MISCELLANEA GEOGRAPHICA – REGIONAL STUDIES ON DEVELOPMENT
Vol. 20 • No. 1 • 2016 • pp. 41-46 • ISSN: 2084-6118 • DOI: 10.1515/mgrsd-2016-0007

Mapping asbestos-cement roofing with the use of APEX hyperspectral airborne imagery: Karpacz area, Poland – a case study

Abstract

Asbestos and asbestos containing products are harmful to human health, and therefore its use has been legally forbidden in the EU. Since there is no adequate data on the amount of asbestos-cement roofing in Poland, the objective of this study was to map asbestos-cement roofing with the use of hyperspectral APEX data (288 bands at the spatial resolution of 2.7 m) in the Karpacz area (southwest Poland). A field survey constituted the basis for training and verification polygons in the classification process. A SAM classification method was performed with the following classification results: 62% producer's accuracy, 73% user's accuracy and an overall accuracy of 95%. The asbestos-cement roofing for buildings may be discriminated with a high classification accuracy with the use of hyperspectral imagery. The vast majority of the classified buildings were characterised by their small area (i.e. residential type buildings), which reduced the overall accuracy of the classification.

Keywords

Asbestos • asbestos containing products • SAM classification • APEX data • asbestos removal process • Poland

Małgorzata Krówczyńska[1,2], Ewa Wilk[1,2], Piotr Pabjanek[1], Bogdan Zagajewski[1], Koen Meuleman[3]

[1]University of Warsaw, Faculty of Geography and Regional Studies, Department of Geoinformatics, Cartography and Remote Sensing, Warsaw, Poland;
[2]WGS84 Polska Sp. z o.o., Milanówek, Poland
[3]VITO - Centre for Remote Sensing and Earth Observation Processes

e-mail: mkrowczynska@uw.edu.pl; ewa.wilk@student.uw.edu.pl; p.pabjanek@uw.edu.pl, bogdan@uw.edu.pl

Received: 9 September 2015
Accepted: 26 January 2016

Introduction

According to the World Health Organisation more than 107 thousand people die every year from asbestos-related diseases resulting from exposure at work or in the home (WHO 2014). Since exposure to asbestos causes a wide spectrum of diseases; such as mesothelioma, lung cancer and asbestosis; it was decided that asbestos-related diseases needed to be eliminated. The World Health Organization and the International Labour Organization have recommended discontinuing the use of all types of asbestos (ILO and WHO 2007). The term asbestos refers to a set of minerals: chrysotile (white asbestos), amosite (brown asbestos), crocidolite (blue asbestos), tremolite, anthophyllite and actinolite (Ross et al. 2007). Asbestos fibres have tensile strength, are flexible, resistant to thermal and chemical degradation, may be woven and have a high electrical resistance (Hendry 1965; Ross et al. 2007; Wilk et al. 2014).

Asbestos production has been banned in 55 countries around the world (IBAS 2014). In the European Union, legal obligations have been enforced to ban the use of asbestos containing products since January 1, 2005 with the adoption of the Commission Directive 1999/77/EC of 26 July 1999. Member States were supported in preparing strategies for national asbestos removal programs (Directive 2003/18/EC of the European Parliament and of the Council of 27 March 2003). Poland is the only EU Member State to have adopted an action plan for an asbestos-free country (European Parliament resolution of 14 March 2013). Asbestos production, trade and imports were forbidden in Poland in 1997 by the Act of 19 June 1997.

The vast majority of asbestos-containing products currently in use are asbestos-cement roofing and building construction materials (Collegium Ramazzini 2010). In Poland, two types of asbestos-cement roofing were used: flat and corrugated sheets (Krówczyńska et al. 2014). Based on the estimation that was performed in the Programme for Asbestos Abatement in Poland, there are still about 14.5 million tons of asbestos containing products being used in Poland (PfAAiP 2010). Since these assessments need to be validated, local governments in Poland are obliged to prepare a register listing the amount of asbestos-containing products still in use. A physical counting system through field visits is used, which is a time-consuming and labour-intensive process (Krówczyńska and Wilk 2013). Therefore, it is crucial to propose different methods for evaluating the amount of asbestos-containing products used in Poland, using different data sources.

The mapping and estimation of the amounts of asbestos-cement roofing is of interest to many researchers as it is an important issue to contribute to the process of abatement and monitoring (Krówczyńska & Wilk 2013), and also because of the use of hyperspectral imagery and remote sensing data (Fiumi et al. 2012; Fiumi et al. 2014; Frassy et al. 2014; Iwaniak et al 2002). Mapping of asbestos-cement roofing appeared to be feasible at the local level (e.g. Fiumi et al. 2012 in Magliana, Italy; Fiumi et al. 2014 in Tiburtina, Rome, Italy; Fiumi et al. 2014 in the Lazio Region; Frassy et al. 2014 in the Aosta Valley). The mapping classification accuracy ranges from 48.9% to 75.4% and depends on the size of classified objects (minimum area of 3x3 pixels) according to the survey undertaken in the Aosta Valley (Frassy et al. 2014). The accuracy of the mapping of asbestos-cement roofing, on the basis of tested buildings larger than 150 m^2 (16 pixels) in the Lazio Region of Italy, gave results of67% to 75% (Fiumi et al. 2014). For building

Vol. 20 • No. 1 • 2016 • pp. 41-46 • ISSN: 2084-6118 • DOI: 10.1515/mgrsd-2016-0007

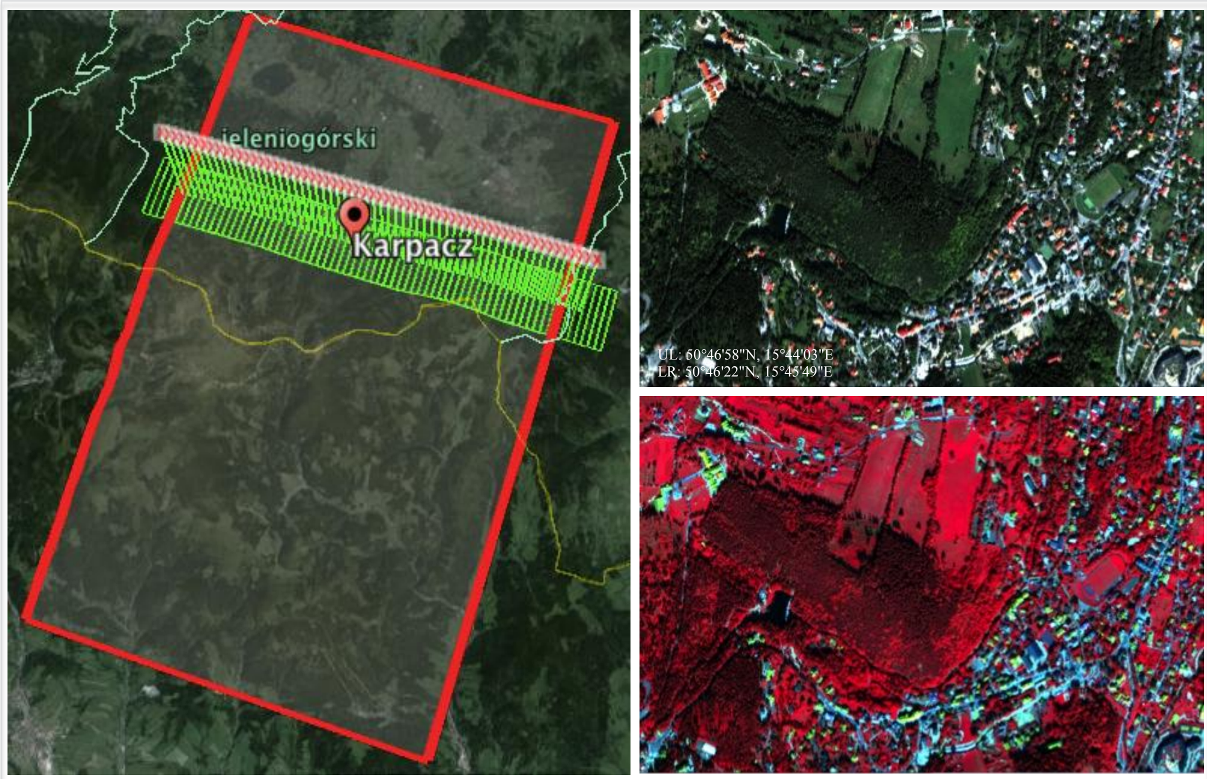

Figure 1.A – The area covered by the APEX, along with the flight plan transect stripes; 1.B. Survey area in RGB composition, 1.C. Survey area in CIR composition

roofing classification, the accuracy obtain by the authors varies from 43% for all types of buildings, to 75% for buildings where the roof area is greater than 3x3 pixels (Frassy et al. 2014, the Aosta Valley). In the area of Debrecen, Hungary the application of the SAM method of classification gave an accuracy of 59.8%, while 79.9% was obtained with the use of the SVM method (Szabo et al. 2014).

The aim of this work is to classify APEX hyperspectral airborne imagery in order to discriminate asbestos-cement roofing in the area of Karpacz, Poland as a potential source of data to enable validation of the amount of asbestos-containing products.

Study area

The study area consists of a section of Karpacz (Figure 1B; Figure 1C), which is a spa town and ski resort in the southwest of Poland next to the border with the Czech Republic. It is the second largest city in the neighbourhood of the Karkonosze National Park, which was the subject of an APEX flight within the HyMountEcos project. The population of Karpacz amounts to 5,062 inhabitants (Local Data Bank 2012). The dominant type of building is residential; there is no industrial area.

The study area is characterised by a large variation in roof coatings. There are various types of roofing materials used in the Karpacz area, for example, concrete tiles, ceramic tiles, sheet metal, roofing sheet, roofing felt, shingle and asbestos-cement roofing. The size of the study area is over 2 km^2, consisting of 757 columns by 400 rows.

Methods

Data Collection

Our survey was undertaken with the use of an airborne (dispersive push broom) imaging spectrometer (APEX) registered with two scanners: VNIR and SWIR. The airborne survey was performed on September 10, 2012 using a Dornier DO-228 plane belonging to DLR Braunschweig, as a part of HyMountEcos project within the EUFAR (European Facility For Airborne Research). The flight plan included fifteen transect strips over the Polish and Czech parts of the Karkonosze National Park and its buffer, which included Karpacz (Figure 1A). The APEX imagery taken, covers a wavelength range between 0.4134 μm and 2.4478 μm, with 288 spectral bands at the spatial resolution of 2.7 m.

Field survey

Data on the types of roofing materials were collected during the fieldwork. The field survey for calibration purposes was carried out on July 6 to 13, 2012. During the fieldwork, the orthophoto map printouts were used with assigned symbols to differentiate the following attributes: type of asbestos roofing (flat or corrugated asbestos sheets), type of roofing, colour of roof, roof slope and location (Figure 3). Data gathered during the fieldwork was digitalized; building outlines were developed and then assigned attributes collected during the fieldwork. This information has been used further, for the classification process and the evaluation of the results.

Image processing

The atmospheric and geometric correction of the imagery used in the survey was performed by VITO (Belgium), the APEX data supplier. Further analyses were performed using ENVI 5.0 software. The original set was composed of 288 spectral bands. Taking into account the previous survey on hyperspectral data, the APEX data was spectrally reduced to form a subset after removing noisy bands and zero-value data by means

Vol. 20 • No. 1 • 2016 • pp. 41-46 • ISSN: 2084-6118 • DOI: 10.1515/mgrsd-2016-0007

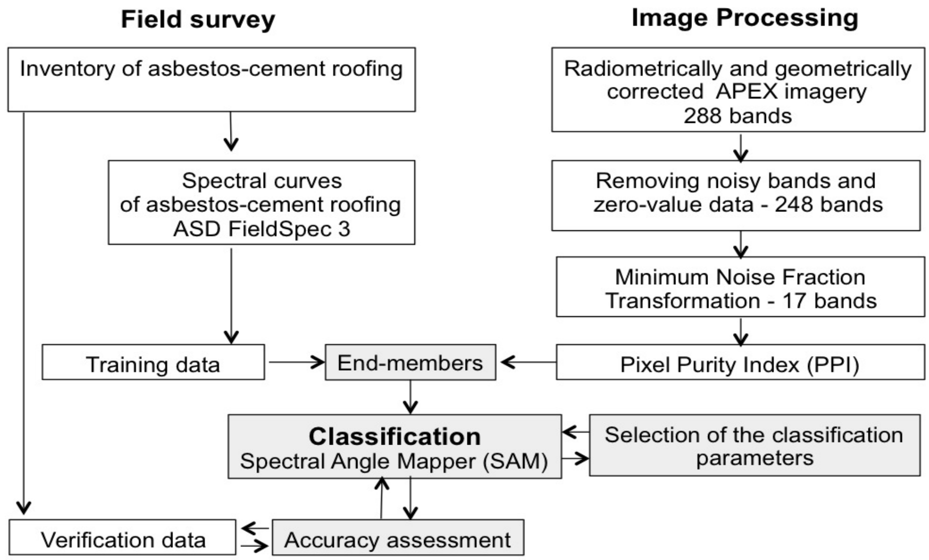

Figure 2. Workflow
Source: own study

Figure 3. Asbestos-cement building roof covering A– corrugated asbestos cement sheets, B – flat asbestos cement sheets
Author: Małgorzata Krówczyńska

of the visual interpretation (Shahtahmassebi et al. 2013; Frassy et al. 2009). After the removal of the noise from the data, the basis for the survey consisted of 248 bands. Rejected bands were characterized by an aberrant response to spectral bands in the following wavelengths: 1.3256–1.4509 μm and 1.7676–1.9701 μm. The process of data normalization and reduction of the residual noise was executed through the use of the Minimum Noise Fraction (MNF) transformation (Green et al. 1988; Frassy et al. 2009; Frassy et al. 2013). Based on the final eigenvalues and the spatial distribution of the MNF bands, the inflection line chart has been placed in band 17; for the further analysis of the 17 bands, MNF transformations were adopted.

The MNF transformation was elaborated on because, in further analysis, the Pixel Purity Index (PPI) was enhanced in order to find the most spectrally pure pixels in the hyperspectral imagery: the implementation of the PPI requires MNF transformation (Green et al. 1988; Lee et al. 1990). The volume of spatial data was reduced by using the Pixel Purity Index (Boardman et al. 1995). The PPI was used for the end-member extraction; it was run with 10 thousand iterations using a threshold of 2.5 standard deviations. The image end-members were then compared to the field inventory of the asbestos-cement roofing results. Pure asbestos-cement pixels were extracted from the confluence of these two layers; then they were compared to the spectral curves of the asbestos-cement roofing acquired under laboratory conditions with the use of the ASD FieldSpec 3 Spectroradiometer within the wavelength range of 350 nm to 2,500 nm. The selected spectral curve acquired from the PPI, was the most similar in shape to the one obtained under laboratory measurements.

For classification purposes, 17 bands of MNF transformation were used. The mapping of asbestos-cement roofing was performed using the Spectral Angle Mapper (SAM) algorithm. The selection of classification parameters was adjusted using a trial and error approach on the basis of the 15 test samples of asbestos-cement roofing mapped during the field survey. The workflow is presented in Figure 2.

Vol. 20 • No. 1 • 2016 • pp. 41-46 • ISSN: 2084-6118 • DOI: 10.1515/mgrsd-2016-0007

Table 1. Classification accuracy results for the asbestos-cement roofing for buildings in the Karpacz area

Classification accuracy				
Class	**producer's accuracy**	**user's accuracy**	**omission error**	**commission error**
Asbestos-cement roofs	61.54%	72.73%	38.46%	27.27%
Other roofs	97.98%	96.68%	2.02%	3.32%
Overall accuracy	95.05%			
Cohen-Kappa coefficient	0.64			

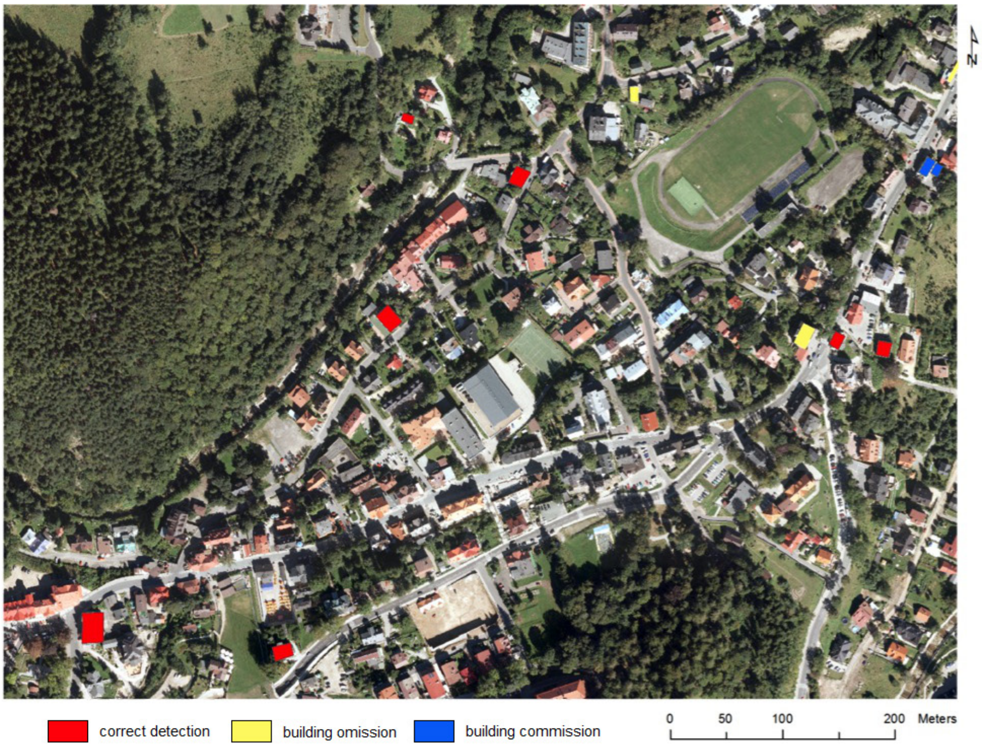

Figure 4. Asbestos-cement roofing in the study area
Source: own study based on geoportal.gov.pl

Results and discussion

During the field survey, data on 26 asbestos-cement roofs were acquired; 16 of these asbestos buildings were classified correctly using the SAM algorithm, with 62% producer's accuracy. In the output image, 22 asbestos-cement roofs were classified; of which 16 were detected correctly, which gave a 72.7% user's accuracy (Table 1). Classification results are presented in Figure 4.

Validation showed a larger omission error of 38% than a the commission error of 27%. It is worth noting that all buildings that were misclassified as asbestos-cement appeared to be covered with roofing felt in various colours, for example green, red, grey and black. The geometric resolution of the data set influenced the level of omission error (Frassy et al. 2014). The classification accuracy results obtained were calculated for the following groups of asbestos-cement roofing area: 0–100 m^2, 101–150 m^2, 151–200 m^2 and 200–350 m^2 (Figure 5).

The classification accuracy increases along with an increase in the asbestos-cement roofing area; from 36% for roofing grouped in the first class size of up to 100 m^2, to 75% for roofs falling within the range of 200–300 m^2. Within the surveyed area there were no buildings with an asbestos-cement roof size over 300 m^2. Classification results are affected by the type of buildings within the survey area that is characterised by smaller roof areas than industrial buildings, and thus affected classification results.

The SAM algorithm classification accuracy results are similar to those obtained by other authors: classification accuracy claimed at 60% for asbestos-cement roofing with areas up to 300 m^2; and for roof areas lower than 3x3 pixels it amounted to 20% (Frassy et al. 2014).

The APEX data used in the survey is characterized by a spatial resolution of 2.7 m; having assumed that the minimum window size producing a spectrally pure pixel should embrace a minimum 3x3 pixels, which gives a minimum asbestos-cement roofing area of about 80 m^2. The greater the roofing area is, the higher the probability of detecting the spectrally pure pixel, resulting in a higher accuracy of the classification. Use of the Spectral Angle Mapper algorithm requires at least one pure

Vol. 20 • No. 1 • 2016 • pp. 41-46 • ISSN: 2084-6118 • DOI: 10.1515/mgrsd-2016-0007

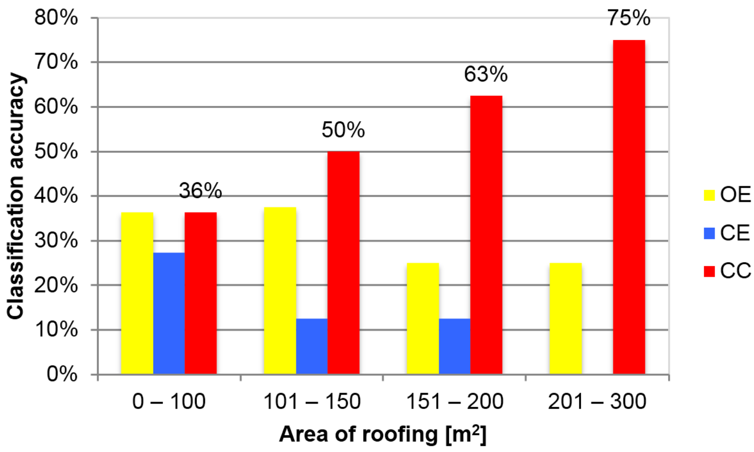

Figure 5. Classification accuracy results in regards to roofing surface [m²] [OE – omission error, CE – commission error, CC – correct classification]

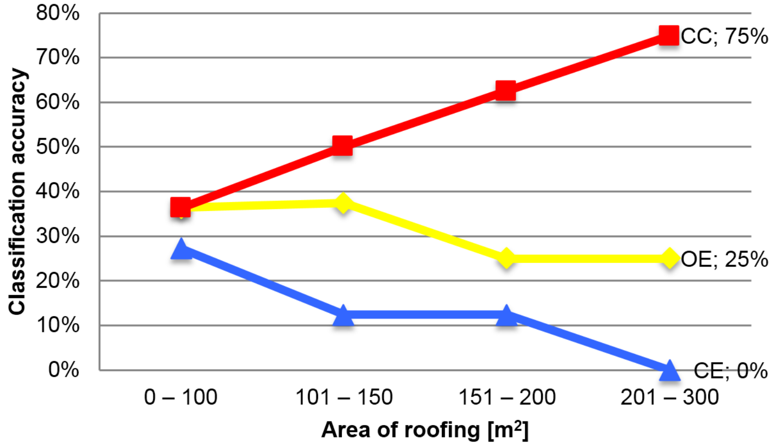

Figure 6. The trend line of the classification accuracy in relation to the area of roofing [OE – omission error, CE – commission error, CC – correct classification]

asbestos sample to work properly within the complex area, and this is not assured for smaller roofs (Kruse at al. 1993). This relation is confirmed by the classification results obtained, where the classification accuracy increases for an asbestos-cement roofing area of over 100 m², i.e. with a roof area bigger than the window size of 3x3 pixels (Figure 6).

Conclusions

The study that has been undertaken has focused on methodological aspects; therefore the small geographic area of Karpacz was surveyed. It covered a mountainous area of Poland, which is more difficult to analyse than flat areas; additionally the asbestos-cement roofing for buildings identified in the survey area is characterized by the small surface of residential buildings.

The study results obtained show that the identification of asbestos-cement roofing for buildings with the use of hyperspectral techniques might appear an effective tool in reducing the need to conduct the in-situ tests. The adopted method may be used effectively for monitoring of asbestos-cement roofing abatement, regarding the amount of asbestos containing products still in use. Buildings inventoried in an area in previous years will be recognized in the acquired aerial imagery, which will further reduce the need for a costly and time-consuming field inventory being taken of the entire area. Field inventory work should therefore be undertaken for the buildings that were not detected as asbestos-cement roofing using hyperspectral discrimination methods; particularly the class of buildings with a roof area smaller than 80 m² (window size of 3x3 pixels).

In general, asbestos-cement building roofing was distinguishable with a high classification accuracy using the hyperspectral imagery analysis and SAM classification algorithm. However, in order to confirm the obtained results, further studies should be undertaken over a larger geographical area that is characterised by a greater number of asbestos-cement roofing on different types of buildings. The analysis of the hyperspectral data provided sufficient accuracy for the mapping of asbestos cement roofing using the SAM algorithm.

Vol. 20 • No. 1 • 2016 • pp. 41-46 • ISSN: 2084-6118 • DOI: 10.1515/mgrsd-2016-0007

References

Act of 19 June 1997 on the prohibition of the use of asbestos-containing products, 1997, Journal of Laws, no 101, item 628 as amended.

Boardman, JW, Kruse, FA & Green, RO 1995, 'Mapping target signatures via partial unmixing of AVIRIS data', in *Fifth JPL Airborne Earth Science Workshop*, *JPL Publication 95–1, vol. 1,* Pasadena, CA, pp. 23–26.

Collegium Ramazzini 2010, Asbestos is still with us: repeat call for a universal ban', *Odontology*, vol. 98, pp. 97–10.

Commission Directive 1999/77/EC of 26 July 1999 adapting to technical progress for the sixth time Annex I to Council Directive 76/769/EEC on the approximation of the laws, regulations and administrative provisions of the Member States relating to restrictions on the marketing and use of certain dangerous substances and preparations (asbestos) 1999. Available from: <http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:31999L0077>. [18 September 2014].

Directive 2003/18/EC of the European Parliament and of the Council of 27 March 2003 amending Council Directive 83/477/EEC on the protection of workers from the risks related to exposure to asbestos at work. OJ L 97, 15.4.2003, p. 48-52. Available from: <http://eur-lex.europa.eu/legal-content/GA/TXT/?uri=CELEX:32003L0018>. [18 September 2014]

European Parliament resolution of 14 March 2013 on asbestos related occupational health threats and prospects for abolishing all existing asbestos (2012/2065(INI)).

Fiumi, L, Campopiano, A, Casciardi, S & Ramires, D 2012, 'Method validation for the identification of asbestos-cement roofing', *Applied Geomatics*, vol. 5, pp. 55–64.

Fiumi, L, Congedo, L & Meoni, C 2014, 'Developing expeditious methodology for mapping asbestos-cement roof coverings over the territory of Lazio Region', *Applied Geomatics*, vol. 6, pp. 37–48.

Frassy, F, Candiani, G, Rusmini, M, Maianti, P, Marchesi, A, Nodari, FR, Via, GD, Albonico, C & Gianinetto, M 2014, 'Mapping Asbestos-Cement Roofing with Hyperspectral Remote Sensing over a Large Mountain Region of the Italian Western Alps', *Sensors*, vol. 14, no 9, pp. 15900–15913.

Frassy, F, Dalla Via, G, Maianti, P, Marchesi, A, Rota Nodari, F & Gianinetto, M 2013, 'Minimum noise fraction transform for improving the classification of airborne hyperspectral data: Two case studies', in *Proceedings of the 5th Workshop on Hyperspectral Image and Signal Processing: Evolution in Remote Sensing*, Gainesville, FL, USA, pp. 1–4.

Frassy, F, Morra Di Cella, U, Bocca, M & Bovio, M 2009. 'Habitat cartography using color infrared and hyperspectral images', in *Proceedings of the 4th Symposium of the Hohe Tauern National Park for Research in Protected Areas*, ed. K Bauch, Salzburg, Austria, pp. 89–92.

Green, AA, Berman, M, Switzer, P & Craig, MD 1988, 'A transformation for ordering multispectral data in term of image quality with implication to noise removal', *IEEE Transactions on Geoscience and Remote Sensing*, vol. 26, no. 1, pp. 65–74.

Hendry, NW 1965, 'The Geology, Occurrences, And Major Uses Of Abestos', *Annals of the New York Academy of Sciences*, vol. 132, pp. 12–21.

IBAS, *International Ban Asbestos Secretariat* 2014, Available from: <http://www.ibasecretariat.org/lka_alpha_asb_ban_280704.php>. [30 January 2014].

ILO and WHO, *Outline for the Development of National Programmes for Elimination of Asbestos-Related Diseases 2007*, International Labour Organization and World Health Organization. Available from: <http://www.who.int/occupational_health/publications/Out_NPEAD_ENG.pdf>. [30 January 2014].

Iwaniak, A, Krówczyńska, M & Paluszyński, W, 2002, 'Using neural networks for urban area classification in satellite images', in *23rd EARSel Symposium on Remote Sensing in Transition*, ed. R. Goossens, Ghent, Belgium, pp. 109–113.

Krause, FA, Boardman, JW, Lefkoff, AB, Heidebrecht, KB, Shapiro, AT, Barloon, PJ & Goetz, AFH 1993. 'The Spectral Image Processing System (SIPS) - interactive visualization and analysis of imaging spectrometer Data', *Remote Sensing of Environment*, vol. 44, pp. 145–163.

Krówczyńska, M, Wilk, E & Zagajewski, B 2014, 'The Electronic Spatial Information System – tools for the monitoring of asbestos in Poland', *Miscellanea Geographica – Regional Studies On Development*, vol. 18, no. 2, pp. 59–64.

Krówczyńska, M & Wilk, E 2013, 'Aerial imagery and geographic information systems used in the asbestos removal process in Poland' in *33th EARSeL Symposium Towards Horizon 2020: Earth Observation and Social Perspectives*, eds. R Lasaponara, N Masini & M Biscione, EARSeL, Matera, pp. 823–828.

Lee, JB, Woodyatt, AS & Berman, M 1990, 'Enhancement of high spectral resolution remote sensing data by a noise-adjusted principal components transform', *IEEE Transactions on Geoscience and Remote Sensing*, vol. 28, no. 3, pp. 295–304.

Local Data Bank 2012, *Central Statistical Office.* Available from: <http://www.stat.gov.pl/bdlen/app/strona.html?p_name=indeks>. [27 January 2014].

PfAAiP*, Programme for Asbestos Abatement in Poland 2009-2032, 2010,* Ministry of Economy. Available from: <http://www.mg.gov.pl/files/upload/8380/PROGRAM_ENG.pdf>. [10 December 2013].

Ross M, Langer, AM, Nord, GL, Nolan, RP, Lee, RJ, Van Orden, D & Addison J, 2007, 'The mineral nature of asbestos', *Regulatory Toxicology And Pharmacology*, vol. 52 (1 Suppl), pp. 26–30.

Shahtahmassebi, A, Yang, N, Wang, K, Moore, N & Shen, Z 2013, 'Review of shadow detection and de-shadowing methods in remote sensing', *Chinese Geographical Science,* vol. 23, pp. 403–420.

Szabó, S, Burai, P, Kovács, Z, Szabó, G, Kerényi, A, Fazekas, I, Paládi, M, Buday, T & Szabó, G 2014, 'Testing algorithms for the identification of asbestos roofing based on hyperspectral data' *Environmental Engineering and Management Journal*, vol. 143, no. 11, pp. 2875–2880.

WHO, World Health Organization 2006, *Elimination of asbestos-related diseases* WHO/SDE/OEH/06/03. Available from: <http://whqlibdoc.who.int/hq/2006/WHO_SDE_OEH_06.03_eng.pdf>. [10 December 2013].

WHO, World Health Organization 2014, 'Asbestos: elimination of asbestos-related diseases'*, Fact sheet N°343*. Available from: <http://www.who.int/mediacentre/factsheets/fs343/en/>. [5 May 2015].

Wilk E, Krówczyńska M & Zagajewski B 2014, 'Asbestos manufacturing plants in Poland', *Miscellanea Geographica – Regional Studies on Development*, vol. 18, no. 2, pp 53–58.