the EDS. Counting time was set as 100 s and probe current at 2 nA with accelerating voltage of 20 kV was used.

**Results**

The results assess the presence of asbestos fibres in the rehabilitated former asbestos mines. They are presented in terms of their type, quantity and different possibilities to detect the fibres using remote sensing and conventional sample analysis. The spectral characteristics of the minerals are used to profile their presence for risk assessment, whereas the conventional analytical methods verify and validate spectroscopy observations identifying samples beyond the detection limits of the spectrometer. The aim was to observe the limits for remote sensing spatial epidemiology assessments.

**Spectral reflectance of asbestos minerals**

The spectral characteristics of different asbestos minerals were recorded and observed. The results, the form of specific spectral reflectance curves, are plotted in Figure 3. The spectral reflectance of asbestos minerals such as crocidolite, amosite, anthophyllite and chrysotile depicts a generally similar pattern of reflectance. A slightly different pattern is observed for tremolite. Similarity of reflectance was also observed between anthophyllite and chrysotile, with variations in the level of reflectance at various wavelengths. Anthophyllite and tremolite show a similar reflectance but saturate at about 1.2-1.4 μm wavelengths. They can both be separated spectrally at about 1.5-1.6 μm because anthophyllite does not saturate in this region when compared to tremolite.

![Figure 3: Spectral profiles of different asbestos minerals](image-url)
Scanning electron microscopy

Figure 4 shows a backscattered electron (BSE) image of the identified asbestos minerals for sample WP58 along with a short description of the morphology of the fibres and their dimensions. The fibre size may not always correspond to actual size either because they are partially exposed or of submicron size. In case of fragment and bundle of fibres, usually the dimensions of the longest and thinnest (smallest diameter) that might potentially be produced is given. The mineral chemistry of selected representative fibre was used in the interpretation of the results. All minerals identified by XRD were also observed here as well as some trace minerals that were below the detection limits of the XRD. These included ilmenite, Ti-oxide, REE-oxides and siliceous diatoms in the water residue samples. The asbestos minerals were identified based on their fibrous or fibre-like morphology and their major element proportions. Some are observed as massive fragments with visible cleavage potentially separating into fibre and others as bundles of more defined fibrous morphology. Serpentine (chrysotile) was positively detected in sample CS2 where it was also identified by XRD. In some cases fibre of chrysotile composition was noted in the water residue samples W3 and possibly, but quite unclear, W10. The identification and characterisation followed a standard recommended by NIOSH.21

Figure 4 shows a BSE image of sample WP58 showing a straight to slightly curved riebeckite and curved fibrous grunerite (dimensions of individual fibre: riebeckite – 56.77 x 0.572 μm and smaller diameter grunerite -9.83 x 0.666 μm).

Figures 5 and 6 show the BSE images of asbestos minerals identified in sample CS1 and sample W3, respectively. The individual fibre size of tremolite found in sample CS1 is 40.53 x 2.880 μm and 15.41 x 0.353 for sample W3 that also have a chrysotile fibre of 45.47 x 5.00 μm. Both CS1 and W3 recorded about 2wt% of amphibole asbestos from XRD. These samples were collected from a stream flowing through rehabilitated areas.

Assessment of asbestos pollution using reflectance spectroscopy

Figure 7 shows the presence of crocidolite asbestos fibres in a soil sample collected at site WP58. The variation in reflectance in regions 0.4-1 μm and 1.7-1.8 μm may be attributed to other components of the soil. The graph for 1_CFL (cork flowing water) represents the reflectance of sample W3, whereas 5_CWS (cork wet soil) represents the reflectance of sample CS1. Both curves do not show any correspondence to the

<table>
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<th>Wt%</th>
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</thead>
<tbody>
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<tr>
<td>WP66/dry soil</td>
<td>40</td>
</tr>
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<td>CS1/wet soil</td>
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<tr>
<td>W3/water</td>
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Table 2: Concentrations of asbestos minerals obtained from soil and water samples using XRD (summarised results) as weighted percentage (Wt%)
crocidolite curve. However, traces of possible asbestos were detected in these samples using conventional analytical methods, i.e. XRD reported 2-4% of amphibole minerals and their fibrous habit was confirmed by SEM. This is either because water absorbs a large proportion of radiation and reflects less back to the sensor, or because of trace concentrations of asbestos in these wet samples. These findings may suggest that reflectance spectroscopy cannot detect asbestos fibres from the wet soil and water samples.

Figure 8 shows the spectral profile of crocidolite and that of a soil sample collected at site WP58. The two patterns compare very well, suggesting that the field spectrometer was able to detect the type and the presence of the asbestos fibres at this dry soil sample.

Field-based reflectance spectroscopy represents the imaging capabilities of satellite-derived hyperspectral sensors at the ground level. The most important aspect is the high spectral resolution that makes it easy to distinguish different minerals as opposed to available multispectral sensors. It is the hyperspectral satellite that brings in the advantage of a high spatial coverage after having explored the mapping possibilities using this field-based study. It is possible to use reflectance spectroscopy to monitor and assess the distribution of asbestos pollution on dry soil. This is done by mapping the presence of the fibres using collected asbestos spectral signatures through hyperspectral image processing and spectral differentiation. These processed field data allow production of accurate maps covering relatively larger areas. However, at present, hyperspectral imaging is at a developing stage for satellite sensors. The satellite data were not available for experimentation in this study.

This research examined possibilities for applications of hyperspectral remote sensing in spatial epidemiology. The study reported in this paper reflects similar findings obtained from studies conducted in North America. The reflectance patterns from the wet riverbed soils and residual water solids could not be associated with any of the asbestos minerals. Water shows generally similar patterns of reflectance and absorption of radiation, whether in the field or in the laboratory. However, the conventional sample analysis showed that serpentine and amphibole minerals are present in low concentrations (2-4%). This is either because water absorbs a large proportion of the solar radiation, or because of trace concentrations of asbestos in these samples. These findings show that reflectance spectroscopy cannot detect asbestos fibres from wet soil and water media and, when monitoring of asbestos in such environments is necessary, remote sensing should be supported by conventional analytical methods. Alternative remote sensing techniques may need to be explored to determine the future possibility of detecting fibres in water, for example microwave/radar sensing techniques.

Overall, conventional techniques showed different capabilities and limitations in detecting the presence of asbestos minerals. Of all, SEM produced the most detailed results that compliment the XRD results. Reflectance spectroscopy was able to detect traces of asbestos in dry soil samples. However, wet soil and flowing water samples showed inconclusive results, which implies that the usefulness of the reflectance spectroscopy in detecting and monitoring the distribution of asbestos is limited to reasonably larger areas on dry land surface. This makes it an important method for spatial epidemiology risk assessment in former asbestos mining land surface areas. Unlike the conventional epidemiological studies, which rely on patient evaluations, this technique would provide much earlier detection of environmental hazards that are risky for public health. Usually, evidence of asbestos-related illnesses in patients takes long after exposure to detect. This makes spatial epidemiology risk assessment using remote sensing a fast and reliable tool for early warning of potential disease detection. Although the study reported in this paper was experimental using in situ remote sensing techniques, the results hold true for hyperspectral remote sensing images as well, as the same sensing instruments are
used on board satellites. This study revealed the presence of asbestos fibres on rehabilitated sites. Except for the water media, remote sensing techniques can be used to monitor asbestos pollution and its spatial distribution over dry land surfaces. This will, however, be limited to hyperspectral imagery.

Implications for public health

Asbestos is a serious health hazard when exposed to the public in its finest form over an extended period. If asbestos polluted environments remain unmonitored, fine particles of asbestos fibres released into the air could reach critical levels and become a hazard. An exposure dosage of 500 fibre years (i.e. 50 years of breathing air with fibre concentration of 10 f/ml) will cause asbestos-related illnesses in most people.23 The Helsinki criteria for the risk of developing lung cancer is an estimated cumulative exposure to 25 fibres per millimeter per year and retained fibre levels of two million amphibole fibres per gram of dry lung tissue.24 Because of chronic effects of asbestos, it may take approximately 30 years before the first signs of asbestos illness are identified in people.22 The level of fine asbestos fibres may increase to higher concentrations in the atmosphere. This is because of land use activities currently continuing on the rehabilitated environments. This study revealed the presence of asbestos fibres on rehabilitated sites using both remote sensing and conventional laboratory-based sample testing techniques. It has demonstrated that remote sensing techniques can be used to monitor asbestos pollution and its spatial distribution over dry land surfaces. As the results hold true for hyperspectral imagery as well, space- and air-borne remote sensing could, therefore, be used to monitor the distribution of asbestos fibres in the environment. Space- and air-borne remote sensing provides less labour intensive opportunities for environmental assessments. They provide data and information for areas that are less accessible on the ground, and their spatial and temporal resolution is continuously being improved. This technique may, therefore, contribute positively to the public health sector for various applications in spatial epidemiology by providing regular, comprehensive and reliable data on pollution. Several hyperspectral sensors are currently under development which will make it possible to map the distribution of asbestos fibres over larger surface area. Current mapping experimentations reveal a promising output, which may be applicable to South Africa.25

Conclusion

The study reported in this paper showed that different types of asbestos minerals can be spectrally distinguished using remote sensing techniques. It also demonstrated that reflectance spectroscopy can be used to monitor the distribution of asbestos minerals over the dry soils of the rehabilitated environments. This was confirmed through the use of conventional analytical methods (XRD and SEM). This study also showed that there is presence of asbestos minerals on the rehabilitated sites. It is important that the findings of this study can be applied with cost-effective, and time-saving compared to detailed laboratory investigations.

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References

7. Tursingh T. The town that battles blue death: where breathing can kill you. True Love Magazine 2000: 258