

AperTO - Archivio Istituzionale Open Access dell'Università di Torino

Respirable inorganic fibers dispersed in air and settled in human lung samples: Assessment of their nature, source, and concentration in a NW Italy large city

This is a pre print version of the following article:

Original Citation:

Availability:

This version is available <http://hdl.handle.net/2318/1765516> since 2021-01-05T12:59:51Z

Published version:

DOI:10.1016/j.envpol.2020.114384

Terms of use:

Open Access

Anyone can freely access the full text of works made available as "Open Access". Works made available under a Creative Commons license can be used according to the terms and conditions of said license. Use of all other works requires consent of the right holder (author or publisher) if not exempted from copyright protection by the applicable law.

(Article begins on next page)

Manuscript Details

Manuscript number	ENVPOL_2019_4889
Title	Respired inorganic fibers dispersed in air and settled in human lung samples: assessment of their nature, source, and concentration in a NW Italy large city
Article type	Research Paper

Abstract

The present investigation represents a new approach useful to evaluate the general population risk due to air dispersed inorganic fibers environmental exposure. The used method is based on the evaluation of the inorganic fibers both air dispersed in a big city and in lungs of the general population following their respiration. Moreover, these data make feasible to identify the sources of dispersion (anthropogenic or natural) in air of the inorganic fibers and therefore to put in place strategies to improve air quality. To describe this approach, the authors investigated air samples from a big city in NW Italy and lung inorganic burden of people here lived. This paper reports the data of the airborne inorganic fibers detected in two sampling campaign (2014 and 2016), in 24 districts of Torino (Piemonte - Italy), and in some autoptic lungs of general population lived here. The airborne fibers (collected on cellulose esters membrane by an air sampling system) were characterized by scanning electron microscopy (SEM) with annexed energy dispersive spectroscopy (EDS). We identified 5 main groups of inorganic fibers species, among which 2 types of asbestos. These last are grouped as tremolite/actinolite asbestos. They are dispersed from natural sources, (i.e. certain kinds of rocks outcropping in the surroundings). In no-one of the 24 districts of Torino their concentration highlighted a situation of asbestos pollution in place. A correlation with inorganic fibers (also collected on cellulose esters membrane and characterized by SEM-EDS) detected in lung tissue samples of 10 subjects lived in Torino all their life and without professional exposure to asbestos, were attempted. The only types of fibers identified as asbestos are tremolite/actinolite asbestos, and correspond to those detected in air sampling. Their amount is lower than the quantities reported as indicative of significant asbestos exposure. We observed interesting gender differences.

Keywords	inorganic fibers; asbestos; air pollution; dispersion sources; lung; SEM-EDS
Corresponding Author	Silvana Capella
Order of Authors	Silvana Capella, Elena Belluso, DONATA BELLIS, Elena Fioretti, Roberto Marinelli
Suggested reviewers	Ruggero Vigliaturo, Petra Pokorna, Mickey Gunter, monireh khadem, Alessandro Cavallo

Submission Files Included in this PDF

File Name [File Type]

cover letter.doc [Cover Letter]

highlights .docx [Highlights]

graphical abstract.pptx [Graphical Abstract]

respired inorganic fibers.docx [Manuscript File]

fig. 1.pdf [Figure]

fig. 2.pdf [Figure]

fig. 3.pdf [Figure]

fig. 4.pdf [Figure]

fig. 5.pdf [Figure]

tables.docx [Table]

supplementary material.docx [Supplementary Material]

To view all the submission files, including those not included in the PDF, click on the manuscript title on your EVISE Homepage, then click 'Download zip file'.

Torino, 10 October 2019

Silvana CAPELLA*
Department of Earth Sciences
University of Torino
Via Valperga Caluso, 35
10125 Torino, Italy

Dear Editors,

I would like to submit to your attention our manuscript entitled “**Respirable inorganic fibers dispersed in air and settled in human lung samples: assessment of their nature, source, and concentration in a NW Italy large city**” as potential contribution to your journal “**Environmental pollution**”.

The above mentioned manuscript has not been published elsewhere, accepted for publication elsewhere or under editorial review for publication elsewhere.

The submitted work suggests a new approach useful to evaluate the general population risk due to air dispersed inorganic fibers environmental exposure. The used method is based on the evaluation of the inorganic fibers both air dispersed in a big city and in lungs of the general population following their respiration.

Moreover, these data make feasible to identify the sources of dispersion (anthropogenic or natural) in air of the inorganic fibers and therefore to put in place strategies to improve air quality. The knowledge from these kind of results allows stakeholders both to evaluate correctly the possible increase of airborne inorganic fibers including asbestos, and to carry out programs to reduce or eliminate dispersion.

To describe this approach, the authors investigated air samples from a big city in NW Italy and lung inorganic burden of people here lived. The fibers investigation was performed by the analytical scanning electron microscope (SEM) with an annexed energy dispersive spectrometer (EDS).

The authors agree in the content of the manuscript.

With best regards Silvana Capella

*Corresponding Author
e-mail: silvana.capella@unito.it
tel: + 39 011 6705121

Names and e-mail address of five potential reviewers:

Mickey Gunter mgunter@uidaho.edu (University of Idaho)

Ruggero Vigliaturo ruggero@sas.upenn.edu (University of Pennsylvania)

Alessandro Cavallo alessandro.cavallo@unimib.it (University of Milano Bicocca)

Petra Pokorná pokornap@icpf.cas.cz (University Prague)

Monireh Khadem khadem@sina.tums.ac.ir (Tehran University of Medical Sciences)

Highlights

A new approach to evaluate airborne inorganic fibershazardous exposure

Inorganic fibres are identified and quantified by SEM-EDS investigation

Air dispersed inorganic fibers are compared with those respired, extracted by lungs

Some potentially harmful air dispersed and lung settled inorganic fibres are asbestos

Different biopersistence of the respired fibers could be related to gender

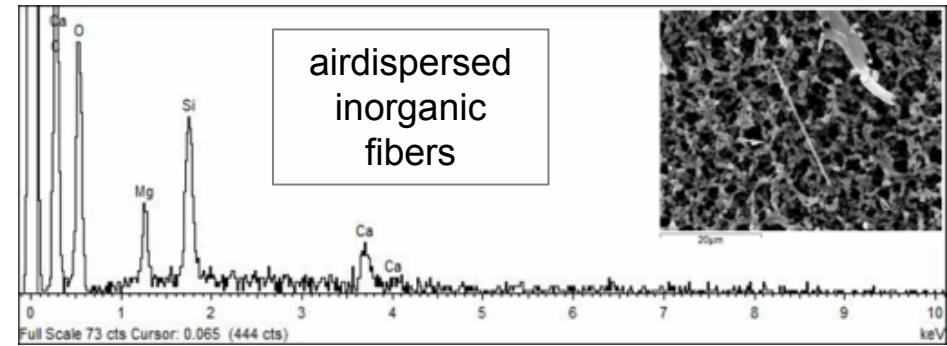


natural sources
i.e. lithologies containing naturally occurring asbestos (NOA)

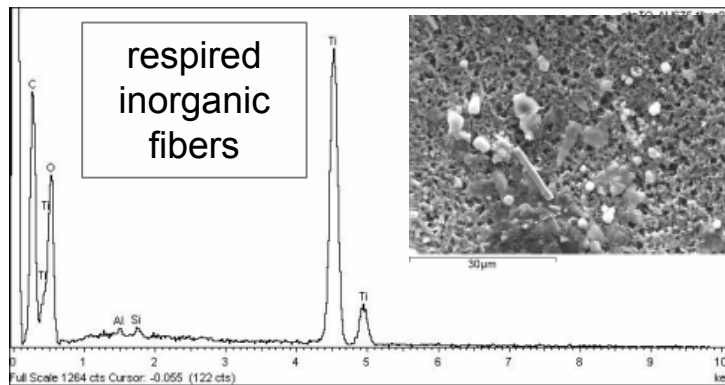


anthropogenic sources
i.e. roofs containing asbestos

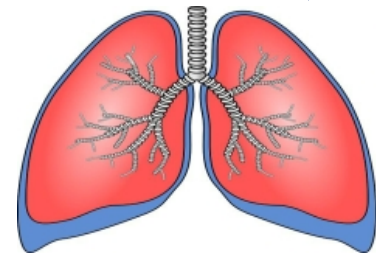
SEM-EDS investigation
of inorganic fibers
from air



environmental exposure to
air dispersed inorganic fibres



SEM-EDS investigation
of inorganic fibers
from lungs (respired)



1 **Capella S.^{a,b}, Bellis D. ^{d,b}, Fioretti E.^e, Marinelli R.^f, Belluso E.^{a,b,c}**

2

3 **Respirable inorganic fibers dispersed in air and settled in human lung samples:**
4 **assessment of their nature, source, and concentration in a NW Italy large city**

5

6 ^a Department of Earth Sciences, University of Torino, Torino, Italy

7 ^b Interdepartmental Centre for Studies and other Toxic Particulates "G. Scansetti", University of Torino, Torino, Italy

8 ^c Institute of Geosciences and Earth Resources, CNR, Unit of Torino, Italy

9 ^d Department of Surgery, Pathological Anatomy, Ospedale degli Infermi, Ponderano, Biella, Italy

10 ^e Strada Bussolino 68, 10090 - Gassino Torinese, Italy

11 ^f Via Parma 11/C, 39100 - Bolzano, Italy

12

13 Corresponding author: silvana.capella@unito.it ; +39-011/6705121

15 **Abstract**

16 The present investigation represents a new approach useful to evaluate the general
17 population risk due to air dispersed inorganic fibers environmental exposure. The used
18 method is based on the evaluation of the inorganic fibers both air dispersed in a big city and
19 in lungs of the general population following their respiration. Moreover, these data make
20 feasible to identify the sources of dispersion (anthropogenic or natural) in air of the inorganic
21 fibers and therefore to put in place strategies to improve air quality. To describe this
22 approach, the authors investigated air samples from a big city in NW Italy and lung inorganic
23 burden of people here lived. This paper reports the data of the airborne inorganic fibers
24 detected in two sampling campaign (2014 and 2016), in 24 districts of Torino (Piemonte -
25 Italy), and in some autoptic lungs of general population lived here. The airborne fibers
26 (collected on cellulose esters membrane by an air sampling system) were characterized by
27 scanning electron microscopy (SEM) with annexed energy dispersive spectroscopy (EDS).
28 We identified 5 main groups of inorganic fibers species, among which 2 types of asbestos.
29 These last are grouped as tremolite/actinolite asbestos. They are dispersed from natural
30 sources, (i.e. certain kinds of rocks outcropping in the surroundings). In no-one of the 24
31 districts of Torino their concentration highlighted a situation of asbestos pollution in place.
32 A correlation with inorganic fibers (also collected on cellulose esters membrane and
33 characterized by SEM-EDS) detected in lung tissue samples of 10 subjects lived in Torino
34 all their life and without professional exposure to asbestos, were attempted. The only types
35 of fibers identified as asbestos are tremolite/actinolite asbestos, and correspond to those
36 detected in air sampling. Their amount is lower than the quantities reported as indicative of
37 significant asbestos exposure. We observed interesting gender differences.

38

39 **Summary of the main result of the work**

40 The present investigation represents a new approach useful to evaluate the general
41 population risk due to air dispersed inorganic fibers environmental exposure.

42

43 **Keywords:** inorganic fibers; asbestos; air pollution; dispersion sources; lung; SEM-EDS

44 Introduction

45

46 The air quality control of the particulate matter (PM) is an important issue in the field of
47 human health and environmental protection.

48 Among the various types of particles constituting PM, there are also inorganic fibers, both
49 natural and synthetic. Some of them, i.e. asbestos, several asbestiform minerals (e.g.
50 asbestiform winchite and fluoredenite), and certain synthetic vitreous fibers (e.g., Gunter et
51 al, 2007; Utell and Maxim, 2018) are well known for their adverse health effects when
52 respired in high doses as in case of professional exposure Lippman, 2014; Park, 2018).
53 Currently, attention is being paid to the evaluation of health effects due to exposure to low
54 doses, such as the environmental one, to asbestos and eventually other types of inorganic
55 fibers. Regarding these compounds, there are not scientific studies that report an exposure
56 threshold value below which clinical effects does not occur, but only some indication. For
57 example, the State of California (USA) has established that there is not a significant health
58 risk with concentration $\leq 0,01$ ff/Lof asbestos fibers in air (Proposition 65 - Safe Drinking
59 Water and Toxic Enforcement Act, 1986); the World Health Organization (WHO) indicates
60 a situation of alarm and of pollution when the concentration of asbestos in air is respectively
61 between 1 and 2 ff/L and more than 2 ff/L (WHO, 1986). Obviously, in any case the exposure
62 should therefore be kept as low as possible (WHO 2000a).

63 About the presence in urban air of inorganic fibers, both natural and synthetic, there are few
64 investigations, mostly dealing with airborne asbestos and regarding few cities. The
65 concentrations reported vary a lot and depend on the used investigation techniques: 0.2 to
66 5 ff/l in Germany, 0.47 ff/L in France, 2 to 4 ff/L in Canada, 4.6 ff/L in Australia, 4 to 111 ff/L
67 in Japan, 0.2 to 4.6 ff/L in Italy (e.g. Bourdés et al., 2000; Gualtieri et al., 2009).

68 These kinds of investigations, aimed to risk evaluation for human health, are complicated
69 by necessary knowledge of the background concentration, which depends on the
70 anthropogenic and natural characteristics, these last being specific for every site. In general,
71 nature and concentration of airborne inorganic fibers also varies greatly based on on the
72 regulation of the country regarding their use.

73 As an example, the six minerals classified as asbestos (i.e. anthophyllite asbestos, amosite,
74 tremolite asbestos, actinolite asbestos, crocidolite, and chrysotile) have been banned for all
75 of Europe since 2006 and therefore they are not used in products made after this date.
76 However some of them (chrysotile, crocidolite, amosite, and antophyllite asbestos) are
77 contained in products, known as asbestos containing materials (ACM), installed before the

78 asbestos ban and constitute anthropogenic sources of fiber release in air. In fact, ACM, as
79 for example cement-asbestos roof, release more and more asbestos fibers in air as they
80 deteriorate due to atmospheric agents and if they are not properly maintained. The other
81 two types of asbestos, i.e. tremolite asbestos and actinolite asbestos, have not been
82 industrially used owing their scarce physical and chemical properties, but in Italy, owing to
83 both natural weathering and anthropogenic activities, they are dispersed in air from several
84 rocks that contain them; in this case rocks constitute natural sources of asbestos air
85 dispersion. In Italy, also chrysotile, the less diffused anthophyllite asbestos, and other fibrous
86 minerals are dispersed in air by natural sources. The fibers, once they have been dispersed
87 in air, depending on the winds and atmospheric conditions, can be transported for distances
88 before their deposition.

89 Since the airborne fibers having respirable dimensions, during their residence in air, can be
90 respired and mostly settled in lungs, the investigation of the lung content of general
91 population (i.e. people not professionally exposed to inorganic fibers) allows to understand
92 what kind of exposure is suffered and, knowing the characteristics of the environment, to
93 establish from which sources the fibers have been dispersed.

94 Based on these introductory statements, the present investigation represents a new
95 approach to improve the knowledge on the presence and concentration of inorganic fibers
96 present in air of a large city as Torino (NW of Italy), the variations relating to the same period
97 in two different years, and the correlation with the different possible dispersion sources
98 (anthropogenic or natural). This last information is made possible by knowing the geological
99 and anthropogenic characteristics of the investigated and surrounding area.

100 This is a preliminary study carried out, by scanning electron microscopy (SEM) with annexed
101 energy dispersive spectroscopy (EDS), to assess the presence of airborne inorganic fibers
102 in 24 districts of Torino (Piemonte – Italy).

103 Owing to the still open issue on the definition of fiber term, that assumes different meanings
104 in different scientific fields (e.g., Belluso et al., 2017), in this paper we distinguish between
105 fiber, fibrous and asbestiform. We attribute the word “fiber”, and the adjective “fibrous”, to
106 any elongated inorganic particle having breathing characteristics (according to D.Lgs 277/91
107 and Directive 2003/18/EC,WHO, 1997) i.e. length > 5 μm , width < 3 μm , and length/diameter
108 ratio > 3. The adjective “asbestiform” is relative to fibers non asbestos classified having the
109 “fiber” dimensions and at least one of the asbestos properties as flexibility, splitting etc.

110 Torino is a city where ACM factories have never been present but asbestos containing roofs
111 and other placed ACM are abundant and widespread. Moreover, natural sources (i.e. rocks)

112 containing naturally occurring asbestos (NOA) and naturally occurring asbestiform minerals
113 non asbestos classified (NONA) surround the city.

114 On the base of this knowledge, a correlation with the nature and amount of respired
115 inorganic fibers, present in lung tissue samples of subjects lived in Torino all their life and
116 without professional exposure, was attempted for the first time.

117 Although a high amount of samples needs in order to obtain statistically significant data, the
118 availability of lung samples from the general population is very scarce since the autopsies
119 are limited to specific deaths. As a matter of fact, only 10 suitable samples have been
120 recovered for this investigation. Besides, since the exposure is not attributable to a specific
121 time slot, the data obtained from the lung investigation are referred to the whole life duration
122 of the investigated subject.

123 Finally, a further target of this investigation is the attempt to evaluate a possible correlation
124 between type (and burden) of inorganic fibers both detected in air of a big city and in lungs
125 of general population lived here.

126 Description of the sampling area

127 The city of Torino is sited in NW Italy, at the mouth/termination of Susa Valley, and
128 surrounded by Western Alps where there are abundant bodies of serpentinitic rocks,
129 matrices of several asbestiform minerals non asbestos classified (NONA), and three
130 asbestos species (NOA): chrysotile, tremolite asbestos and the less diffused actinolite
131 asbestos (Belluso et al., 1995; Compagnoni & Groppo, 2006).

132 Torino, covering about 130 km², is the capital of Piemonte Region, one of the largest
133 urbanised areas in Northern Italy and with about 880,000 inhabitants it is considered the 4th
134 Italian city (ISTAT, 2018).

135 Known for years as the city of working class for excellence, Torino is home to major industrial
136 complexes since the nineteenth century, although over the years the city has gone through
137 a long period of industrial transformation, and in the eighties the industry was reduced in
138 favour of the service sector.

139 It is an important knot of the road and networks, being located at the foot of important and
140 busiest passages and tunnels of the Western Alps (e.g. tunnel of Frejus and Mont Blanc).

141 The topography of the area and geographic location make it one of the most problematic
142 Italian cities in terms of reducing atmospheric emissions. In effect, because of its closed
143 position, the city core and the surrounding urbanized area are exposed to long-lasting
144 episodes of air pollution during both summer and winter, when European air quality

145 standards for PM10, NO2, O3 concentrations are often exceeded (Città Metropolitana di
146 Torino, 2019).

147 Local atmospheric circulation is strongly influenced by the "shell" effect of the Alpine chain
148 whose orography is able to divert and block the flow of the winds that reach. The protection
149 offered by the alpine relief is reflected in weak and irregular winds. Strong winds, especially
150 in the autumn and spring, blown from the main Alpine ridge to the plain. The plain enclosed
151 on three sides by mountains and hills is also a place favourable to the stagnation of cold air
152 in the winter months (thermal inversion), while in summer the warm breezes local favour the
153 mixing of low atmospheric layers (ARPA, 2019).

154 Another weather factor that can contribute to a greater or lesser air pollution is the amount
155 and distribution of rainfall. The average annual precipitation of Torino is approximately 900
156 mm; the rainiest period is April/June, whereas the least rainy period is December/February.
157 Its geographical position, the surrounding rocks containing NOA and NONA, and the
158 presence of ACM widely used in building constructions, make Torino a suitable area of study
159 about inorganic fibers background.

160

161 **Material and methods**

162

163 Monitoring of airborne inorganic fibers

164 Air samples were collected in the 24 districts of Torino city (FIG.1; TAB.1), in the morning of
165 24 different days in the period between April and November 2014 and 2016, provided that
166 there were not rainfall in the previous 2 days.

167 The sampling points were chosen as central as possible of the district, and positioned near
168 a crossroad with medium vehicular traffic.

169 The sampling was carried out by means of a portable air sampler (Delta HF TCR Tecora)
170 with fibres sampling head and nitrocellulose filters ($\varnothing 2.5$ mm and pore of $0.8 \mu\text{m}$) placed on
171 the top of a portable tripod at 1.5 m above ground level.

172 The volume of air sampled in each area of the city was at least 3,000 litres, as indicated in
173 the Italian decree (DM 6/9/94 Annex 2B) for determining the concentrations of airborne
174 asbestos fibres in indoor environments, using scanning electron microscopy (SEM) with
175 annexed energy dispersive spectroscopy (EDS) at high flow rate (20 l/min).

176 Inorganic fibers in lung tissue

177 Through a retrospective study, in collaboration with the pathologist author, lung tissue samples
178 (preserved in formalin) of 10 subjects (5 women and 5 men) resident in Torino all their life and
179 not dead for professional exposure to asbestos have been selected.

180 They have been prepared for SEM-EDS investigation to quantify and identify the inorganic
181 fibers according to Belluso et al. (2006) protocol.

182 SEM-EDS analysis

183 The 24 filters of air samples and the 10 filters of lung tissue samples were prepared for SEM-
184 EDS investigation and examined at the department of Earth Sciences of the University of
185 Torino, to assess the presence, type and burden of inorganic fibers airborne and respired,
186 respectively .

187 The filters were coated with a thin layer of carbon (metallization step). Subsequently an area
188 about of 2 mm² (the double of the area reported in DM 6/9/94, where an official method for
189 analyzing airborne asbestos is indicated), was analysed at 2000 magnification by SEM
190 following a systematic path according to a predetermined scheme. Only particles having
191 length > 5 µm, width < 3 µm, and length/diameter ratio > 3, and were considered (D.Lgs
192 277/91; Directive 2003/18/EC; WHO, 1997).

193 Each fibre was analysed with the annexed EDS to acquire its chemical composition. The
194 EDS-SEM spectra obtained were compared with that characteristics for the different types
195 of inorganic species constituting the data-base of the fibre laboratory at Earth Sciences
196 department.

197 Whenever possible, each fiber was identified as a mineral species. In the case of doubtful
198 identification due to structural or chemical differences non solvable with the used technique,
199 the fiber was attributed to a mineralogical group, as for chrysotile and asbestiform antigorite
200 which have similar morphology and chemical composition but different crystalline structure,
201 and for tremolite asbestos and actinolite asbestos, having a similar structure and chemical
202 composition. In this case, we used the following group names: chrysotile/asbestiform
203 antigorite, tremolite/actinolite asbestos.

204 To obtain the burden of airborne inorganic fibers in each district, the amount (number) of
205 every type of fiber detected was related to the number of fiber per liter (ff/L) of sampled air.
206 To obtain the burden of inorganic fibers in the lung samples (i.e. respired fibers) the amount
207 (number) of each type of fiber detected was normalized to 1 gram of dry weight (gdw) of the
208 tissue, according to the international standard (De Vuyst et al., 1998).

209

210 **Results**

211
212
213
214
215
216
217
218
219
220
221
222
223
224
225
226
227
228
229
230
231
232
233
234
235
236
237
238
239
240
241
242
243
244

Airborne inorganic fibers

Investigation by SEM-EDS allowed to detect and identify several types of inorganic fibers (TAB.2).

The inorganic fibers were classified into five main groups: silicates, oxides, carbonates, sulfates, synthetics. As far as the silicates concern, we used the mineral classification (e.g., Gaines et al., 1997); we indicated the mineral species, the groups (nesosilicates, sorosilicates, double and single chain silicates, phyllosilicates, tectosilicates) and, when possible, also the sub-groups. In case of the impossibility to classify the compound as mineral, we indicated the chemical species. In cases where the chemical composition was evidently due to a mixture, we defined the compounds as “non identified”.

Asbestos fibers.

The only type of identified asbestos fibers belongs to the group tremolite/actinolite asbestos (TAB.2; FIG.2a). Because in Italy these asbestos have never been industrially used, their presence in air is related to the dispersion from natural sources (i.e. rocks). Serpentinite rocks, outcropped in many areas, containing several fibrous minerals including tremolite/actinolite asbestos and chrysotile, were found in the Western Alps (Belluso et al., 1995).

Crocidolite, grunerite asbestos and anthophyllite asbestos, contained in many ACM, were not detected in any district.

The fibers belonging to tremolite/actinolite asbestos are present in 41.7% of the districts of both the campaigns (2014-2016).

Fibers potentially classifiable as asbestos.

The fibres that cannot be unequivocally identified as asbestos only on the base of the elemental chemical analysis (EDS-SEM) have been grouped in a “potentially classifiable as asbestos”. This is the case of the fibres classified as chrysotile/asbestiform antigorite (FIG. 2b) because their chemical composition and Mg/Si ratio are similar, other than their morphology. Therefore, the used technique is not decisive to univocal identification of these mineral species. Their possible origin can be attributed either to the natural (e.g. they are abundant and frequent in many areas of the Western Alps, Belluso et al., 1995) and anthropogenic sources (e.g. dispersion caused by alteration of the ACM).

The fibers belonging to chrysotile/asbestiform antigorite are present in all the districts of 2014 campaign (100%) and in 55.5% of the districts of 2016 campaign. They represents the most abundant species both in 2014 and 2016 campaign (TAB.2).

245 Non-asbestos fibres.

246 Other than the two previous groups, we also found non-asbestos fibers belonging to 8
247 chemical groups, as below detailed. Neso-sorosilicates (represented by fayalite, forsterite,
248 epidoto, sillimanite and Al-silicates); single chain silicate (represented by diopside, enstatite,
249 ferrosilite, wollastonite); double chain silicates (represented by hornblende); phyllosilicates
250 (represented by micas, chlorites, clay minerals) and other phyllosilicates; tectosilicate
251 (represented by feldspars); carbonates (Ca or Mg); sulfate of Ca; and synthetic fibers.

252 Owing to the impossibility to distinguish hydroxides from oxides with the used technique,
253 and owing a large diffusion of these last, we named as “oxide groups” the compounds with
254 O and one or more of the following metals: Si, Ti, Al, Fe, Cr, Ni, Cu.

255 Respired fibers: burden of inorganic fibres in lung tissue

256 Investigation by SEM-EDS allowed to detect and to identify several types of inorganic fibers
257 both, in lung samples of 10 subjects (5 women and 5 men) resident in Torino all their life
258 and not dead for professional exposure. Among them, fibers belonging to tremolite/actinolite
259 asbestos group and chrysotile/asbestiform antigorite group (TAB.3 and TAB.4) have been
260 identified.

261

262 **Discussion**

263

264 This report is a preliminary study dealing a monitoring activity of the airborne inorganic
265 fibers, in 24 districts of Torino (Piemonte – NW Italy). We also reported the asbestos lung
266 burden detected in 10 subjects (5 women and 5 men) lived in this city all their life and
267 without professional exposure.

268 The inorganic fibers are not routinely sampled, therefore their nature and concentrations are
269 not know. The mineralogical investigation by SEM-EDS carried out in this study allowed to
270 evaluate which types of mineralogical species and inorganic compounds are airborne in
271 Torino and their amount.

272 Despite the rainfall are considered a factor of abatement of the particulate matter and fibers
273 too, the results highlight that it would not seem to be there any relationship between number
274 of days since the last rainfall and the concentration of the total fibers in both the 2014
275 (FIG.3a) and the 2016 (FIG.3b) sampling, unlike what we would have expected.

276 The district with more types of mineral species/inorganic compounds (respectively 15 and
277 16) and the most total number of ff/L (respectively 2 ff/L and 1 ff/L) is Nizza Millefonti
278 (SPOT2) in both 2014-2016 samplings.

279 In the 2014, the district with fewer types of mineral species/inorganic compounds and also
280 the lowest total number of ff/L is Mirafiori sud (SPOT 21).

281 In the 2016, the districts with fewer types of mineral species/inorganic compounds and also
282 the lowest total number of ff/L are Lingotto (SPOT 4) and Cenisia (SPOT 7).

283

284 Although commercial use of asbestos in Italy has been banned since 1992 (L.257/92),
285 asbestos is continuously airborne from both natural and anthropogenic sources; therefore it
286 is present everywhere and can be respired.

287 The asbestos species detected in Torino and certainly dispersed from natural source
288 belongs to the tremolite/actinolite asbestos group. The presence of tremolite/actinolite
289 asbestos in Torino air can be correlated to the wind direction that transport the mineral fibers
290 dispersed from the outcropping rocks containing them (i.e. from outcropping serpentine
291 rocks in Western Alps – S.1). In 2014 and 2016, in the period between April and November,
292 the wind direction was respectively from N to W sector and from NNE to W sector (FIG.4).

293 The maximum concentration of tremolite/actinolite asbestos detected is 1×10^{-1} ff/L in both
294 SPOT4 (2014 sampling campaign) and SPOT18 (2016 sampling campaign).

295 As concerns the fibers belong to the chrysotile/asbestiform antigorite group, they were the
296 most abundant and present in all districts in the 2014 sampling campaign) and in 75% of the
297 districts in the 2016 sampling campaign). Their presence in Italy in general and in examined
298 area in particular can be attributed to dispersion both from natural (i.e. from outcropping
299 serpentine rocks by Western Alps – S.1), and anthropogenic (i.e. in ACM – S.2) sources.

300 The absence of detection in of asbestos undoubtedly dispersed from anthropogenic sources
301 (i.e. crocidolite, amosite, and antophyllite asbestos) the SPOTs of the 24 districts, could be
302 explained by the fact that ACM are being progressively renovated or dismantled with a
303 subsequent reduction of the background asbestos level in the air.

304 Considering the total amount of asbestos, regardless their dispersion sources, in no areas
305 there is a situation of asbestos pollution highlighted (FIG.5). The relative quantity of asbestos
306 detected in all sampling area is fairly lower than the proposed pollution limits. They are: 2
307 ff/L established for environments reclaimed (DM06/09/1994), 1 ff/L (WHO guideline, 2000),
308 and the probability of developing mesothelioma that is $1:10^6$ if the subjects breathing
309 continuously air containing an average asbestos concentration of 0.004 ff/L for the whole
310 life (EPA, 2017).

311

312 Despite the limited number of lung tissue samples of the investigated subjects, it is
313 interesting to note that the only kind of asbestos, and of fibres potentially classifiable as
314 asbestos detected, correspond to those detected in air sampling.

315 The maximum concentration of tremolite/actinolite asbestos and chrysotile/asbestiform
316 antigorite fibers detected in the lung tissue have been respectively 0.10×10^5 ff/gdt and 0.28
317 $\times 10^5$ ff/gdt (TAB.3).

318 These values are lower than the quantities reported by the European Respiratory Society
319 guidelines (ERS) as indicative of significant asbestos exposure for amphiboles (1×10^5
320 ff/gdt) (De Vuyst et al., 1998).

321 Moreover, although the data cannot be considered sufficient for a significant statistically
322 analysis, the following aspects of the present investigation can be considered as a starting
323 point for further studies (TAB.3 and TAB.4):

- 324 - the average of fibers detected in women's lung tissue samples is much greater than that
325 found in men;
- 326 - the fibers belonging to the tremolite/actinolite asbestos group are present in all women's
327 lung tissue samples, but only in the 25% of the men's lung tissue samples;
- 328 - the fibers belonging to the chrysotile/asbestiform antigorite group were only detected in
329 women's lung tissue samples.

330 Gender differences are a current issue, in relation to the environmental factor and to health
331 (Matud, 2017).

332 The mesothelioma has principally affected men because it is a type of cancer mainly linked
333 to the asbestos occupational exposure (most asbestos exposures occur in blue-collar jobs,
334 traditionally male-dominated work settings). In women, mesothelioma is more likely to reflect
335 environmental or para-occupational asbestos exposure. However, information about women
336 is of particular interest because clinical differences have been reported between men and
337 women and differing susceptibility towards mesothelioma is also suspected (Hyland et al.,
338 2007).

339 Almost all the studies carried out in industrialized countries have shown that malignant
340 mesothelioma is much more common among men than among women with a proportion of
341 approximately 5:1 for men:women, confirming its occupational etiology (Spirtas et al., 1994,
342 Yates et al., 1997, Albin et al., 1999).

343 Studies from Turkey examining the risk of development of malignant mesothelioma from
344 environmental exposure to asbestos-contaminated soil mixtures have, on the contrary,
345 found a female gender predilection with a male:female ratio of 1:1.4. In addition, the data

346 reported indicate that the risk of mesothelioma is 88.3 times greater in men and 799 times
347 greater in women, in comparison to world background incidence rates (Metintas et al., 2002).

348

349 **Conclusions**

350 The present research represents: i) a new approach to improve the knowledge on kinds and
351 concentration of inorganic fibers, potentially harmful for humans, air dispersed in any
352 outdoor environment, constituting the background and respired; ii) makes possible to face
353 the problem about the health risks following low exposures.

354 Moreover, the collected data make feasible to identify the sources of dispersion
355 (anthropogenic or natural) in air of the inorganic fibers, knowing geological and
356 anthropogenic characteristics of the investigated and surrounding area, and therefore to put
357 in place strategies to improve air quality.

358 In our study, among the inorganic fibres detected, the only types classified asbestos are
359 tremolite/actinolite asbestos, whose presence in Torino city air depends not only on the ACM
360 presence on the territory, but also (or above all) on the kind of NOA contained in outcropped
361 rocks surrounding the city and transported to it by the wind. The results would seem to be
362 confirmed that in Torino, as regards the probability of developing mesothelioma because of
363 environmental exposure , the risk is extremely low, even if not quantifiable.

364 But, is there a threshold limit below which there is no health effects to asbestos exposure?
365 Furthermore, is it possible to hypothesize a different behavior of the asbestos within the
366 human organism in the relationship to gender? To date, these questions are open issues.

367

368 This research did not receive any specific grant from funding agencies in the public,
369 commercial, or not-for-profit sectors.

370

371 *Acknowledgements*

372 The authors wish to thank Corrado Leone for the assistance in the radar diagrams
373 preparation of the figure 4.

374

375 **References**

376

377 Albin, M., Magnani, C., Krstev, S., Rapiti, E., Shefer, I., 1999. Asbestos and cancer: an
378 overview of current trends in Europe. *Environ Health Perspect*, 107, 2:289–98.

379

380 ARPA, 2019a.
381 https://www.arpa.piemonte.it/rischinaturali/accesso-ai-dati/annali_meteoidrologici/annali-
382 [meteo-idro/banca-dati-meteorologica.html](https://www.arpa.piemonte.it/rischinaturali/accesso-ai-dati/annali_meteoidrologici/annali-meteo-idro/banca-dati-meteorologica.html)
383
384 ARPA, 2019b.
385 http://webgis.arpa.piemonte.it/amianto_storymap_webapp/
386
387 Belluso, E., Compagnoni, R., Ferraris, G., 1995. Occurance of asbestiform minerals in the
388 serpentinites of the Piemonte Zone, Western Alps. IN: *Politecnico di Torino Ed. Giornata di*
389 *studio in ricordo del prof. Stefano Zucchetti*, 57-66.
390
391 Belluso, E., Bellis, D., Fornero, E., Capella, S., Ferraris, G., Coverlizza, S., 2006.
392 Assessment of Inorganic Fibre Burden in Biological Samples by Scanning Electron
393 Microscopy – Energy Dispersive Spectroscopy, *Microchim Acta*, 155, 95–100.
394
395 Belluso, E., Cavallo, A., Halterman, D., 2017. Crystal habit of mineral fibres. In: *EMU Notes*
396 *in Mineralogy*, 18, 3, 65–110.
397
398 Bourdès, V., Boffetta, P., Pisani, P., 2000. Environmental exposure to asbestos and risk of
399 pleural mesothelioma: review and meta-analysis. *European journal of epidemiology*, 16, 5,
400 411-417.
401
402 Città Metropolitana di Torino, 2019.
403 <http://www.cittametropolitana.torino.it/cms/ambiente/qualita-aria/dati-qualita-aria/relazioni->
404 [annuali](http://www.cittametropolitana.torino.it/cms/ambiente/qualita-aria/dati-qualita-aria/relazioni-annuali)).
405
406 Compagnoni, R., Groppo C., 2006. Gli amianti in Val di Susa e le rocce che li contengono.
407 *Rendiconti della Società Geologica Italiana*, 3, Nuova Serie, 21-28.
408
409 Decreto Legislativo n. 277 del 15/08/1991. Attuazione delle direttive n. 80/1107/CEE, n.
410 82/605/CEE, n. 83/477/CEE, n. 86/188/CEE e n. 88/642/CEE, in materia di protezione dei
411 lavoratori contro i rischi derivanti da esposizione ad agenti chimici, fisici e biologici durante
412 il lavoro, a norma dell'art. 7 legge 30 luglio 1990, n. 212. Doc. 391B0277.900 di Origine
413 Nazionale. Gazzetta. Ufficiale del 27/08/1991 - Suppl. Ordinario n. 200.

414

415 Decreto Ministeriale del 6/09/1994. Normative e metodologie tecniche di applicazione
416 dell'art. 6, comma 3, e dell'art. 12, comma 2, della legge 27 marzo 1992, n. 257, relativa alla
417 cessazione dell'impiego dell'amianto. *Gazzetta Ufficiale*, Serie Generale n.220 del 20-09-
418 1994 - Suppl. Ordinario n. 129.

419

420 De Vuyst, P., 1998. Guidelines for mineral fibre analyses in biological samples: report of the
421 ERS Working Group. *European Respiratory Journal*, 11:1416-1426.

422

423 Directive 2003/18/EC of the European Parliament and of the Council of 27 March 2003
424 amending Council Directive 83/477/EEC on the protection of workers from the risks related
425 to exposure to asbestos at work. *Official Journal L97 of 15.4.2003*, 48.

426 Environmental Protection Agency 2017. Health Effects Assessment for Asbestos, EPA/1-
427 86/049 (NTIS PB 86134608), September 1984, retrived April 2017.

428

429 Gaines, R. V., Skinner, H. C., Foord, E. E., Mason, B., Rosenzweig, A., 1997. Dana's New
430 Mineralogy, 8th edition. John Wiley, New York.

431

432 Gualtieri, A.F., Mangano, D., Lassinantti, Gualtieri M., Ricchi, A., Foresti, E., Lesci, G.,
433 Roveri, N., Mariotti, M., Pecchini G., 2009. Ambient monitoring of asbestos in selected
434 Italian living areas. *Journal of Environmental Management* 90: 3540–3552.

435

436 Gunter, M.E., Belluso, E., Mottana, A., 2007. Amphiboles: environmental and health
437 concerns. Pp. 453-516. In: *Amphiboles: Crystal Chemistry, Occurrence and Health Issues*
438 (F.C. Hawthorne, R. Oberti, G. Della Ventura and A. Mottana, editors). Reviews in
439 Mineralogy and Geochemistry, 67, Mineralogical Society of America and Geochemical
440 Society, Chantilly, Virginia, USA.

441

442 Hyland, R. A, Ware, S., Johnson, A. R., Yates, H., 2007. Incidence trends and gender
443 differences in malignant mesothelioma in New South Wales, Australia, *Scandinavian*
444 *Journal of Work, Environment & Health*, 33, 4:286–292.

445

446 ISTAT, 2018. <http://demo.istat.it/pop2018/index.html>

447

448 Italian law 27 marzo 1992, n. 257. Norme relative alla cessazione dell'impiego dell'amianto.
449 *Gazzetta Ufficiale*, Serie Generale n.87 del 13-04-1992 - Suppl. Ordinario n. 64.
450

451 Lippmann, M., 2014. Toxicological and epidemiological studies on effects of airborne fibers:
452 Coherence and public health implications *Critical Reviews in Toxicology*, 44, 8: 643–695.
453

454 Matud, M.P., 2017. Gender and health. In: *Gender differences in different contexts* (Ed
455 A.Alvinus), 4, 57-76.
456

457 Metintas, S., Metintas, M., Ucgun, I., Oner, U., 2002. Malignant mesothelioma due to
458 environmental exposure to asbestos: follow-up of a Turkish cohort living in a rural area.
459 *Chest*, 122, 6:2224–9.
460

461 Park, S.N., 2018. Types and Health Hazards of Fibrous Materials Used as Asbestos
462 Substitutes. *Safety and Health at Work*, 9, 360-364.
463

464 Proposition 65 - Safe Drinking Water and Toxic Enforcement Act, 1986.
465

466 Spirtas, R., Heineman, E.F., Bernstein, L., Beebe, G.W., Keehn, R.J., Stark, A., Harlow, B.L.,
467 Benichou, J., 1994. Malignant mesothelioma: attributable risk of asbestos exposure.
468 *Occupational Environment Medicine*, 51, 12:804–11.
469

470 Utell, M.J., Maxim, L.D., 2018. Refractory ceramic fibers: Fiber characteristics, potential
471 health effects and clinical observations. *Toxicology and Applied Pharmacology*, 15,
472 361:113-117.

473 WHO, 1986. Asbestos and other natural mineral fibres. *Environmental Health Criteria*, 53.
474 Geneva
475

476 WHO air quality guidelines for Europe, 2nd edition, 2000.
477

478 [http://www.euro.who.int/en/health-topics/environment-and-health/air-](http://www.euro.who.int/en/health-topics/environment-and-health/air-quality/publications/pre2009/who-air-quality-guidelines-for-europe,-2nd-edition,-2000-cd-rom-version)
479 [quality/publications/pre2009/who-air-quality-guidelines-for-europe,-2nd-edition,-2000-cd-](http://www.euro.who.int/en/health-topics/environment-and-health/air-quality/publications/pre2009/who-air-quality-guidelines-for-europe,-2nd-edition,-2000-cd-rom-version)
480 [rom-version](http://www.euro.who.int/en/health-topics/environment-and-health/air-quality/publications/pre2009/who-air-quality-guidelines-for-europe,-2nd-edition,-2000-cd-rom-version)
481

482 Yates, C.B, Stidolph, B. K., 1997. Malignant mesothelioma in south-east England:
483 clinicopathological experience of 272 cases. *Thorax*, 52, 6:507–12.
484

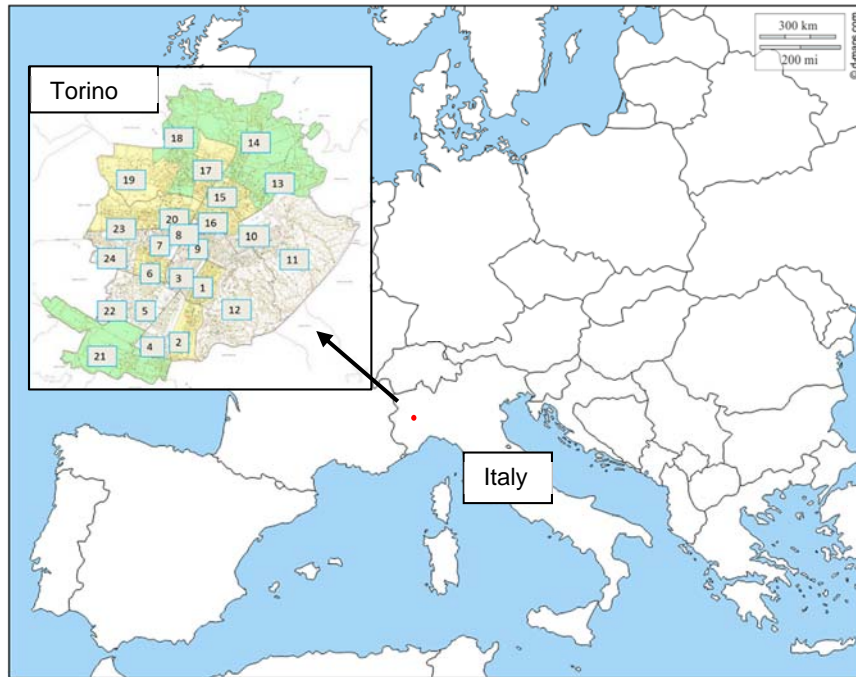


FIG.1 – Distribution of the 24 sampling districts in Torino city, NW Italy.

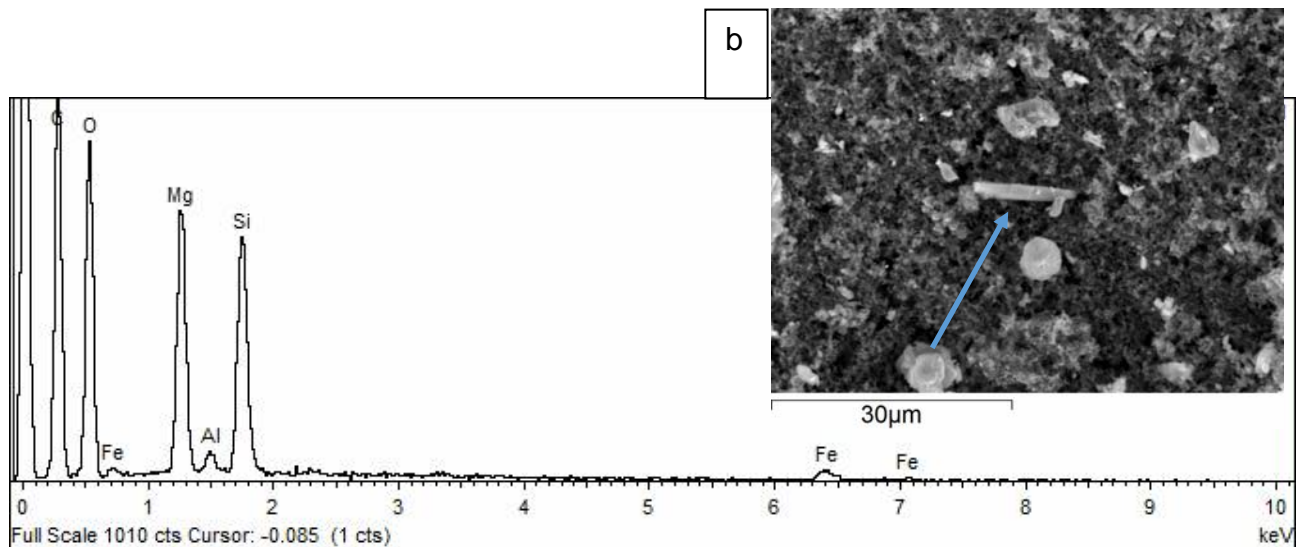
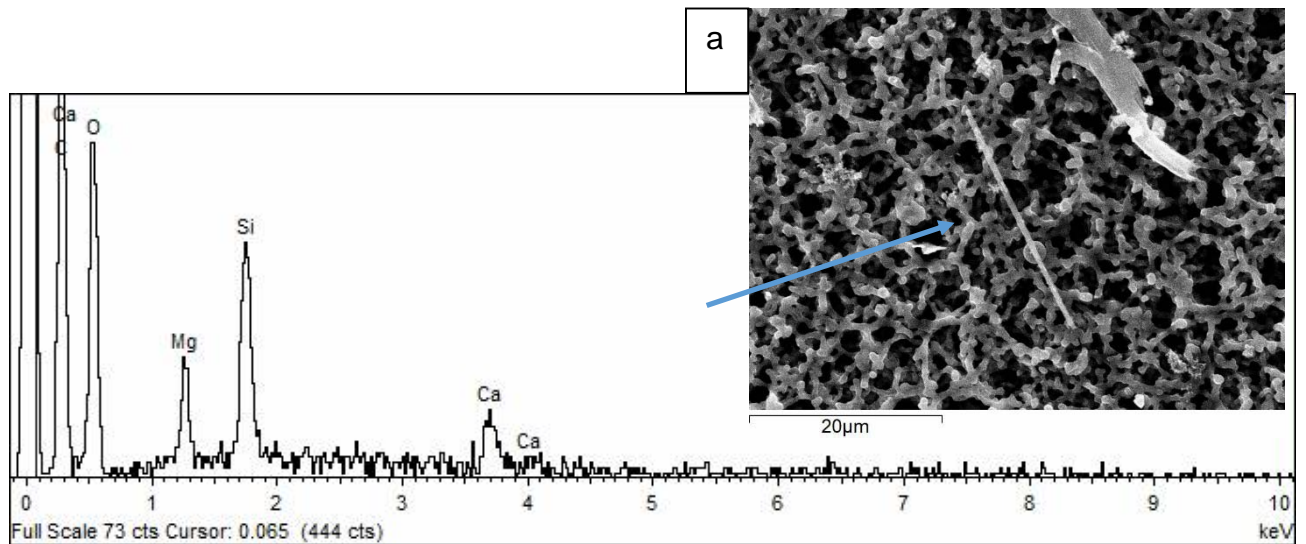


FIG.2 – (a) Backscattered electron SEM image and EDS spectrum of tremolite/actinolite asbestos; (b) secondary electron SEM image and EDS spectrum of chrysotile/asbestiform antigorite.

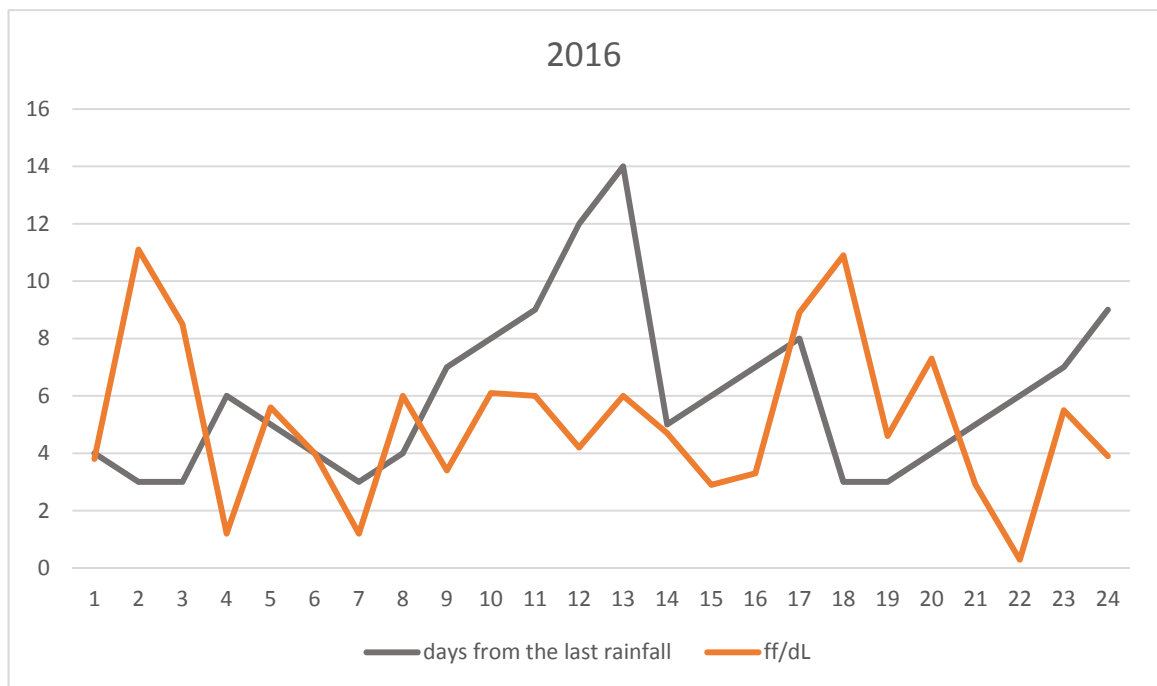
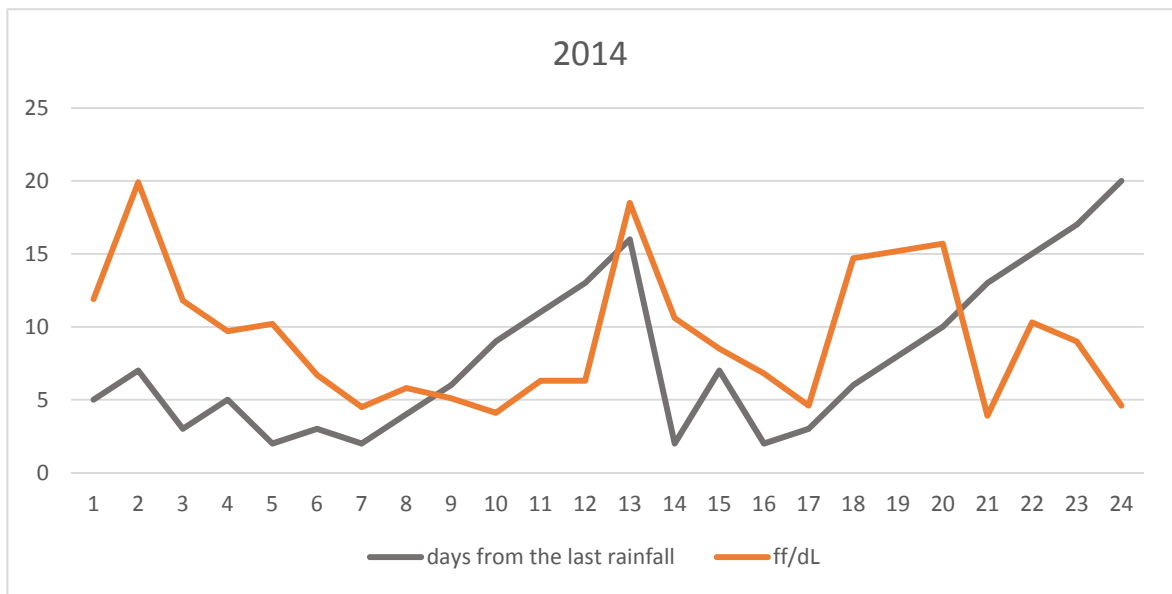


FIG.3 – (a) Total inorganic fibers amount and days from the last rainfall in 2014 (fibres are expressed as ff/dL to enhance the correlation view respect to the number of dry days before the sampling); (b) total inorganic fibers amount and days from the last rainfall in 2016 (fibres are expressed as ff/dL to enhance the correlation view respect to the number of dry days before the sampling).

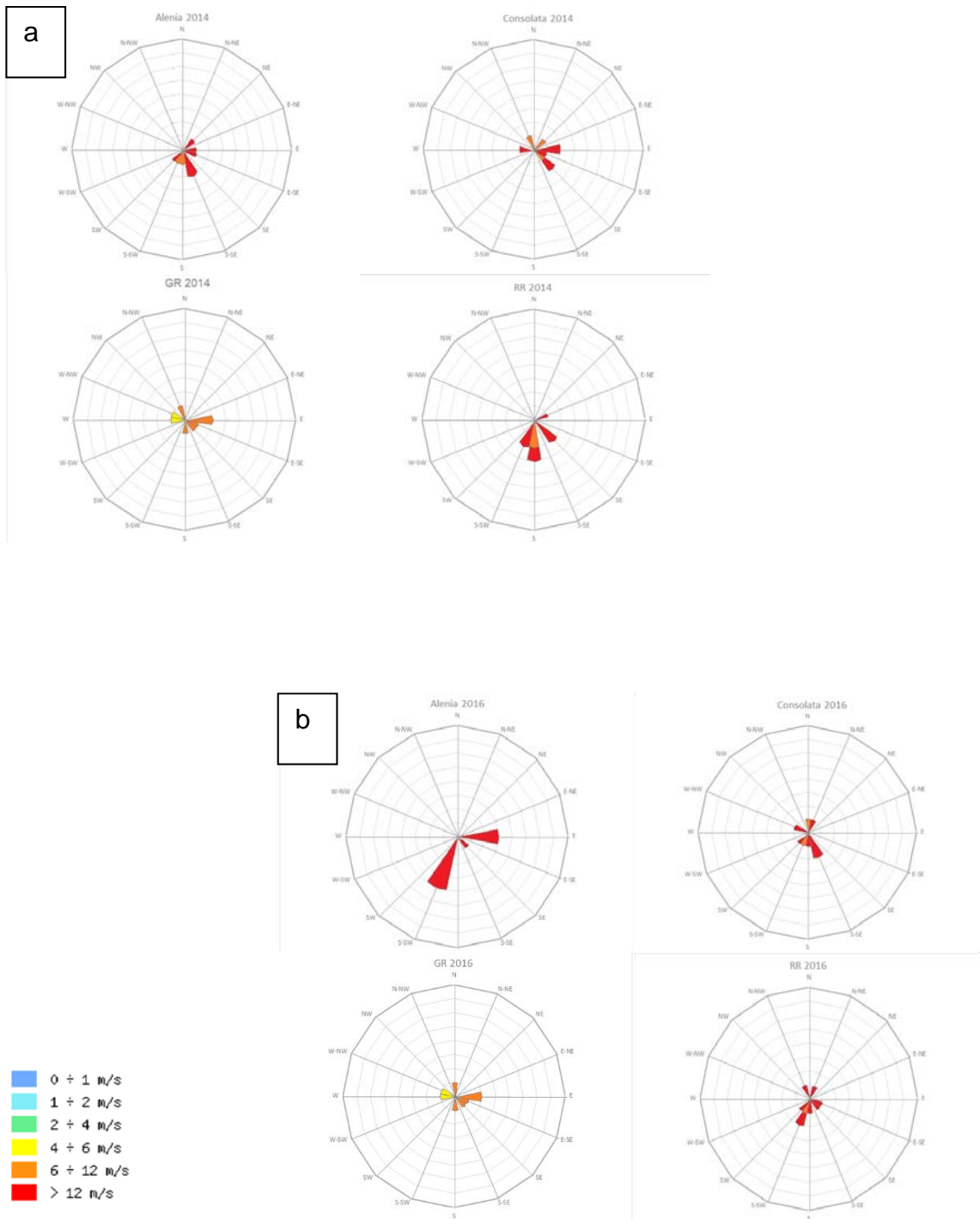


FIG.4 - (a) Wind radar diagrams, in 2014, between April and November registered at Alenia, Giardini Reali, Via Reiss Romoli and Via della Consolata stations (Arpa Piemonte, 2019); (b) - Wind radar diagrams, in 2016, between April and November, registered at Alenia, Giardini Reali, Via Reiss Romoli and Via della Consolata stations (Arpa Piemonte, 2019).

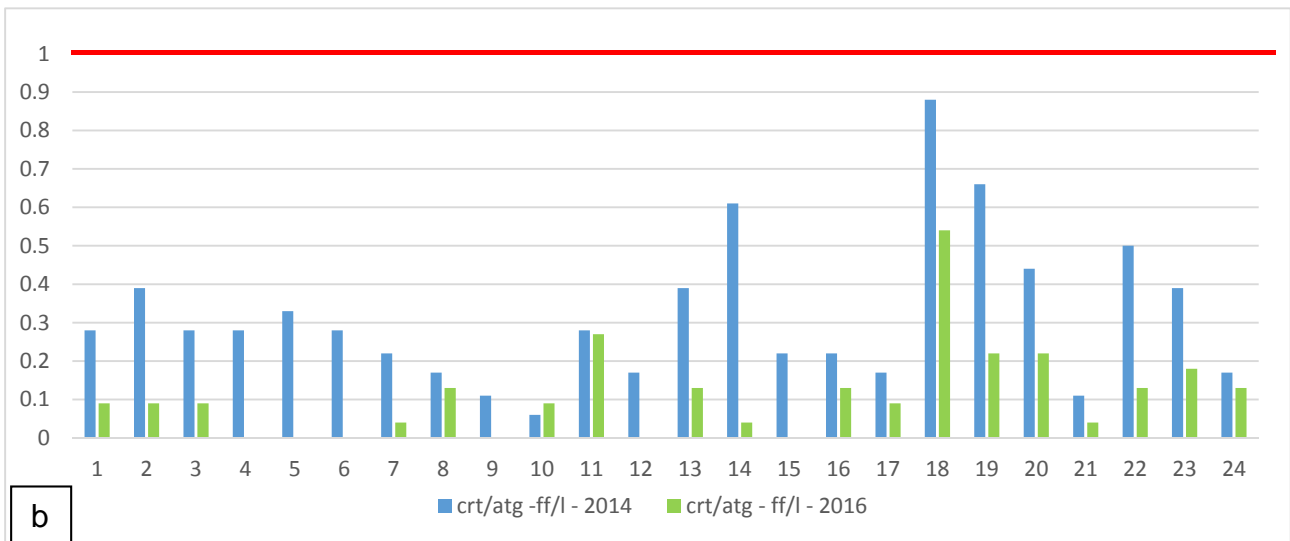
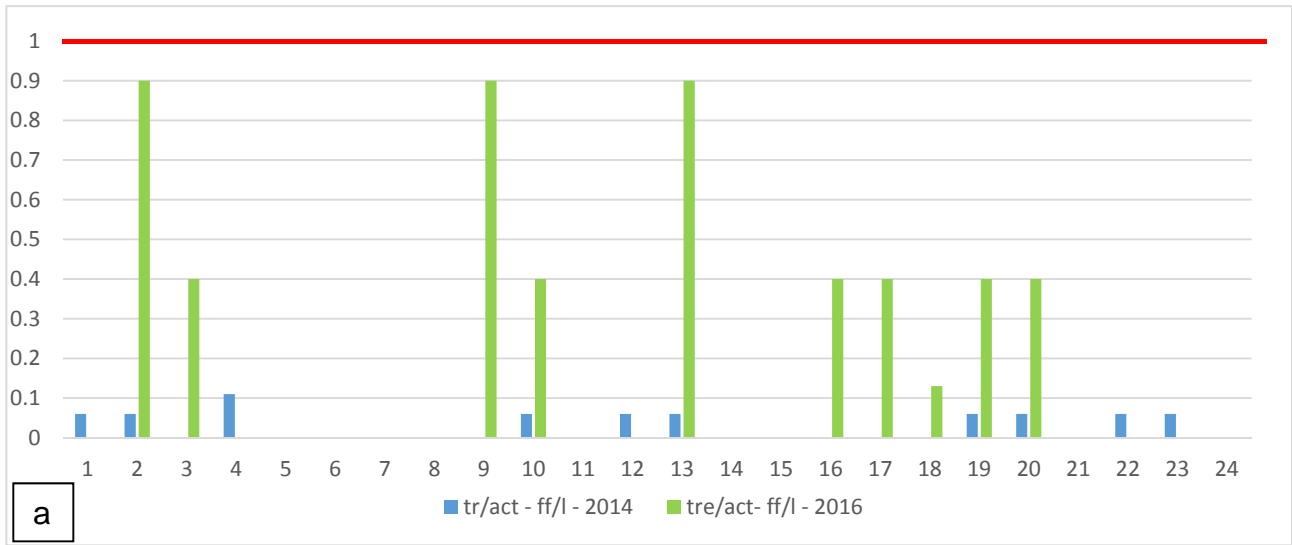


FIG.5 – (a) Tremolite/actinolite asbestos concentration (ff/L) in the 24 sampling points for 2014 and 2016. The line red indicates the alarm limit for asbestos fibers in air (1 ff/L) according WHO (2000); (b) - Chrysotile/asbestiform antigorite concentration (ff/L) in the 24 sampling points for 2014 and 2016. The line red indicates the alarm limit for asbestos fibers in air (1 ff/L) according WHO (2000).

Spots number	districts	number of days from the last rainfall in the 2014 sampling period	number of days from the last rainfall in the 2016 sampling period
1	San Salvario	5	4
2	Nizza Millefonti	7	3
3	Crocetta	3	3
4	Lingotto	5	6
5	Santa Rita	2	5
6	San Paolo	3	4
7	Cenisia	2	3
8	Cit Turin	4	4
9	Centro	6	7
10	Vanchiglia	9	8
11	Madonna del Pilone	11	9
12	Borgo Po Cavoretto	13	12
13	Regio Parco - Barca	16	14
14	Falchera – Villaretto	2	5
15	Barriera di Milano	7	6
16	Aurora	2	7
17	Borgata Vittoria	3	8
18	Madonna di Campagna	6	3
19	Vallette - Lucento	8	3
20	San Donato	10	4
21	Mirafiori Sud	13	5
22	Mirafiori Nord	15	6
23	Parella	17	7
24	Pozzo Strada	20	9

TAB.1 – Spots number for sampling sites, districts, and number of days from the last rainfall for 2104 and 2016 sampling.

inorganic fibres						
main classes	groups	sub-groups	minerals or chemical species	2014 sampling (ff/L)	2016 sampling (ff/L)	
SILICATES	NESO-SORO SILICATES		fayalite; forsterite; epidoto; sillimanite	5 x 10 ⁻¹	1 x 10 ⁻¹	
	CHAIN SILICATES	pyroxenes	diopside; enstatite; ferrosilite; wollastonite	4 x 10 ⁻¹	15 x 10 ⁻¹	
		amphiboles	tremolite/actinolite asbestos		6 x 10 ⁻¹	6 x 10 ⁻¹
	hornblende			40 x 10 ⁻¹	8 x 10 ⁻¹	
	PHYLLOSILICATES		micas		6 x 10 ⁻¹	3 x 10 ⁻¹
			<i>chrysotile/asbestiform antigorite</i>		75 x 10 ⁻¹	27 x 10 ⁻¹
			clorites		9 x 10 ⁻¹	5 x 10 ⁻¹
			clay minerals		27 x 10 ⁻¹	10 x 10 ⁻¹
			other phyllosilicates		15 x 10 ⁻¹	8 x 10 ⁻¹
	TECTOSILICATES	feldspars		12 x 10 ⁻¹	3 x 10 ⁻¹	
OXIDES		SiO ₂ , TiO ₂ , Al ₂ O ₃ , Fe >Cr> Ni- oxides, Fe >Cr-oxides, Fe > Cu-oxides, Fe-oxides	9 x 10 ⁻¹	26 x 10 ⁻¹		
CARBONATES		CaCO ₃ and MgCO ₃	1 x 10 ⁻¹	3 x 10 ⁻¹		
SULFATES		CaSO ₄	6 x 10 ⁻¹	5 x 10 ⁻¹		
SYNTHETICS		Al-Si-O; Mg-Al-Si-Ca-O	4 x 10 ⁻¹	5 x 10 ⁻¹		
NON IDENTIFIED			7 x 10 ⁻¹	0		
Total fibers				226 x 10⁻¹	123 x 10⁻¹	

TAB.2 - Inorganic fibres, grouped according to mineralogical classes and chemical species, detected in the 24 districts for 2014 and 2016 and expressed in ff/L.

Asbestos are reported in bold; the mineralogical group including chrysotile and the similar asbestiform antigorite is reported in italics and bold.

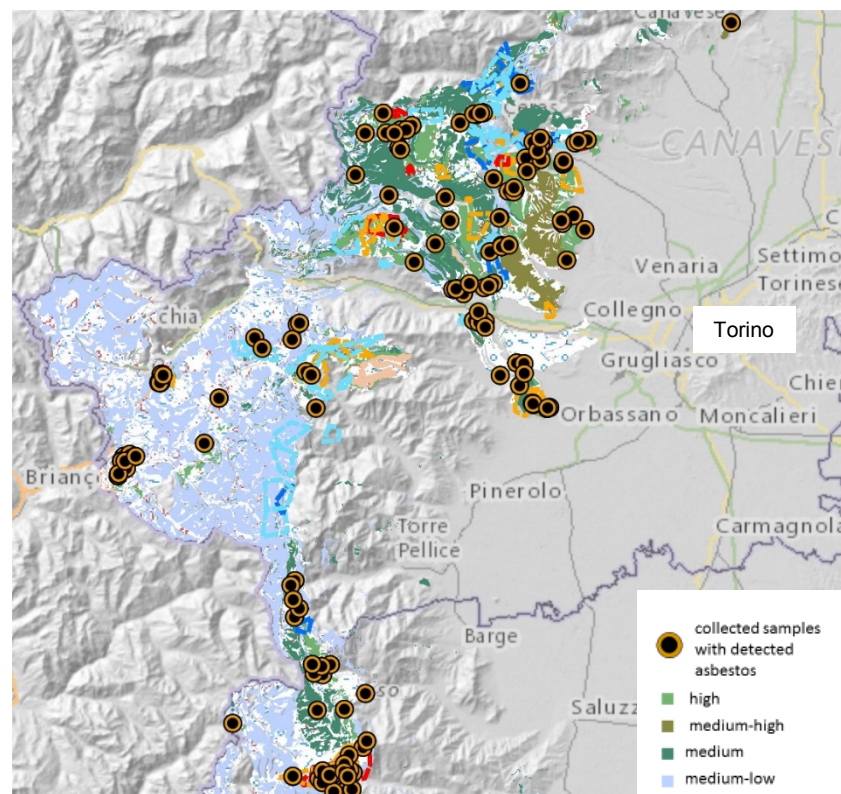
women	age	tremolite-actinolite asbestos ff/gdw	<i>chrysotile-asbestiform antigorite ff/gdw</i>	fibrous clay minerals ff/gdw	other fibrous phyllosilicates ff/gdw	fibrous oxides ff/gdw	fibrous feldspar ff/gdw
F 13	67	0.03 x 10 ⁵	0.02 x 10 ⁵	1.13 x 10 ⁵	0.01 x 10 ⁵	/	/
F 12	68	0.10 x 10 ⁵	0.01 x 10 ⁵	0.07 x 10 ⁵	0.09 x 10 ⁵	0.01 x 10 ⁵	/
F 11	70	0.04 x 10 ⁵	0.02 x 10 ⁵	0.19 x 10 ⁵	0.38 x 10 ⁵	0.01 x 10 ⁵	0.14 x 10 ⁵
F 4	74	0.04 x 10 ⁵	0.14 x 10 ⁵	0.01 x 10 ⁵	0.07 x 10 ⁵	0.03 x 10 ⁵	/
F 5	76	0.01 x 10 ⁵	0.28 x 10 ⁵	0.03 x 10 ⁵	0.07 x 10 ⁵	0.04 x 10 ⁵	/

TAB.3 – Tremolite/actinolite asbestos, chrysotile/asbestiform antigorite, other inorganic fibres burden, and the averaged concentration (ff/gdw) detected in lung tissue of 5 women (resident in Torino all their life and not dead for professional exposure to asbestos). Asbestos are reported in bold; the mineralogical group including chrysotile and the similar asbestiform antigorite is reported in italics and bold.

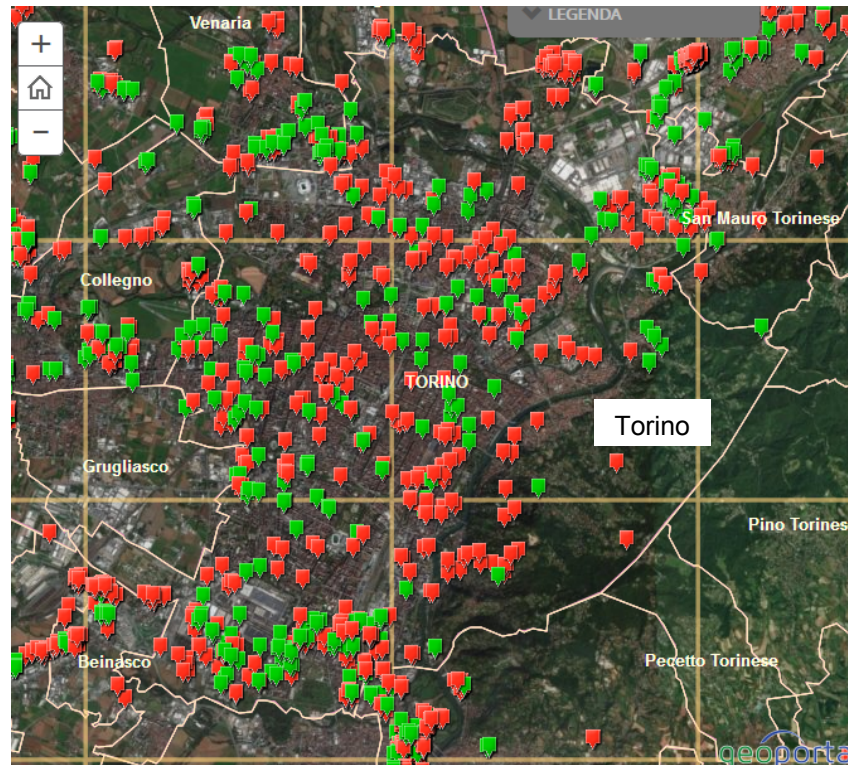
men	age	tremolite-actinolite asbestos ff/gdw	<i>chrysotile-asbestiform antigorite ff/gdw</i>	fibrous clay minerals ff/gdw	other fibrous phyllosilicates ff/gdw	fibrous feldspar ff/gdw	fibrous oxides ff/gdw	synthetic fibres ff/gdw
M1	59	/	/	/	/	/	0.18 x 10 ⁵	/
M11	61	/	/	/	/	0.06 x 10 ⁵	0.12 x 10 ⁵	/
M12	66	/	/	/	/	/	0.12 x 10 ⁵	/
M3	76	/	/	/	0.03 x 10 ⁵	/	0.03 x 10 ⁵	0.03 x 10 ⁵
M9	81	0.06 x 10 ⁵	/	/	0.06 x 10 ⁵	/	0.18 x 10 ⁵	/

TAB.4 - Tremolite/actinolite asbestos, chrysotile/asbestiform antigorite and other inorganic fibres burden (ff/gdw) detected in lung tissue of 5 men (resident in Torino all their life and not dead for professional exposure to asbestos) and their average.

Asbestos are reported in bold; the mineralogical group including asbestos chrysotile and the similar asbestiform antigorite is reported in italics and bold.



S.1. Probability from high to low (according to colors) of naturally occurring asbestos (NOA) in different lithologies near Torino city. The yellow dots with black interior indicate the sites where asbestos has been detected in the collected samples (Arpa Piemonte, 2019).



S.2. Distribution map of in situ ACM roofs (red plates) and reclaimed roofs (green plates) in Torino (ARPA Piemonte, 2019).