Available online at www.sciencedirect.com
ScienceDirect
Journal of Hazardous Materials 153 (2008) 955–965
Journal of Hazardous Materials
www.elsevier.com/locate/jhazmat

Investigative studies for the use of an inactive asbestos mine as a disposal site for asbestos wastes

Evangelos Gidarakos*, Kalliopi Anastasiadou, Emmanuil Koumantakis, Stappas Nikolaos

Laboratory of Toxic and Hazardous Waste Management, Department of Environmental Engineering, Technical University of Crete, Politechnioupolis, Chania, P.C. 73100, Greece

Received 6 September 2006; received in revised form 13 September 2007; accepted 14 September 2007
Available online 21 September 2007

Abstract

Although, according to European legislation the use of Asbestos Containing Materials is forbidden, many buildings in Greece still contain asbestos products, which must be removed at some point in the near future. Therefore, suitable disposal sites must be found within Greece, so that the unverified disposal of asbestos waste in municipal waste Landfills is brought to an end. In the present work, an innovative approach to the disposal problem of asbestos wastes in Greece has been examined, through a risk assessment analysis of the inactive asbestos mine of Northern Greece and an evaluation of its suitability as a disposal site for asbestos wastes in the future. According to the research carried out, two areas (Site 1 and Site 2) inside the mine area are suitable for the construction of a disposal site for asbestos wastes. The geological investigations showed that in Site 1 and Site 2 ultrabasic rocks of ophiolite complex were prevalent, which have been intensely serpentinized and converted into the fibrous shape of serpentine (asbestos). Concentrations of hazardous substances such as heavy metals in the soil of Site 1 and Site 2 oscillate at low levels, with the exception of the concentrations of nickel and chrome which are high. The investigative work also included the collection of meteorological data and the monitoring of the water level of the artificial lake, which has developed inside the open mine. The main aim is to safely dispose asbestos wastes inside the mine, to minimize any pollution of the wider vicinity of the mine, as well as to engage in restoration activities.

Keywords: Asbestos; Mine; Wastes; Disposal site

1. Introduction

Even though the mineral "asbestos" has been widely used in the past for manufacturing of more than 3000 products, today its use is prohibited [1,2], because it is considered to cause serious health problems (carcinogenesis, amiantosis, etc.). Therefore, any this reason asbestos containing material (ACM) require special treatment, concerning its management and its disposal.

The most common methodology of asbestos waste management is the disposal in special landfills for toxic and hazardous wastes. However, identifying an appropriate location for the installation of these Landfills is difficult, due to the specific requirements that these sites according to current legislation and to common operational difficulties.

This investigation explores the possibility to use "inactive" mines as disposal sites for asbestos wastes. At first sight, these sites have a particular advantage against other sites because they are usually located far away from cities and towns are characterized as being environmentally downgraded.

The use of inactive mines (such as open pit mines and underground mines) as disposal sites for municipal and hazardous wastes has been examined intensely by the developed countries of the European Union. The use of inactive mines has been accomplished with success in these countries, considering it as an easily applied technique of low risk and cost, in comparison to more common methods. Countries with intense mining activity, such as Germany, Italy and England, constitute members of the European Union which already use inactive mines as disposal sites for municipal and hazardous wastes [3,4].

Table 1 presents several cases of the use of inactive mines as disposal sites in Europe. It must be mentioned that the most uses of inactive mines as disposal sites are found in Germany.

* Corresponding author. Tel.: +302821037789; fax: +302821037850.
E-mail address: gidarako@mred.tuc.gr (E. Gidarakos).

0304-3894/$ – see front matter
doi:10.1016/j.jhazmat.2007.09.060

Table 1
Use of old mines as disposal sites [3]

Country	Number of mines
Germany	10
Italy	3
England	2
Sweden	1
France	1
Former Soviet Union	1
Slovenia	1

Specifically, in Germany, underground mines such as salt and iron mines have been used for the deposition of waste with low and medium risk. The salt mines of Asse in West Germany and Morsleben in East Germany were used in the past as disposal sites, during the period 1967–1978 and 1971–1998, respectively [4,5].

Consequently, no intense social reactions are expected from using "inactive" mines as disposal sites. Simultaneously these sites, which until now have remained unexploited, will be restored and used to help resolve an important environmental problem—the management of hazardous waste such as asbestos. It is announced that more than 70 underground mines will become disposal sites for municipal and hazardous wastes in the future, mainly in Germany, Sweden, Finland and England, after the end of their mining activity [3].

2. History of the asbestos mine in Greece

2.1. Location of the asbestos mine

The inactive asbestos mine of Northern Greece (known as MABE) is located at the Zidani Region in the Kozani Prefecture (Western Macedonia), situated only 1 km south of the Aliakmonas River, the longest river in Greece, and the artificial lake Polyfytou through which the Aliakmonas River flows [6,7]. The asbestos mine of Northern Greece is located 40 km SW of the city of Kozani. Due to presence of the asbestos mine in the area

Fig. 1. Relative locations of the old mine of Zidani, the Aliakmonas River and the artificial lake Polyfytou.

all the environmental means (air, soil and water) are exposed to unknown quantities of asbestos fibres.

Fig. 1 shows the relative locations of asbestos mine, the Aliakmonas River and the artificial lake Polyfytou.

In the wider vicinity of the mine, at a distance of roughly 2.5 km W–SW, a small settlement named Mikrobalto is located, while at a distance of 3.5 km S–SW there is another settlement named Tranovalto.

2.2. Mining activity and unit structure of the asbestos mine

The operation of the mine started in 1982 and ended in February 2000. The asbestos mine belonged to a semi-private company and was controlled by the Greek State.

Previous research has calculated the exploitable reserves of the asbestos mine to be around 100 million t [6,7]. During the operation of the mine, the capacity of the production factory was 100,000 t/year (3.5% of the entire world production) but, because of disposal problems and the diminishing promotion of asbestos products, the annual production oscillated between 50,000 and 80,000 t. According to international statistical data, 70 million t of the mineral serpentine were excavated from the asbestos mine, of which 881,000 t of chrysotile asbestos were produced [6,8,9].

The region of the asbestos mine of Northern Greece covers an area of 4.14 km^2. It is separated schematically into four structural units that consist of [7,8]:

(1) The mine—occupying an area of 335,000 m^2, in which mineral exploitation took place using the open pit method.
(2) The depositions—occupying an area of 532,000 m^2. The depositions originated from the process of asbestos in the plant and the sub-products from the mine's extraction.

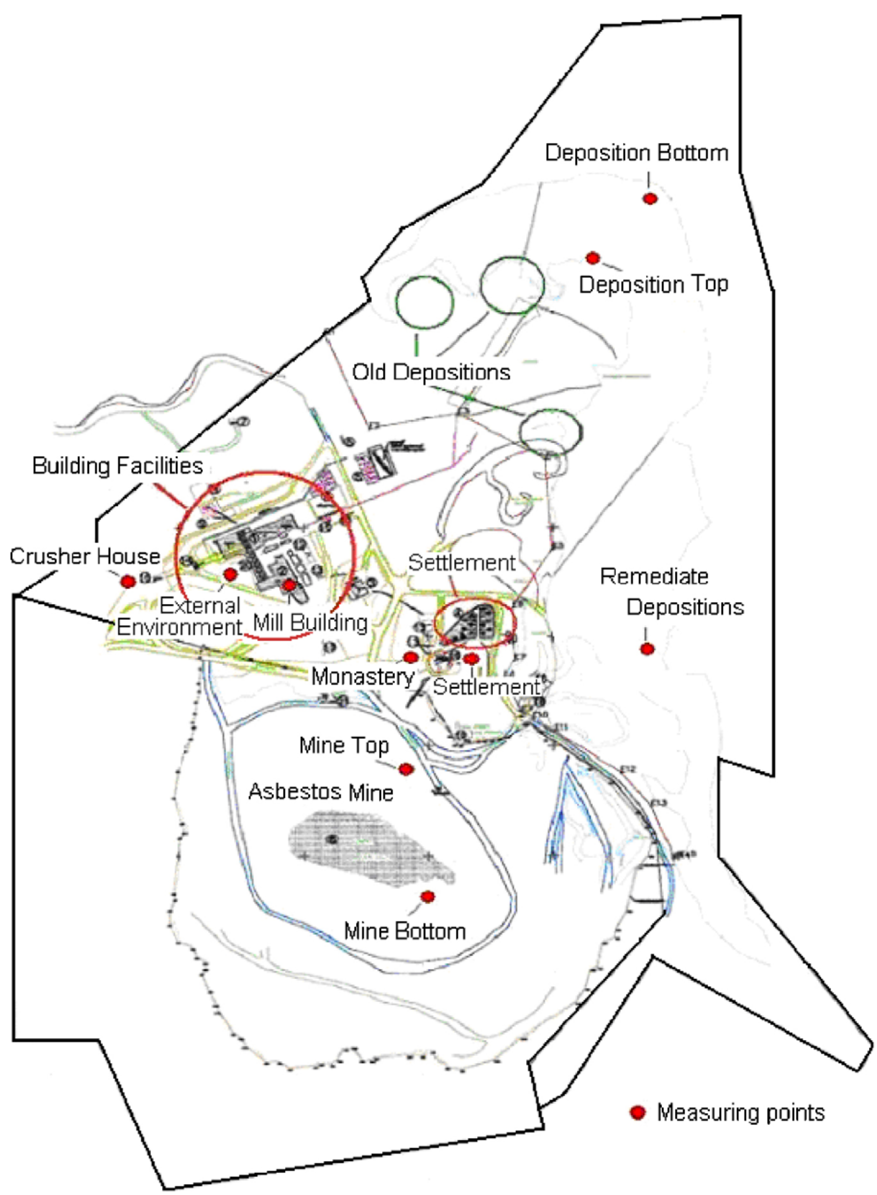

Fig. 2. Map of the asbestos mine area [7].

Table 2
Concentration of asbestos fibres in air [7,13]

Sampling location	Concentration of asbestos fibres (f/cm^3)											Detection limit	Permissible level (f/cm^3)
	2005	2004	1999	1998	1997	1996	1995	Maximum	Year	Minimum	Year		
Mine	0.12	0.13	0.15	0.13	0.14	0.15	0.27	0.27	1995	0.12	2005	0.007	<0.1[a]
Deposition	0.16	0.14	–	–	–	–	–	0.16	2005	0.14	2004		
Building facilities	0.17	0.16	0.57	0.46	0.65	0.47	0.54	0.65	1997	0.16	2004		
External environment	0.10	0.09	0.15	0.18	0.12	0.10	0.12	0.18	1999	0.09	2004		

Note: confidence limit: 95%, no measurements of the asbestos concentration n the air exist for the area of the depositions, before 2004.
[a] Directive 2003/18/EC, modification of Directive 83/477/EC.

(3) The buildings facilities—occupying an area of 25,000 m^2, whilst the total buildings' surface area is about 44,000 m^2.
(4) The external environment—occupying approximately 3,500,000 m^2.

Fig. 2 presents the entire region of the asbestos mine of Northern Greece. The mine and the depositions, as well as, the building facilities are clearly shown.

2.3. Existing environmental status of the asbestos mine and the wider area

Nowadays, the region of the asbestos mine is considered to be a hot spot of pollution for the entire wider region due to:

- the natural erosion of the mine's rock and the release of asbestos fibres;
- the depositions, which consist of 69,000,000 t of barren material (although this material is considered to be unexploitable, it contains asbestos according to previous investigations approximately 138,000 t of chrysotile asbestos fibres are found in the depositions [6]);
- the building facilities, in which enormous quantities of free asbestos fibres remain emanating since production stopped.

In the past, sampling and analysis for the determination of air and water pollution coming from the asbestos mine have been carried out in the wider region. The concentration of asbestos fibres in the open air (measured at various places inside the mine region) is very high in comparison to the maximum permissible limits [7].

Table 2 presents the average values of previous measurements (1995–2005) of asbestos fibre concentrations in the air taken during the operation of the mine and five (5) years after the mining activity had stopped. It must be pointed out, that the values of asbestos concentrations increased during the 5 years.

Analysis has revealed that the existing asbestos fibre concentration in inhaled air meets the highest permitted level set by the World Health Organization (WHO). Therefore an application of a remediation program must be applied as soon as possible to minimize the air transportation of asbestos fibres from the asbestos mine, the depositions and the mineral processing facilities into the environment.

The nearby Aliakmonas River and the artificial lake Polyfytou, which supply the city of Thessalonica with potable water, have also been contaminated by asbestos fibres [7].

Table 3 presents the concentration of asbestos fibres in the water of the Aliakmonas River and the artificial lake Polyfytou in the years 1993 and 2007. The asbestos fibres concentration is over the permitted level set by Environmental Protection Agency (EPA) in every examined sample.

Water samples taken, in the past, from locations a few kilometers from the depositions of waste materials had concentrations that varied from 8,000,000 to 35,910,000 f/l [7]. New water samples taken by the Technical University of Crete, in June 2005 and in March 2007 at the locations Metoxi Panagia, Auvrika, Saint Athanafios, Saint Barbara and the Serbia Bridge also contained high concentrations of asbestos fibres, especially the year 2007 [10].

Today, according to two European projects (the LIFE 03ENV/GR/00214 Project and the EPPER Project), there are plans for the restoration of the asbestos mine and the deposition area (where the barren material coming from the exploitation of the mine is stored). According to these projects, the sanitation of

Table 3
Concentration of asbestos fibres in water

Sample number	Sampling location	Sampling?	Concentration of asbestos fibres (10^6 f/l)	Measuring error (10^6 f/l)	Year	Permissible level (10^6 f/l)
WS 1	Metoxi Panagia (1.2 km)	Aliakmonas River	24.0 [10]	1.2	2007	
WS 2	Auvrika (1.6 km)	Aliakmonas River	38.9 [10]	1.9	2007	
WS 3	Saint Athanasios (0.7 km)	Periodical stream	21.4 [10]	1.1	2007	
WS 4	Saint Barbara (40 km)	Aliakmonas River	8.5 [7]	0.7	2005	7[a]
WS 5	Bridge Serbia (18 km)	Polyfytou Lake	14.3 [7]	2.5	2005	
WS 6	Dam Sfikia (36 km)	Aliakmonas River	7.8 [7]	1.3	1993	
WS 7	Bridge Rymnio (4 km)	Polyfytou Lake	37.4 [7]	3.4	1993	

[a] US EPA, Environmental Protection Agency.

the building facilities inside the asbestos mine area and the construction of a pilot disposal site inside this area, with a capacity ranging from 100 to 1000 t, must take place in the immediate future if all required specifications are to be fulfilled.

3. Investigative studies at the asbestos mine

The selection of a suitable place for the construction of a disposal site for asbestos wastes involves, first of all, the examination of geographic parameters. Research for the detection of potential locations for the construction of disposal sites starts, once the geographic criteria been determined.

The potential disposal sites must complete several characteristics which were determined during the investigative work, accomplished in this present work.

These following parameters were determined:

- Topographic characteristics.
- Geological characteristics.
- Geotechnical characteristics.
- Hydrological characteristics.
- Climatic data.
- Hazardous substances in soil, rock and water samples.

4. Results

4.1. Examination of the asbestos mine according to geographical criteria

Firstly, the suitability for the asbestos mine to be used as a disposal site is examined regarding the technical requirements of a special landfill for toxic and hazardous wastes (asbestos wastes only).

For this reason, the asbestos mine area must meet the following standards [9–18]:

- Distance from settlement >1 km.
- Distance from archaeological sites and memorials >1 km.
- Distance from coastline >1 km.
- Distance from an airport >3 km.
- Distance from a lake >1 km.
- Possible access to the area for the transportation and disposal of the asbestos waste.
- Electricity and water supply for proper construction and operation.
- Available drainage system.
- Location free of naturally protected areas.

The asbestos mine area qualifies as a potential disposal site according to the above mentioned criteria.

4.2. Selection of the suitable sites within the asbestos mine

The next step is to identify specific locations within the asbestos mine area which can be considered suitable for the construction and operation of a pilot disposal site.

Fig. 3. Asbestos mine excavation using the open pit method.

After years of operation, the mining process created a funnel-shaped excavation, with a depth of 180 m, with rungs of 10 m high and a width of 5 m. The continuous excavation created a small lake at the bottom of mine (altitude + 480 m).

In Fig. 3 a view of the lake of the open pit excavation is present.

At first sight, after a visual observation of the field, two sites were identified as potential disposal sites. Only these sites are large enough to build a proper pilot disposal site for asbestos wastes. These sites were named Site 1 and Site 2. At these sites several investigative works took place, which are presented in the following paragraphs.

The selection of these two separate sites as disposal sites, and not the entire mine, does not preclude the operation of the whole asbestos mine as a disposal site for asbestos waste in the future.

4.3. Topographic mapping and morphological characteristics

The investigative work included the topographic imprinting of Site 1 and Site 2 to a scale of 1:1000. Information regarding morphological characteristics is exported from the topographic imprints of the two selected sites.

In Fig. 4 presents the topographic imprinting of the two sites. Morphological and geological characteristics are also present.

In physical terms, Site 1 is almost the shape of a right triangle. The two vertical sides are 140 and 110 m long. The total area of Site 1 is 11,127 m^2. The surface of the region is almost horizontal with an altitude varying slightly from 577 to 578 m. The two sides of the triangle are surrounded by a slope. The slope's height is mainly between 7 and 8 m. The third side of the triangle is situated at a highest point of the rock's slope (height ∼10 m).

Site 2 is roughly the shape of a parallelogram but has a slight bend with a length of 300 m and a varying width of 30–55 m. The surface of the region is almost horizontal with an altitude of between 518 and 520 m. The two long sides of the parallelogram are formed by the lower and higher points of their respective slopes. The upper slope has a height of 9 m. After this there exists a narrow, level surface that leads to the base of the next slope, which has a height ranging from 4 to10 m. The northern

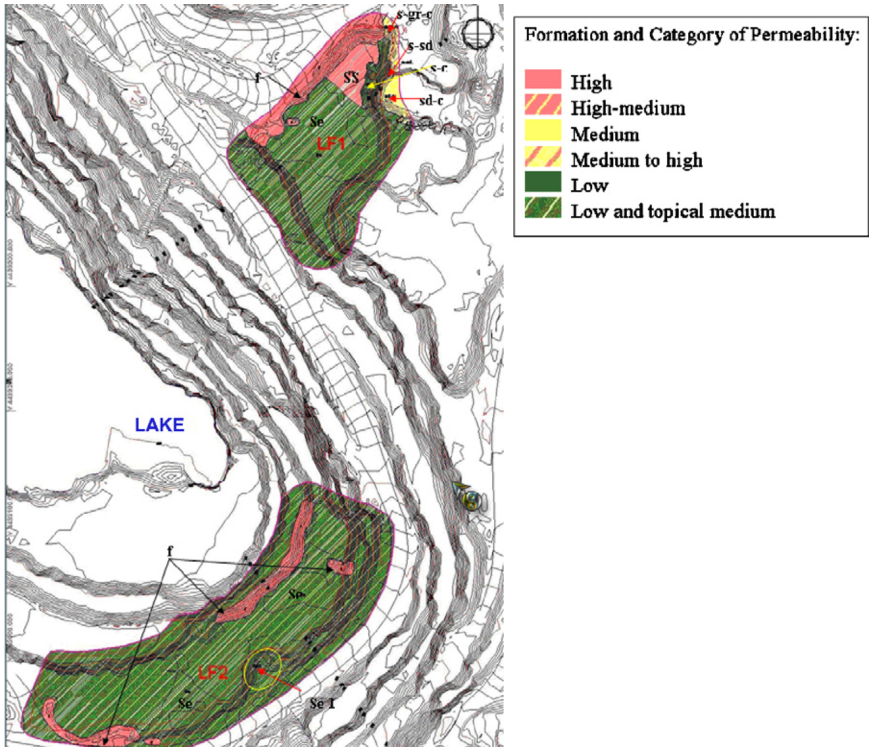

Fig. 4. Geological formations of Site 1 and Site 2 and the hydro-geological characteristics of the site.

limit of the surface is formed by an abrupt rocky slope with a height of roughly 15 m. The total area of Site 2 is 16,724 m^2.

4.4. Geological investigation

The selected sites were examined to determine if they were appropriate for the design of a disposal site according to their geological characteristics. Aspects such as the kind of present geological shaping and the groundwater level must be determined so as to prevent potential instability or flood problems in the future design of the asbestos disposal site.

The wider area of the asbestos mine belongs to the western part of the Pelagonian Zone, which contains many ophiolite complexes. The serpentine in the region of the mine displays internal dislodged slices. The serpentine is cleavaged and crossed by vermiculite amphibolitic dikes. Asbestos is found at the surface of the schistosity of the cleavaged serpentine. The type of the chrysotile asbestos veins is slip-fiber, which means that the fibres are expanded parallel to the walls of the joints in which they are developed [7,12–14].

The geological shapings that were found during the geological mapping of Site 1 and Site 2 are:

- Quarternary
  - Surficial material (thickness: a few cm–1 m).
  - Artificial fill.
- Neogene
  - Calcitic sandstone (thickness: 4 m).
  - Sand and sandstone (thickness: 1 m).
  - Sand, gravel, clay (thickness: 3–7 m).
  - Silty clay (thickness: at least 8 m).
- Pelagonian zone
  - Serpentinite (thickness: ∼100 m).

4.5. Geotechnical investigations

4.5.1. Drillings

Geotechnical investigations were carried out in the two selected sites in order to justify their suitability as a disposal site for asbestos waste. Three drillings were conducted at each site with a total depth of 60 m. Along with the drilling the following tests were also carried out:

- In situ tests
  (1) Measurements of the underground water level.
  (2) Penetrability tests (S.P.T.).
  (3) Permeability tests.
- Laboratorial tests
  (1) Unconfined compressive strength of intack rock samples (E103-84/4, ASTM D 2938-95).
  (2) Point load strength tests (E103-84/5, ASTM D 5731-95).
  (3) Tests for determination of the rock porosity (E103-84).
  (4) Direct shear strength test (ASTM D5607).

The results of the geotechnical investigations conducted at Site 1 and Site 2 are presented below and refer to the upper layer of the mine, which was disturbed by the previous mining activity (such as the use of explosives, etc.):

Table 4
Meteorological data from the asbestos mine of Northern Greece during the period December 2005 until July 2006 [13]

	December	January	February	March	April	May	June	July
Minimum monthly temperature (°C)	−3.9	−8.8	−8.5	−1.3	3.2	6.1	9.0	12.9
Maximum monthly temperature (°C)	9.1	4.7	12.1	17.3	23.7	31.6	34.9	32.0
Mean monthly temperature (°C)	2.5	0.2	2.9	7.5	12.6	17.5	20.9	20.9
Mean daily humidity (%)	75	64	66	66	68	51	51	56
Mean daily rainfall (mm)	6.5	0.12	2.9	1.9	3.7	4.6	10.7	2.0
Total monthly rainfall (mm)	108.9	90.5	82.3	57.5	109.7	141.8	320.2	41.4
Mean monthly wind direction	–	N–NE	N–NE	S–SE	N	N	N	N
Mean monthly wind speed (km/h)	–	–	5	5	7	7	6	6

- The rock mass is considered to be of low-to-medium hardness with an unconfined compressive strength of intack rock, q_c, in the range 5–30 MN/m^2. The values of strength measured in Site 1 (q_c = 5–10 MN/m^2) were lower than those of Site 2 (q_c = 10–30 MN/m^2).
- The rock quality is generally poor, with RQD values from 0 to 25%.
- Weathering is perceptible at the surfaces of discontinuity, while on many occasions intense and extensive erosion of the rock material was observed.
- Water was traced in all of the drillings conducted.
- According to the penetrability tests, the penetrability factor, K, is in the order of 10^{-3} to 10^{-4} cm/s.

4.5.2. *Calculation of the slopes' stability*

The aim of the slope stability study is to investigate and to control the stability of plane or wedge failure in the rocky slopes of the mine. The purpose of this study is to calculate the maximum angle that could be used for cutting and shaping the rocky slopes, in order to ensure their ultimate stability and safety, even in worst-case scenarios regarding earthquakes and floods.

Based on rock-mechanics analyses, calculations and controls, using HOEK and BRAY methods, and using specific rock-mechanic software, the exact conditions and level of stability were calculated. This was achieved by calculating the safety level under different earthquake intensities and water loads. During the geological mapping, measurements of discontinuities in the rock were carried out, in order to evaluate the safety of the slopes. The most appropriate safety measures that need to be continuously applied are shown, in order to guarantee short and long-term stability. The conclusions from the study are the following:

(a) No immediate danger is reported for rock failure or landslides at the investigated slopes of the two sites, since the safety indexes calculated are sufficiently high (1.72–30.98)—above the permissible limits.
(b) In order to reassure the safety of construction works (for example anti-flooding measures at the slope's base), the local application of a low wall or mesh should be investigated.
(c) It should be taken into consideration that detachments are possible, due to local discontinuities which are not statistically significant.

4.6. *Meteorological and climatic characteristics*

During the design of the disposal site meteorological and climatic characteristics play an important role and must be taken into account. The transportation of asbestos fibres through environmental means (soil, air, water) is influenced by the meteorological characteristics of the asbestos mine area. Meteorological data such as rainfall data, temperature, humidity, wind direction and wind speed must be monitored. Previous meteorological data of the wider area is available from the meteorological station Frourio which belongs to the Greek Ministry of the Environment and is located about 3 km away from the asbestos mine. A new meteorological station was installed north of Site 1 inside the asbestos mine area.

Table 4 presents data coming from the meteorological station, during the period December 2005–July 2006. These data were used for the determination of the inflow and the outflow surface water quantities through the sites in order to design the proper anti-flooding measures in the vicinity of the two sites.

4.7. *Determination of water quantities inflow and outflow*

An assessment of the inflow and the outflow surface water quantities through the two selected sites was accomplished using Thornwaite's method, based on existing monthly weather data. The estimation of the inflow and the outflow surface water quantities through the sites is one of the main parameters needed to design and construct proper anti-flooding measures in the vicin-

Table 5
Data from water level logger from the lake inside the asbestos mine of Northern Greece during the period December 2005 to July 2006 [13]

Date	Indication of water level meter (m)	Water level change (m)
15/12/2005	2.80	–
17/01/2006	3.30	0.50
20/03/2006	3.94	0.64
31/03/2006	3.94	0.00
30/04/2006	4.13	0.19
30/05/2006	4.21	0.08
30/06/2006	4.25	0.04
21/07/2006	4.33	0.08
Total change		1.53

Table 6
Results from the analyses of soil and rock [13]

Results														
Parameter	Unit	Soil samples						Rock samples				Method	Detection limit	Measuring error
		Site 1			Site 2			Site 1		Site 2				
		S1[a] 0–30 cm[b]	S2[a] 0–30 cm[b]	S3[a] 0–30 cm[b]	S1[a] 0–30 cm[b]	S2[a] 0–30 cm[b]	S3[a] 0–30 cm[b]	R1[a] 2.6–2.7 m[b]	R2[a] 8.0–8.1 m[b]	R1[a] 6.9–7.0 m[b]	R2[a] 9.6–9.8 m[c]			
pH-value		7.7	7.7	7.9	8.1	7.6	9.3					DIN 10390	0–14	0.01
Anions–cations														
Cyanide, total (CN)	mg/kg	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02					DIN 38405-1 3-1	0.02	14.25%
Chromium VI (Cr VI)	mg/l	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.1	<0.1	<0.1	<0.1	Soil DIN 38405-24, rock DIN 38414-D24	0.05, 0.1	8.60%
Heavy metals														
Arsenic (As)	mg/kg	<10	<10	<10	<10	<10	<10	<1.2	<1.2	<1.2	<1.2	Soil EN ISO 11 885, rock DIN 51001-1	10, 1.2	19.66%
Lead (Pb)	mg/kg	<10	<10	<10	<10	<10	<10	2.1	3.5	12.9	9.6	Soil EN ISO 11 885, rock DIN 51001-1	10, 0.1	18.18%
Barium (Ba)	mg/kg							<2.5	<2.5	27.7	9.9	DIN 51001-1	2.5	15.67%
Cadmium (Cd)	mg/kg	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.3	<0.3	<0.3	<0.3	Soil EN ISO 11 885, rock DIN 51001	0.5, 0.3	29.75%
Chromium (Cr)	mg/kg	370	370	43	330	270	290	4230	831	3490	3220	Soil EN ISO 11 885, rock DIN 51001	10, 1	16.99%
Copper (Cu)	mg/kg	<10	<10	<10	<10	<10	<10	11.0	7.3	13.1	10.1	Soil EN ISO 11 885, rock DIN 51001	10, 0.1	18.55%
Nickel (Ni)	mg/kg	1300	1300	100	1100	1700	1100	2110	3590	1840	1850	Soil EN ISO 11 885, rock DIN 51001	10, 10	13.48%
Mercury (Hg)	mg/kg	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<2.0	<2.0	<2.0	<2.0	Soil EN 1483, rock DIN 51001	0.3, 2.0	12.56%
Zinc (Zn)	mg/kg	21	20	10	<10	22	<10	45.0	32.8	38.7	51.1	Soil EN ISO 11 885, rock DIN 51001	10, 0.1	17.27%
Cobalt (Co)	mg/kg	54	52	<10	47	63	36	27.6	22.3	23	<1	Soil EN ISO 11 885, rock DIN 51001	10, 1	18.97%
Iron (Fe)	%	–	–	–	–	–	–	3.23	3.56	10.4	11.9	DIN 51001	1	18.45%
Magnesium (Mg)	%	–	–	–	–	–	–	24.8	25.2	22.9	22.1	DIN 51001	1	17.65%
Manganese (Mn)	mg/kg	–	–	–	–	–	–	608	395	1420	1060	DIN 51001	100	17.78%
Calcium (Ca)	mg/kg	–	–	–	–	–	–	420	610	533	530	DIN 51001	100	14.92%
Sodium (Na)	mg/kg	–	–	–	–	–	–	<1000	<1000	<1000	<1000	DIN 51001	1000	19.76%
Potassium (K)	mg/kg	–	–	–	–	–	–	<100	<100	<100	106	DIN 51001	100	18.38%
Phosphor (P)	mg/kg	–	–	–	–	–	–	<90	<90	<90	<90	DIN 51001	90	23.76%
Strontium (Sr)	mg/kg	–	–	–	–	–	–	<0.7	<0.7	263	<0.7	DIN 51001	0.7	13.65%
Silicon (Si)	%	–	–	–	–	–	–	23.5	23.5	17.0	19.9	DIN 51001	1	27.65%
TOC	%	0.12	<0.1	<0.1	0.11	0.16	0.51	–	–	–	–	DIN EN 1484	0.1	26.54%

[a] Site sample.
[b] Deep of sampling.

Table 7
Results from the chemical and microbiological analyses of water samples [13]

Results										
Parameter	Units	Water samples						Method	Detection limit	Measuring error
		Aliakmonas River		Lake of the mine		Zidani's Monastery				
		AL1	AL2	AL3	WS4A	WS4B	MZ			
Physical characteristics										
pH		8.15	8.36	8.25	9.55	9.39	9.13	ISO 9001:2000	0-14	0.01
Electric Conductivity	μS/cm	294	278	732	641	693	954	ISO 9001:2000	1–2000	1
Filterable substances	mg/l	80	7.2	2.4	<2	<2	2	DIN8409-2	2	0.2
Chemical composition										
Anions–cations										
Chloride	mg/l	5.1	5.4	5.4	4.2	4.4	1	EN ISO 10304-1	1	27.23%
Sulfate (SO_4)	mg/l	27	23	23	19	19	25	EN ISO 10304-1	2	23.56%
Cyanide, total	mg/l	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	DIN 38405-13-1	0.01	14.25%
Phosphate (PO_4)	mg/l	0.39	0.23	0.23	<0.1	<0.1	0.1	DIN EN ISO 6878	0.1	19.45%
Chromium VI	mg/l	<0.05	<0.05	<0.05	<0.05	<0.05	0.05	DIN 38405-24	0.05	8.60%
Nitrite	mg/l	0.06	<0.01	<0.01	0.061	0.06	0.01	DIN EN 26 777 D10	0.01	24.12%
Sodium (Na)	mg/l	5.4	5.5	5.5	4.2	4.3	0.5	EN ISO 11 885	0.5	19.76%
Potassium (K)	mg/l	1.5	1.3	1.3	7.1	7.1	0.5	EN ISO 11 885	0.5	18.38%
Calcium (Ca)	mg/l	41	41	41	3.6	3.1	0.5	$ENISO11885$	0.5	14.92%
Magnesium (Mg)	mg/l	20	19	19	110	110	0.5	EN ISO 11 885	0.5	17.65%
Heavy metals										
Ferrum (Fe)	mg/l	0.96	0.49	0.49	<0.05	<0.05	0.05	$ENISO11885$	0.05	18.45%
Manganese (Mn)	mg/l	<0.05	<0.05	<0.05	<0.05	<0.05	0.05	EN ISO 11 885	0.05	17.78%
Arsenic (As)	mg/l	<0.005	<0.005	<0.005	<0.005	<0.005	0.005	EN ISO 11 885	0.005	19.66%
Lead (Pb)	mg/l	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	DIN 38406-6-2	0.01	18.18%
Cadmium (Cd)	mg/l	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	EN ISO 5961	0.001	29.75%
Chromium (Cr)	mg/l	<0.015	<0.015	<0.015	<0.015	<0.015	0.015	EN ISO 11 885	0.015	16.99%
Copper (Cu)	mg/l	<0.05	<0.05	<0.05	<0.05	<0.05	0.05	EN ISO 11 885	0.05	18.55%
Nicelium (Ni)	mg/l	0.025	<0.02	<0.02	<0.02	<0.02	0.02	$ENISO11885$	0.02	13.48%
Mercury (Hg)	mg/l	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	0.0002	$EN1483$	0.0002	12.56%
Zinc (Zn)	mg/l	<0.05	<0.05	<0.05	<0.05	<0.05	0.05	$ENISO11885$	0.05	17.27%
Cobalt (Co)	mg/l	<0.05	<0.05	<0.05	<0.05	<0.05	0.05	$ENISO11885$	0.05	18.97%
Silicon (Si)	mg/l	14	9.9	9.9	1.0	1.0	0.1	$ENISO11885$	0.1	27.65%
TOC	%	1.6	<1	<1	<1	<1	1	$EN1484$	1	26.54%
Microbiological analysis										
Total coliforms	Colonies/100 ml	500	0	0	0	0		$EPA600/8-78-017$	0	25%
E. Coli	Colonies/100 ml	200	0	0	0	0		$EPA600/8-78-017$	0	25%
Stercoral coliforms	Colonies/100 ml	100	0	0	0	0		$EPA600/8-78-017$	0	25%
Streptococcus	Colonies/100 ml	400	0	0	0	0		$EPA600/8-78-017$	0	25%

ity of the two sites. The main input data for the model of this method are data of average monthly precipitation and temperature. The main characteristics of the materials used to cover the ground also need to be determined. The results are the average heights of rainfall per month, which percolate into the cover and run off from the surface. Finally, the average heights of rainfall per month are calculated as monthly volumes, based in the landfill's area [15].

In order to calculate the surface water quantities that cause flooding risk, the specifications of the Committee's Ministry Decision (KYA) regarding the "Instruction for development and general guidelines for waste management programs", (FEK 1016, 17-11-1997) was applied. According to this, the protection measures must be increased in order to include the maximum runoff water quantities of the rainiest month in the last 20 years or the maximum of the existing data.

Taking the worst case scenario into account, the intended works of anti-flood protection should include the construction of 2 ditches at each site.

As it was mentioned before, a small lake has been created inside the asbestos mine. The water level of the lake varies since the mine ceased exploitation. The lake's depth is estimated to be approximately of 25 m. There is no data concerning the behavior of the aquifer, the rainfall or the water that ends up in the lake. The location of the lake is near Site 2. These are the main reasons why the monitoring of the lake's changing water level over a long period is of great importance. A water level meter and a water level logger are placed inside the lake. The data coming from these devises is compared to the data from the meteorological station which was installed in the mine area as well.

Table 5 presents the change of the water level. The lake's water level, according to measurements from 15/12/2005 to 21/07/2006, rose by 1.53 m.

A hydro-geological study is necessary for the determination of the hydrological characteristics of the aquifer, the groundwater flow, the depth of the water level and the aquifer recharge characteristics. The determination of the aquifer and the bedrock is only possible by the conduction of deep drillings.

4.8. Sampling and analyses of soil, rock and water

A sampling program was conducted in the region of the asbestos mine in order to collect soil, rock and water samples. The aim of the sampling program is to determine the soil, rock and water quality in the entire area and to detect any hazardous substances.

For the collection of each soil sample, 5 samples were taken randomly. They were homogenized and analysed according to the following: chemical substances, physical parameters. The rock samples were taken from boreholes coming from drillings which were conducted inside the investigated sites. The samples were analysed according to the following: chemical substances, mineral analyses and petrographic determination.

Table 6 presents the results of physical and chemical analyses of soil and rock samples taken from the two candidate sites.

The results from the chemical analysis of soil and rock samples indicate high concentrations of nickel and chromium.

Nearby the inactive asbestos mine area lays a village called Cromio (the Greek word for chromium). In the past chromium mining activities took place in the area. Considering the aforementioned, the increased concentration of these elements is caused by the presence of minerals and not by hazardous waste disposal. In a form of a mineral the heavy metals, chromium and nickel are not extractable because no increased concentrations of these heavy metals there found in the examined water samples. As a result there is no danger of future water contamination since the pH conditions will remain steady during the contraction of the asbestos disposal site. The concentrations of other heavy metals are relatively low and there is no considerable danger for human health. Mineral analyses and petrographic determination indicated that chrysotile asbestos is present in all the serpentine rock samples. This chrysotile asbestos has a structure of thin fibrous crystals with a diameter <3 μm and length >5 μm. Antidorite and lizardite (serpentine minerals) are the most commonly found minerals—covering 80–90% of the entire rock mass. The samples also exhibited increased Mn and Ca concentrations.

As it was mentioned before, sampling and several chemical analyses were also conducted in water from the Aliakmonas River, the artificial lake Polyfytou, the Mine's lake and the spring of the Zidani Monastery, which is located inside the asbestos mine region, so that the concentrations of dangerous substances could be determined. According to chemical and microbiological analysis of the water samples, there is no danger to human health since no heavy metals or pathological elements were detected. The concentrations of heavy metals and other dangerous substances are within the permitted limits for potable water according to Greek legislation.

Table 7 presents the results of physical and chemical analyses of water samples taken from the Aliakmonas River, the Mine's lake and the spring of the Zidani Monastery.

It must be pointed out, as mentioned before, water samples, taken from the river Aliakmonas and the lake of the asbestos mine, contain particularly high concentrations of free asbestos fibres. The concentrations exceeded the permissible limit of asbestos fibre concentration in water (7,000,000 f/l).

The Aliakmonas River is a key source of water for the city of Thessalonica, that is why the EPA action level in drinking water must be used for river water. Precautions measures (filtering) must be taken to collect the asbestos fibres in the water of the Aliakmonas River before consumption.

5. Conclusions

It must be pointed out that even nowadays Greece has no special landfill sites for the disposal of toxic and hazardous wastes. This means that all hazardous wastes, asbestos included, must be transferred abroad. This fact has enormous economical and environmental consequences for the Greek state. A suitable site must be found in the future that can serve as a disposal site for hazardous wastes.

The case of the asbestos mine of northern Greece represents an interesting case as a potential disposal site for asbestos wastes in the future. The disposal site is to be designed according to the topographic imprint. In many cases the site topography can be modified so that it ensures the proper operation of the disposal site (for example, the construction of flood-preventing measures or an alteration to the configuration of the slopes). It must be mentioned that the main substructure needed for the construction of a disposal site, such as building facilities, electricity and water supply, already exist in the asbestos mine region.

According to the investigations completed in the investigated area, the two proposed sites (Site 1 and Site 2) could be used for the disposal of asbestos wastes. It must be pointed out that in order to explore the suitability of the entire mine as an asbestos waste landfill a complete hydro-geological study should be carried out of the broad area of the mine. The only hydrological characteristics determinate in this study are the inflow and the outflow surface water quantities through the two selected sites.

Other hydro-geological characteristics such as the determination of the aquifer depth and thickness, the study of the groundwater flow, the depth of the water level and the aquifer recharge characteristics must be investigated in the future.

For the determination of the bedrock and the estimation of the rock impermeability, the conduction of a drilling at an increased depth (~200 m) is necessary. Carbonate rocks, such as limestone and dolomite marbles with high permeability are supposed to underlay below the serpentine rock. This fact must be examined during the conduction of deep drillings.

Nowadays, the area of the asbestos mine of Northern Greece still remains a hot spot of asbestos pollution and must be remedied before it can be used. During the construction of a disposal site for asbestos waste in the asbestos mine area, the whole place, which until now remained unexploited, will be restored and used for the solution of the important environmental problem – hazardous waste management – such as asbestos.

Acknowledgements

This research was jointly funded by the LIFE 03ENV/GR/00214 Project. The authors would like to thank the Prefecture of Kozani for their cooperation.

References

[1] Directive 1999/31/EC, On the landfill of waste (1999).
[2] Directive 1999/77/EC, 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).
[3] D. Kaliampakos, A. Mavropoulos, J. Prousiotis, Abandoned Mines as Hazardous Waste Repositories in Europe, National Technical University of Athens, 2004.
[4] http://www.beasy.com/projects/lowriskdt/lowrisk_progress_surveymines.html.
[5] Board on Radioactive Waste Management, Disposition of High-Level Waste and Spent Nuclear Fuel, The Continuing Societal and Technical Challenges, 2001, pp. 49–66.
[6] P. Karkanas, The slip-fiber chrysotile asbestos deposit in the Zidani area, northern Greece, Ore Geol. Rev. 10 (1995) 19–29.
[7] K. Anastasiadou, E. Gidarakos, Toxicity evaluation for the broad area of the asbestos mine of Northern Greece, J. Hazard. Mater. A 139 (2006) 9–18.
[8] http://www.asbestmine.org.
[9] A. Vafeiadou, Asbestos Ministry of labor and social affairs, in: European Conference, Greece, 2003.
[10] E. Koumantakis, Quantitative determination of asbestos in the tailing material of the asbestos mine of Northern Greece—estimation of the existing pollution of the river Aliakmonas due to the existence of the tailings, Master Thesis, Technical University of Crete, Chania, 2007.
[11] E. Gidarakos, Hazardous Wastes, Management–Treatment–Disposal, Edition Zygos, Thessaloniki, 2006.
[12] N. Arvanitidis, Northern Greece's industrial minerals: production and environmental technology developments, J. Geochem. Explor. 62 (1998) 217–227.
[13] E. Gidarakos, K. Anastasiadou, E. Koumantakis, Conduction of geotechnical measurements concerning the mechanical conditions of the MABE asbestos mine and the quality of water, LIFE 03ENV/GR00214 for the Utilization of the MABE Asbestos Mine as a Disposal Site for Asbestos Wastes, Technical Report, 2006.
[14] P.B. Karakanas, Study of the Chrysotile Ore at Zidani Area and the Existence of Tremolite, Geologic Department of The University of Athens, Athens, 1994.
[15] I.S. Oweis, R.P. Khera, Geotechnol. Waste Manage. (1990).
[16] L.V. Robert, Mineral Commodity Profiles—Asbestos, U.S. Department of the Interior, U.S. Geological Survey, 2005.
[17] EPA—United States Environmental Protection Agency, Hazardous Waste Land Treatment, EPA, 1893.
[18] D.M. LaGrega, L.P. Buckingham, C.J. Evans, Environmental Resources Management "Hazardous Waste Management", McGraw-Hill Series in Water Resources and Environmental Engineering, 2001.