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

DOI:10.1016/j.envpol.2020.114384

(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

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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

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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 (Unversity of Milano Bicocca)

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

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

Highlights

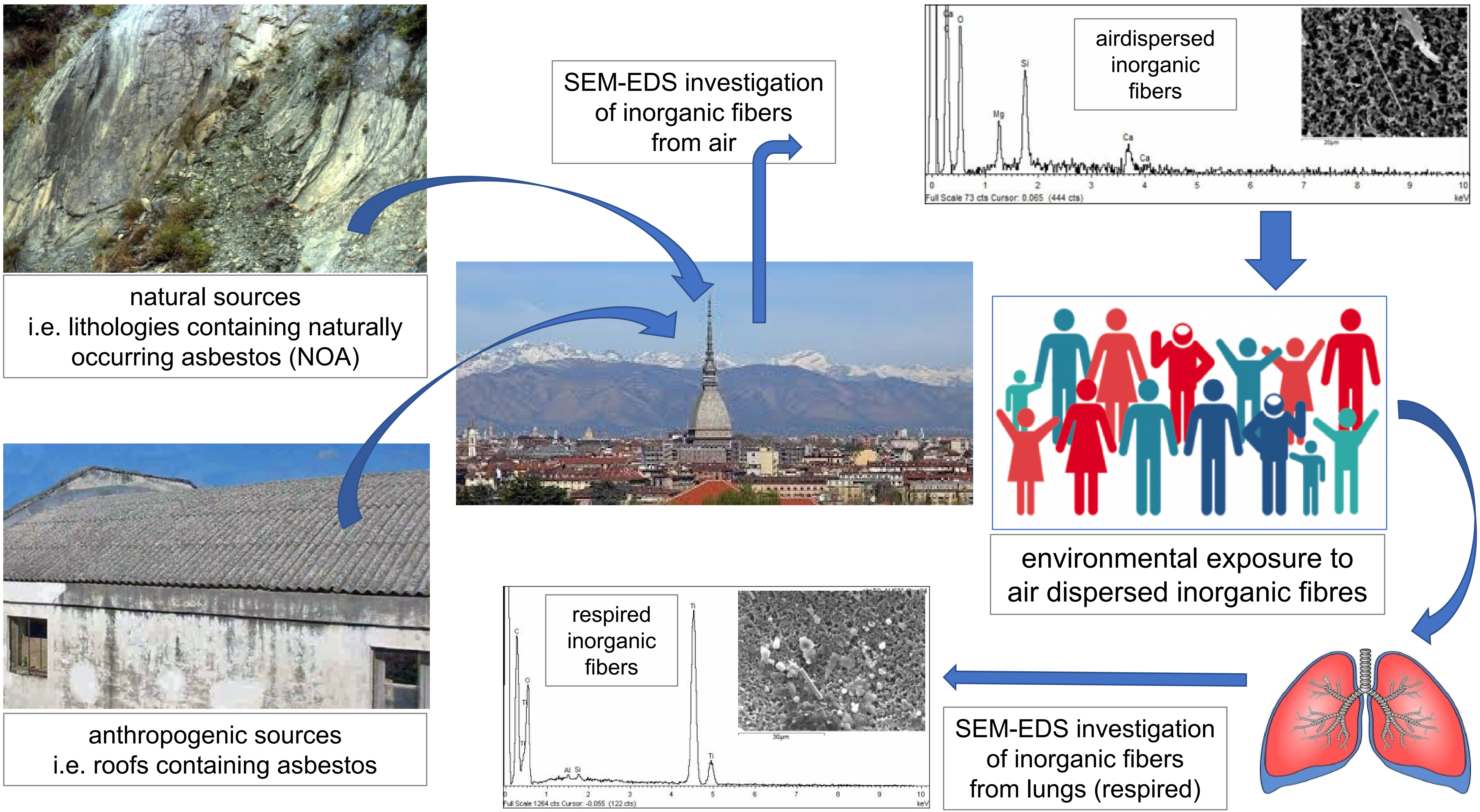
A new approach to evaluate airborne inorganic fibershazardous exposure

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
airdispersed
inorganic
fibers
environmental exposure to
air dispersed inorganic fibres
respired
inorganic
fibers
SEM-EDS investigation
of inorganic fibers
from lungs (respired)

Capella S.[a,b], Bellis D. [d,b], Fioretti E.[e], Marinelli R.[f], Belluso E.[a,b,c]

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

[a] Department of Earth Sciences, University of Torino, Torino, Italy
[b] Interdepartmental Centre for Studies and other Toxic Particulates "G. Scansetti", University of Torino, Torino, Italy
[c] Institute of Geosciences and Earth Resources, CNR, Unit of Torino, Italy
[d] Department of Surgery, Pathological Anatomy, Ospedale degli Infermi, Ponderano, Biella, Italy
[e] Strada Bussolino 68, 10090 - Gassino Torinese, Italy
[f] Via Parma 11/C, 39100 - Bolzano, Italy

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

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.

Summary of the main result of the work

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

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

Introduction

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

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

About the presence in urban air of inorganic fibers, both natural and synthetic, there are few investigations, mostly dealing with airborne asbestos and regarding few cities. The concentrations reported vary a lot and depend on the used investigation techniques: 0.2 to 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 in Japan, 0.2 to 4.6 ff/L in Italy (e.g. Bourdés et al., 2000; Gualtieri et al., 2009).

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

As an example, the six minerals classified as asbestos (i.e. anthophillite asbestos, amosite, tremolite asbestos, actinolite asbestos, crocidolite, and chrysotile) have been banned for all of Europe since 2006 and therefore they are not used in products made after this date. However some of them (chrysotile, crocidolite, amosite, and antophyllite asbestos) are contained in products, known as asbestos containing materials (ACM), installed before the asbestos ban and constitute anthropogenic sources of fiber release in air. In fact, ACM, as for example cement-asbestos roof, release more and more asbestos fibers in air as they deteriorate due to atmospheric agents and if they are not properly maintained. The other two types of asbestos, i.e. tremolite asbestos and actinolite asbestos, have not been industrially used owing their scarce physical and chemical properties, but in Italy, owing to both natural weathering and anthropogenic activities, they are dispersed in air from several rocks that contain them; in this case rocks constitute natural sources of asbestos air dispersion. In Italy, also chrysotile, the less diffused anthophyllite asbestos, and other fibrous minerals are dispersed in air by natural sources. The fibers, once they have been dispersed in air, depending on the winds and atmospheric conditions, can be transported for distances before their deposition.

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

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

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

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

Torino is a city where ACM factories have never been present but asbestos containing roofs and other placed ACM are abundant and widespread. Moreover, natural sources (i.e. rocks) containing naturally occurring asbestos (NOA) and naturally occurring asbestiform minerals non asbestos classified (NONA) surround the city.

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

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

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

Description of the sampling area

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

Torino, covering about 130 km^2, is the capital of Piemonte Region, one of the largest urbanised areas in Northern Italy and with about 880,000 inhabitants it is considered the 4th Italian city (ISTAT, 2018).

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

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

The topography of the area and geographic location make it one of the most problematic Italian cities in terms of reducing atmospheric emissions. In effect, because of its closed position, the city core and the surrounding urbanized area are exposed to long-lasting episodes of air pollution during both summer and winter, when European air quality standards for PM10, NO2, O3 concentrations are often exceeded (Città Metropolitana di Torino, 2019).

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

Another weather factor that can contribute to a greater or lesser air pollution is the amount and distribution of rainfall. The average annual precipitation of Torino is approximately 900 mm; the rainiest period is April/June, whereas the least rainy period is December/February.

Its geographical position, the surrounding rocks containing NOA and NONA, and the presence of ACM widely used in building constructions, make Torino a suitable area of study about inorganic fibers background.

Material and methods

Monitoring of airborne inorganic fibers

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

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

The sampling was carried out by means of a portable air sampler (Delta HF TCR Tecora) with fibres sampling head and nitrocellulose filters (∅2.5 mm and pore of 0.8 μm) placed on the top of a portable tripod at 1.5 m above ground level.

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

Inorganic fibers in lung tissue

Through a retrospective study, in collaboration with the pathologist author, lung tissue samples (preserved in formalin) of 10 subjects (5 women and 5 men) resident in Torino all their life and not dead for professional exposure to asbestos have been selected.
They have been prepared for SEM-EDS investigation to quantify and identify the inorganic fibers according to Belluso et al. (2006) protocol.

<u>SEM-EDS analysis</u>

The 24 filters of air samples and the 10 filters of lung tissue samples were prepared for SEM-EDS investigation and examined at the department of Earth Sciences of the University of Torino, to assess the presence, type and burden of inorganic fibers airborne and respired, respectively .
The filters were coated with a thin layer of carbon (metallization step). Subsequently an area about of 2 mm^2 (the double of the area reported in DM 6/9/94, where an official method for analyzing airborne asbestos is indicated), was analysed at 2000 magnification by SEM following a systematic path according to a predetermined scheme. Only particles having length > 5 μm, width < 3 μm, and length/diameter ratio > 3, and were considered (D.Lgs 277/91; Directive 2003/18/EC; WHO, 1997).
Each fibre was analysed with the annexed EDS to acquire its chemical composition. The EDS-SEM spectra obtained were compared with that characteristics for the different types of inorganic species constituting the data-base of the fibre laboratory at Earth Sciences department.
Whenever possible, each fiber was identified as a mineral species. In the case of doubtful identification due to structural or chemical differences non solvable with the used technique, the fiber was attributed to a mineralogical group, as for chrysotile and asbestiform antigorite which have similar morphology and chemical composition but different crystalline structure, and for tremolite asbestos and actinolite asbestos, having a similar structure and chemical composition. In this case, we used the following group names: chrysotile/asbestiform antigorite, tremolite/actinolite asbestos.
To obtain the burden of airborne inorganic fibers in each district, the amount (number) of every type of fiber detected was related to the number of fiber per liter (ff/L) of sampled air.
To obtain the burden of inorganic fibers in the lung samples (i.e. respired fibers) the amount (number) of each type of fiber detected was normalized to 1 gram of dry weight (gdw) of the tissue, according to the international standard (De Vuyst et al., 1998).

Results

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).

Non-asbestos fibres.

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

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

Respired fibers: burden of inorganic fibres in lung tissue

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

Discussion

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

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

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

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

In the 2014, the district with fewer types of mineral species/inorganic compounds and also the lowest total number of ff/L is Mirafiori sud (SPOT 21).
In the 2016, the districts with fewer types of mineral species/inorganic compounds and also the lowest total number of ff/L are Lingotto (SPOT 4) and Cenisia (SPOT 7).

Although commercial use of asbestos in Italy has been banned since 1992 (L.257/92), asbestos is continuously airborne from both natural and anthropogenic sources; therefore it is present everywhere and can be respired.
The asbestos species detected in Torino and certainly dispersed from natural source belongs to the tremolite/actinolite asbestos group. The presence of tremolite/actinolite asbestos in Torino air can be correlated to the wind direction that transport the mineral fibers dispersed from the outcropping rocks containing them (i.e. from outcropping serpentine rocks in Western Alps – S.1). In 2014 and 2016, in the period between April and November, the wind direction was respectively from N to W sector and from NNE to W sector (FIG.4).
The maximum concentration of tremolite/actinolite asbestos detected is 1×10^{-1} ff/L in both SPOT4 (2014 sampling campaign) and SPOT18 (2016 sampling campaign).
As concerns the fibers belong to the chrysotile/asbestiform antigorite group, they were the most abundant and present in all districts in the 2014 sampling campaign) and in 75% of the districts in the 2016 sampling campaign). Their presence in Italy in general and in examinerd area in particular can be attributed to dispersion both from natural (i.e. from outcropping serpentine rocks by Western Alps – S.1), and anthropogenic (i.e. in ACM – S.2) sources.
The absence of detection in of asbestos undoubtedly dispersed from anthropogenic sources (i.e. crocidolite, amosite, and antophyllite asbestos) the SPOTs of the 24 districts, could be explained by the fact that ACM are being progressively renovated or dismantled with a subsequent reduction of the background asbestos level in the air.
Considering the total amount of asbestos, regardless their dispersion sources, in no areas there is a situation of asbestos pollution highlighted (FIG.5). The relative quantity of asbestos detected in all sampling area is fairly lower than the proposed pollution limits. They are: 2 ff/L established for environments reclaimed (DM06/09/1994), 1 ff/L (WHO guideline, 2000), and the probability of developing mesothelioma that is $1:10^6$ if the subjects breathing continuously air containing an average asbestos concentration of 0.004 ff/L for the whole life (EPA, 2017).

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

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

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

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

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

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

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

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

Studies from Turkey examining the risk of development of malignant mesothelioma from environmental exposure to asbestos-contaminated soil mixtures have, on the contrary, found a female gender predilection with a male:female ratio of 1:1.4. In addition, the data reported indicate that the risk of mesothelioma is 88.3 times greater in men and 799 times greater in women, in comparison to world background incidence rates (Metintas et al., 2002).

Conclusions

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

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

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

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

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

Acknowledgements

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

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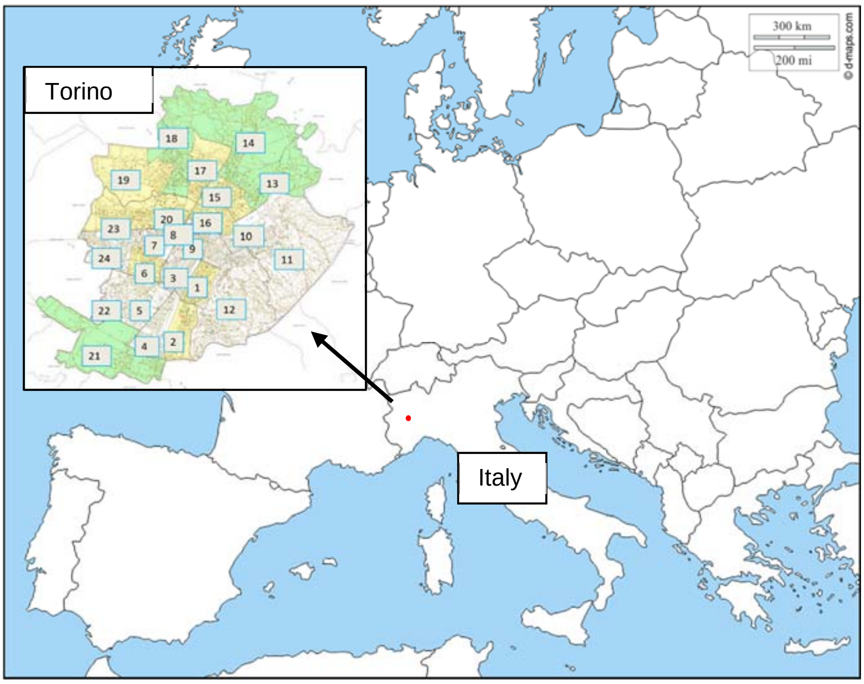


FIG.1 – Distribution of the 24 sampling districts in Torino city, NW Italy.

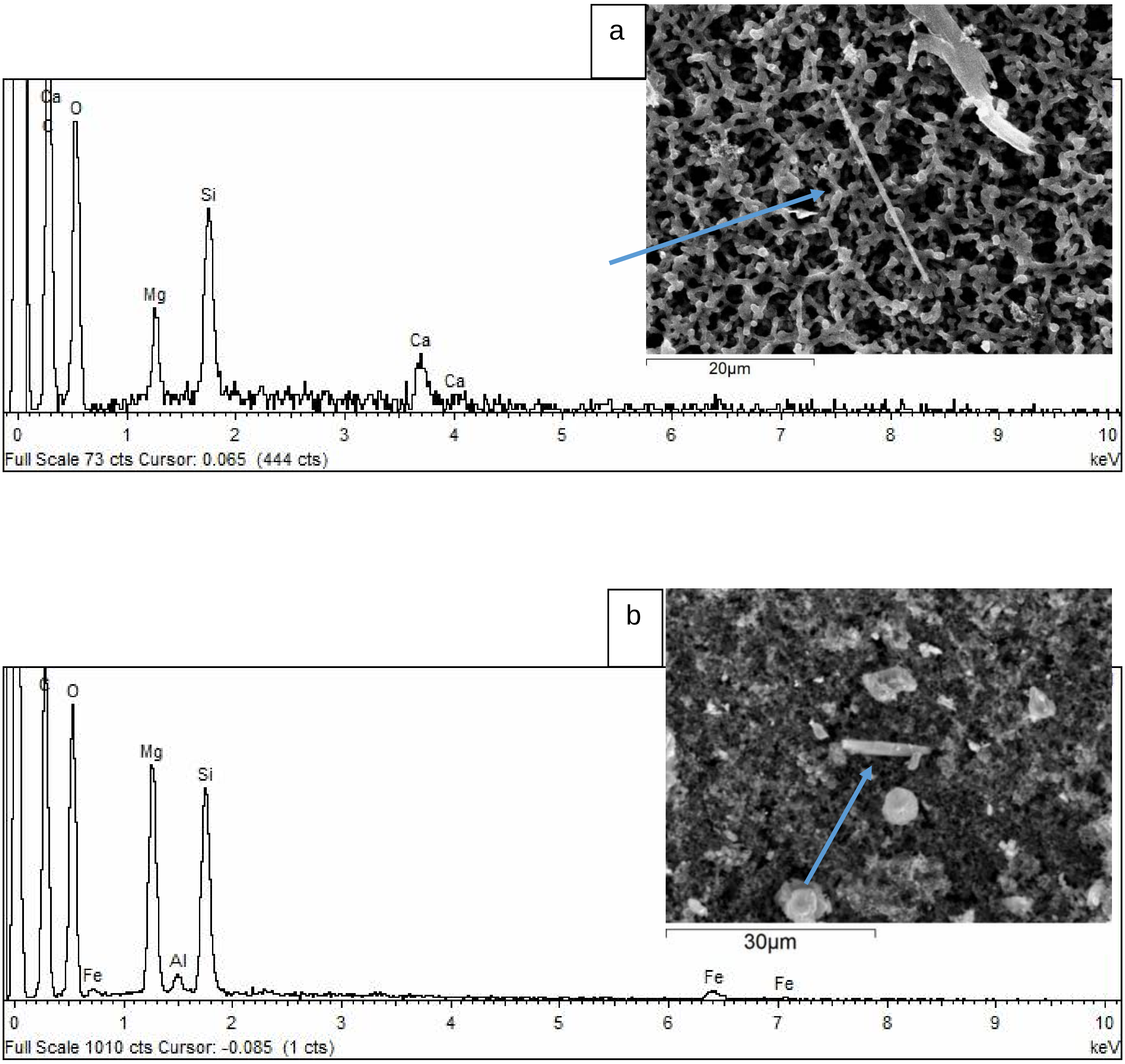


FIG.2 – (a) Backscattered electron SEM image and EDS spectrum of tremolite/actinolite asbestos; (b) secondary electron SEM image and EDS spectrum of chrysotile/asbestiform antigorite.

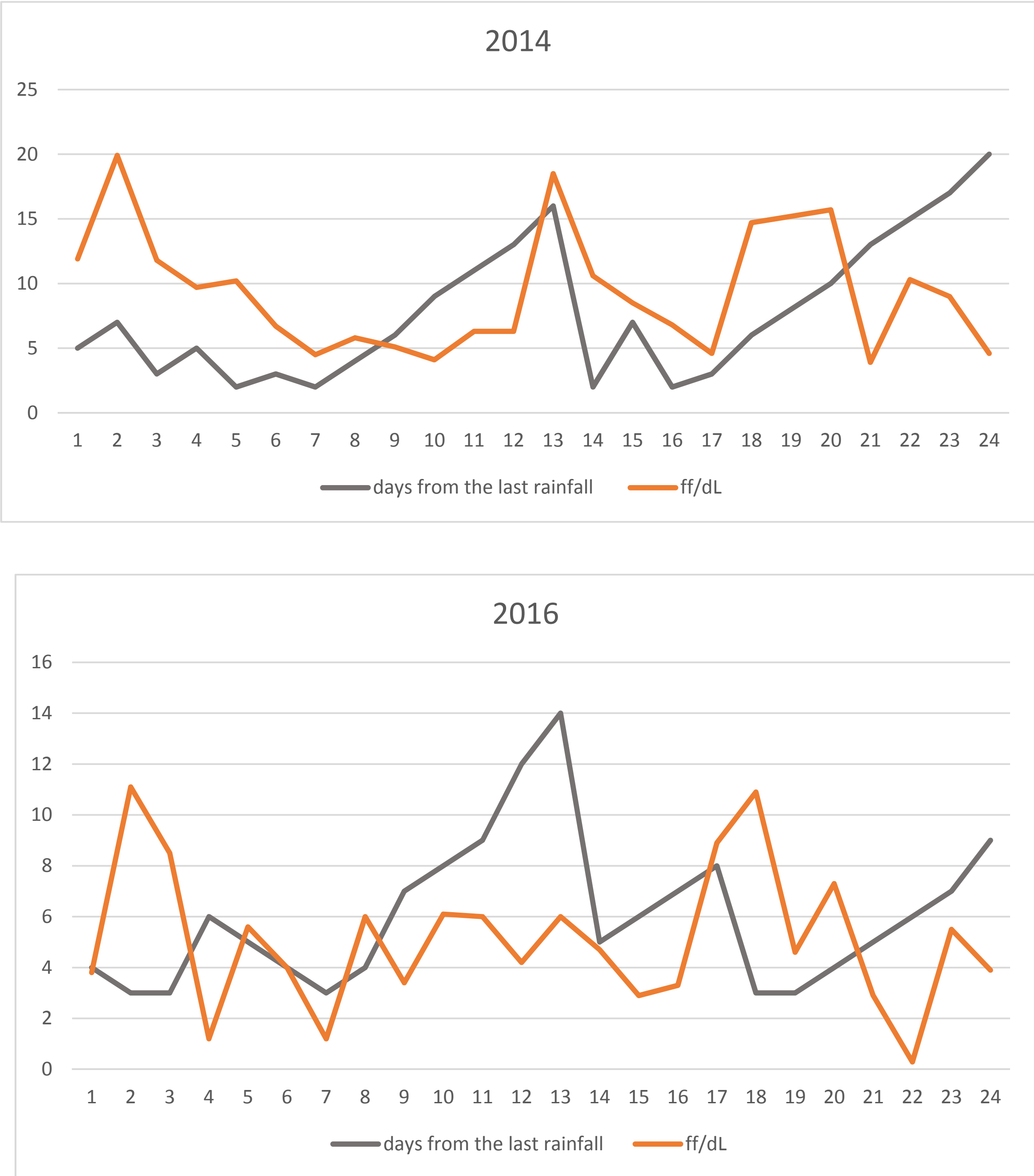


FIG.3 – (a) Total inorganic fibers amount and days from the last rainfall in 2014 (fibres are expressed as ff/dL to enhance the correlation view respect to the number of dry days before the sampling); (b) total inorganic fibers amount and days from the last rainfall in 2016 (fibres are expressed as ff/dL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

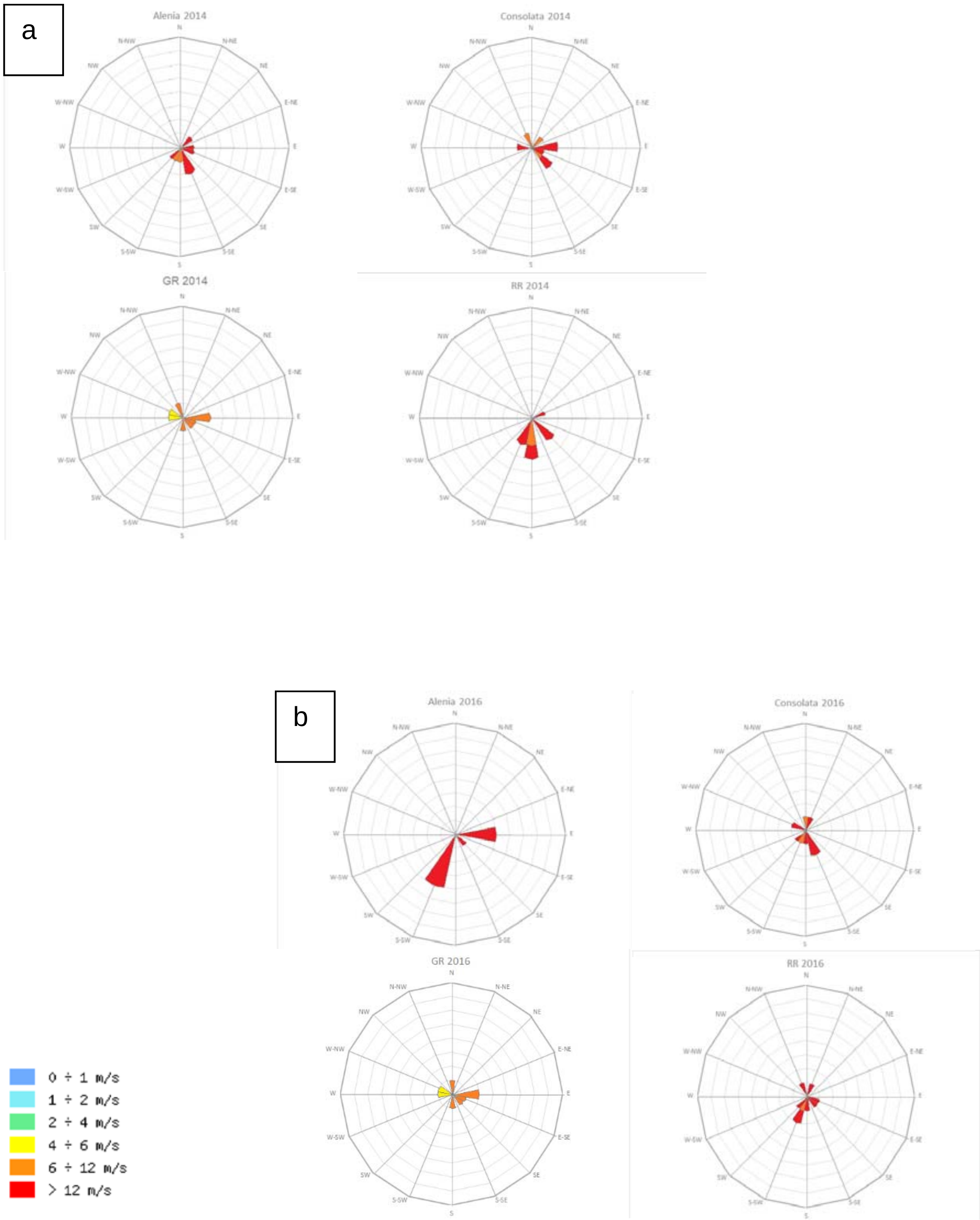
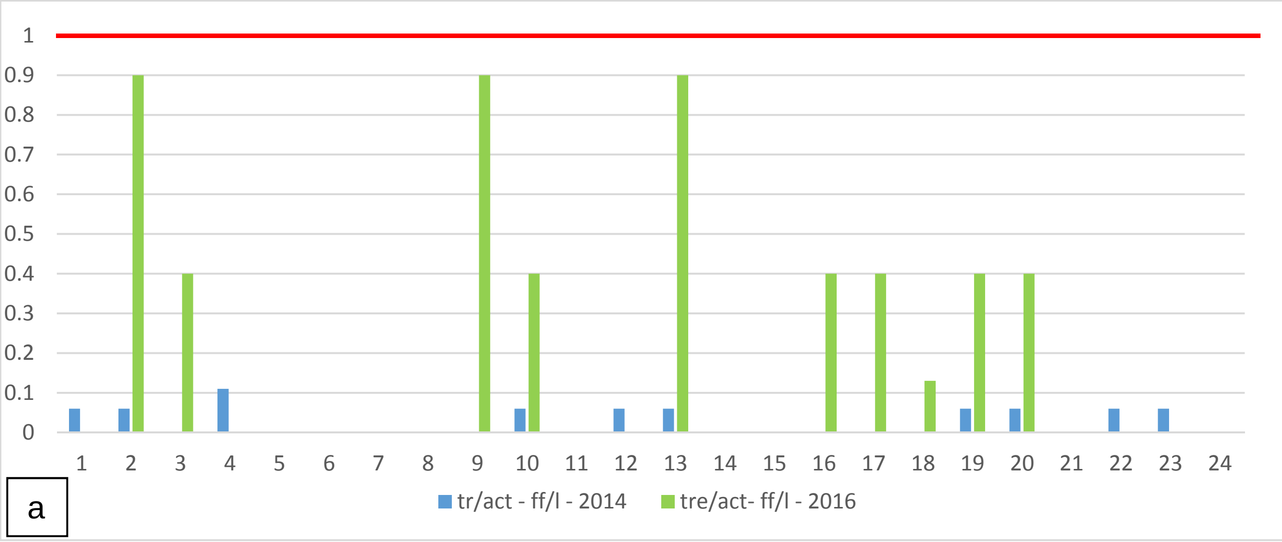


FIG.4 - (a) Wind radar diagrams, in 2014, between April and November registered at Alenia, Giardini Reali, Via Reiss Romoli and Via della Consolata stations (Arpa Piemonte, 2019); (b) - Wind radar diagrams, in 2016, between April and November, registered at Alenia, Giardini Reali, Via Reiss Romoli and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



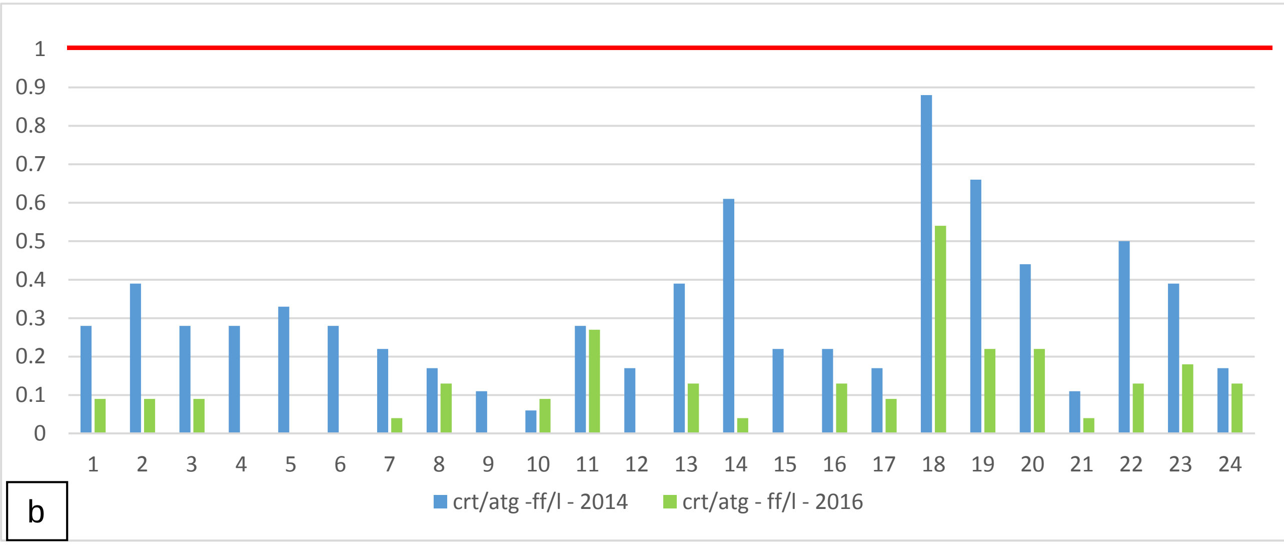


FIG.5 – (a) Tremolite/actinolite asbestos concentration (ff/L) in the 24 sampling points for 2014 and 2016. The line red indicates the alarm limit for asbestos fibers in air (1 ff/L) according WHO (2000); (b) - Chrysotile/asbestiform antigorite concentration (ff/L) in the 24 sampling points for 2014 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}
			chrysotile/asbestiform antigorite	**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_2O_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.

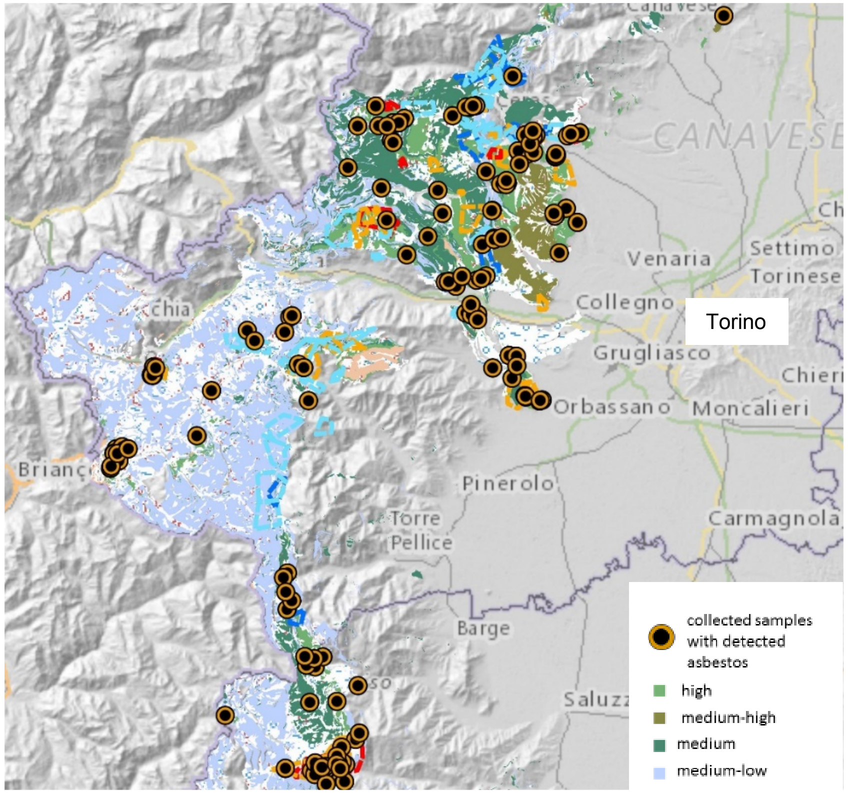
women	**age**	**tremolite-actinolite asbestos ff/gdw**	***chrysotile-asbestiform antigorite ff/*gdw**	fibrous clay minerals ff/gdw	other fibrous phyllosilicates ff/gdw	fibrous oxides ff/gdw	fibrous feldspar ff//gdw
F 13	67	0.03×10^5	0.02×10^5	1.13×10^5	0.01×10^5	/	/
F 12	68	0.10×10^5	0.01×10^5	0.07×10^5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

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.

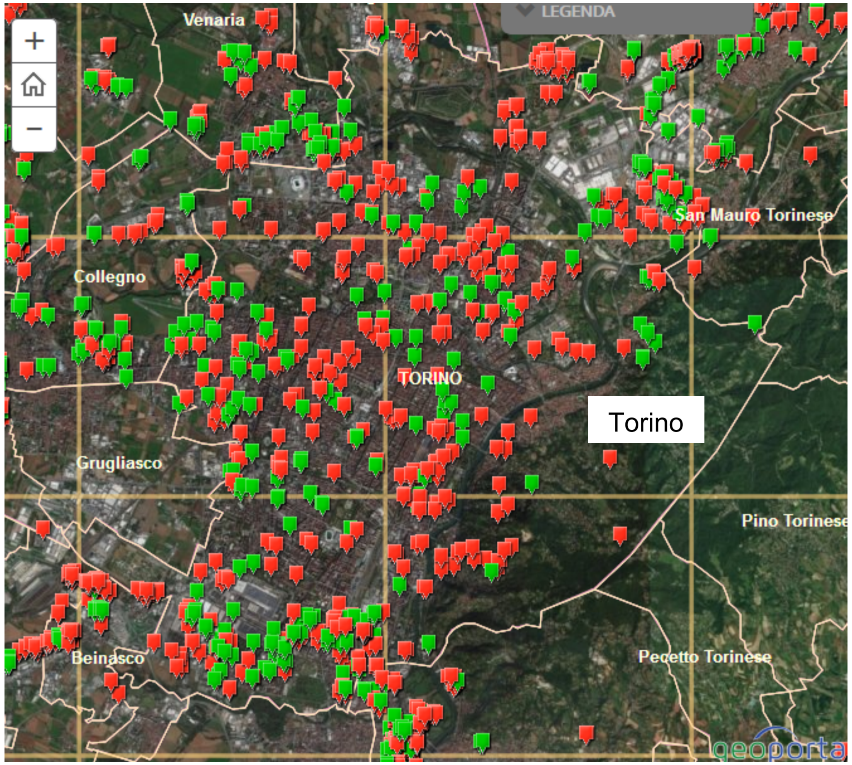
men	age	**tremolite-actinolite asbestos ff/gdw**	***chrysotile-asbestiform antigorite ff/***gdw	fibrous clay minerals ff/gdw	other fibrous phyllosilicates ff/gdw	fibrous feldspar ff/gdw	fibrous oxides ff/gdw	**synthetic fibres ff/**gdw
M1	59	/	/	/	/	/	0.18×10^5	/
M11	61	/	/	/	/	0.06×10^5	0.12×10^5	/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

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).