Elaboration of a combined method to characterize spatial representativeness of PM 10

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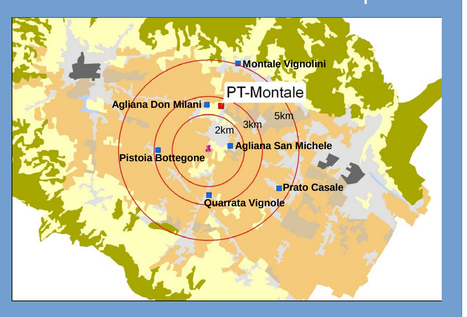
The aim of the study was to determine spatial representativeness of background stations of regional monitoring network in Toscana and to identify the municipalities concerned by air quality measures.
For this purpose three methods to estimate spatial representativeness of PM10 were applied.

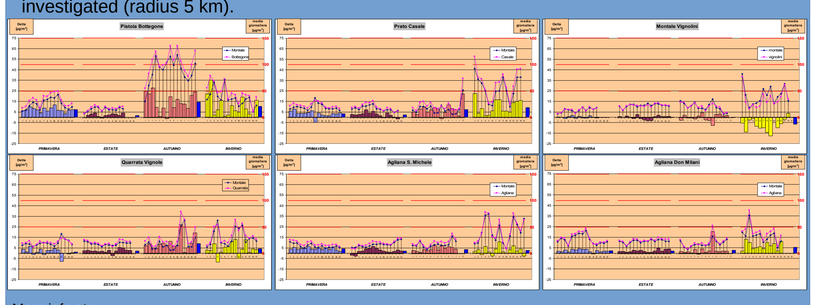
Materials and Methods

M1 - Measurements

Site of PT-Montale characterization:
24 monitoring campaign were made, each lasting 15 days, in 6 different monitoring sites (4 campaign for each site distributed homogeneously on the four seasons, as required by 2008/50 Directive) .
Sites were selected around a central point of the plain where the monitoring station is located and within a radius of 5 km from this point.

Resulting levels and trends (see graphics below) were comparable to the monitoring station data. Daily means on campaign sites were similar or greater than station ones, with the only exception of Montale Vignolini where lower values were found.
Considering data boundaries (urban areas of Pistoia and Prato have their own monitoring sites) and geographic boundaries (the plain is part of a natural basin) the spatial representativeness of the station can be extended to the whole surface investigated (radius 5 km).





More info at:
http://www.arpat.toscana.it/documentazione/catalogo-pubblicazioni-arpat/verifica-della-rappresentativita-spaziale-dei-dati-di-pm10-della-stazione-di-monitoraggio-della-qualita-dellaria-di-montale-pt?searchterm=montale

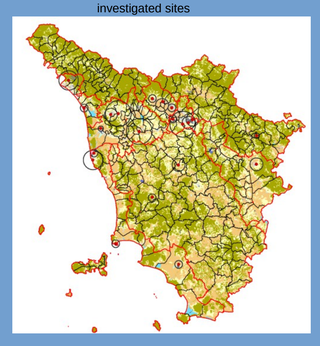
M2 - ß Indicator

A statistical assessment of spatial representativeness was applied, based on the analysis of land cover around the monitoring sites.
The statistical indicator (ß) was developed linking land cover pattern to concentration levels of pollutants [1]. The method was applied for the first time on the whole Italian territory by ENEA [2].

$$\beta = \log\left[1 + \frac{\sum_i a_i \cdot n_{RCLi}}{\sum_i n_{RCLi}}\right]$$

where
n_{RCLi} = number of pixel in the i-th RIO class (combination of Corine Land Cover classes)
ai = weighting coefficient calculated from: a) a first guess based on inventory emission
b) a statistical procedure which optimize the relationship between historical series of measurements and land cover around the site

PM10 – Overall spatial representativeness of the investigated sites

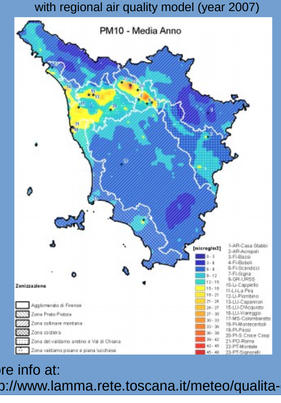


The variability of the ß-indicator was explored within circular buffers around the site, with increasing radius (2 – 3 - 5 – 7.5 – 10 km). As long as ß varies below the established threshold of 30% the monitoring site is considered representative of the area.
The methodology allows an useful and quick assessment of spatial representativeness of a monitoring site. The resulting spatial representativeness of a site is given by a circular area around it. The application of circular buffers appears to be one of the most relevant limits of the method.

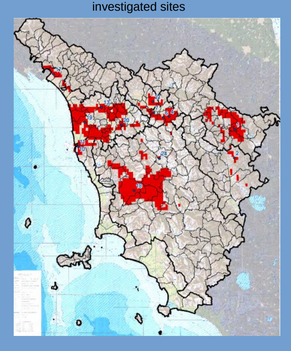
M3 - Regional Air quality Model

In this method [3] spatial representativeness of a monitoring site is assessed using the temporal evolution of simulated concentration fields. The rationale relies on the comparison between concentration time series registered at the site of interest and those registered in the surroundings. Concentration fields derived from the regional air quality model, covering entire territory of Toscana with 2 km spatial resolution and hourly temporal resolution, were analysed.
For a specific monitoring site, the difference between concentration values simulated at the site and those simulated in the surroundings was explored, and the frequency of occurrences of comparable values in relation to a specific threshold (30%) was calculated.
The spatial representativeness of a monitoring site is given by cells where the frequency of comparable values (on daily basis) resulted greater then 90%.

PM10 – Annual mean concentration fields simulated with regional air quality model (year 2007)



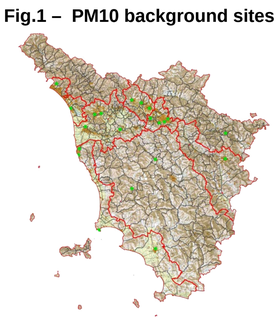
PM10 – Overall spatial representativeness of the investigated sites



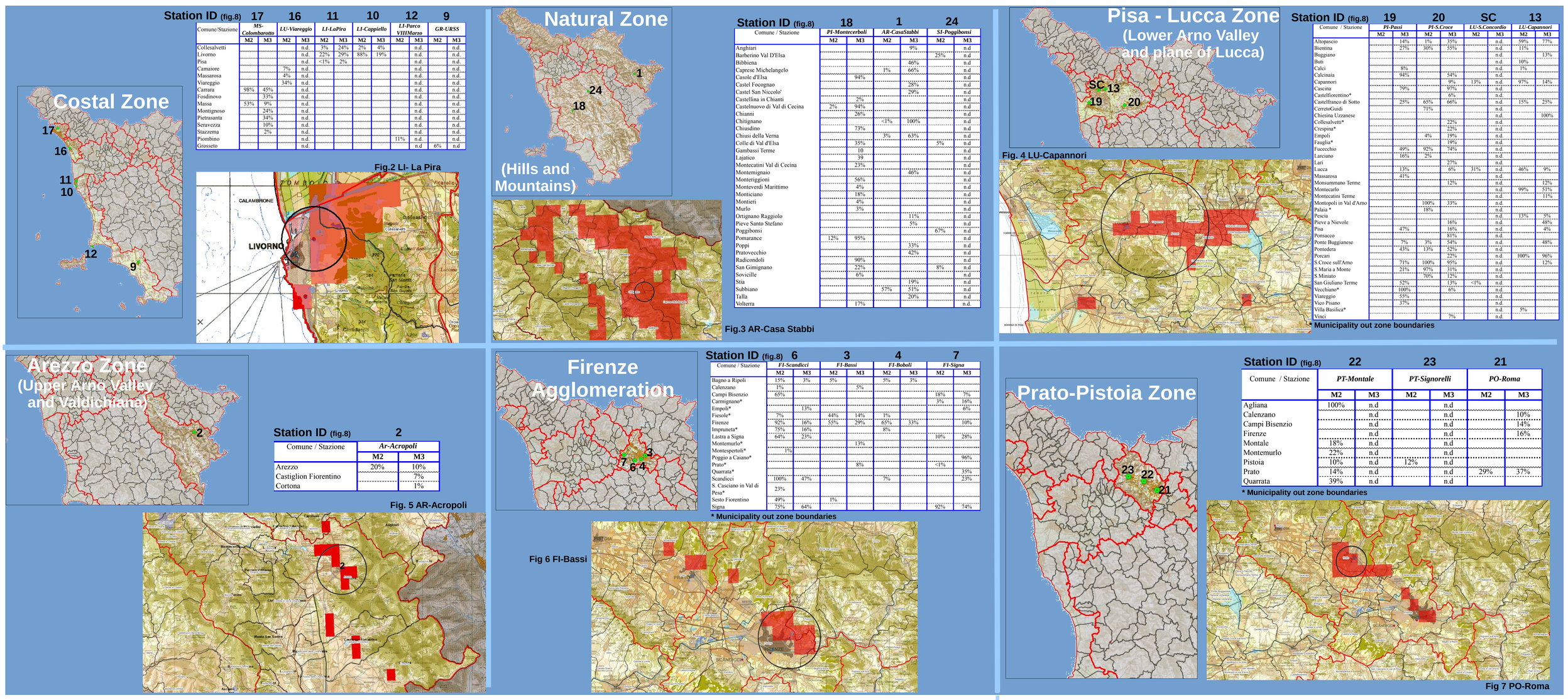
More info at:
http://www.lamma.rete.toscana.it/meteo/qualita-dellaria

These methods were applied to 21 background sites (fig. 1) with the following criteria:
1. The resulting spatial representativeness of each site of measure was referred to the whole area of municipalities involved;
2. Measurements (M1) were applied to a specific site (Montale) and were the main criteria to determine the municipalities represented by the station;
3. For the other monitoring stations: **a)** the representative area of each site of measure was determined both with M2 and with M3; **b)** the percentage of each single municipality covered by the representative area of a site was calculated for both M2 and M3 representative area; **c)** a site of measure was considered representative of a municipality if the resulting percentage from at least one method was over a defined threshold; two different thresholds were applied: a lower threshold of 5% and an upper threshold of 15%. Resulting municipalities were calculated for the two hypothesis;
4. For municipalities represented by more than one site of measure, a choice was made on the basis of: proximity, higher coverage, accordance between methods, spatial continuity and zone consistency (see tab.1). In few cases multiple attribution was maintained because of equivalence or complementarity of sites.

Fig.1 – PM10 background sites



Several examples from the six homogeneous air quality zones, in which Toscana has been divided, are shown below.



Station ID (fig.8) 17, 16, 11, 10, 12, 9

Comune/Stazione	MS-Colombarotto M2	MS-Colombarotto M3	LU-Viareggio M2	LU-Viareggio M3	LI-LaPira M2	LI-LaPira M3	LI-Coppiello M2	LI-Coppiello M3	LI-Parco VIIIMarzo M2	LI-Parco VIIIMarzo M3	GR-URSS M2	GR-URSS M3
Collesalvetti				n.d.	3%	24%	2%	4%		n.d.		n.d.
Livorno				n.d.	22%	29%	88%	19%		n.d.		n.d.
Pisa				n.d.	<1%	2%				n.d.		n.d.
Camaiore			7%	n.d.						n.d.		n.d.
Massarosa			4%	n.d.						n.d.		n.d.
Viareggio			34%	n.d.						n.d.		n.d.
Carrara	98%	45%		n.d.						n.d.		n.d.
Fosdinovo		33%		n.d.						n.d.		n.d.
Massa	53%	9%		n.d.						n.d.		n.d.
Montignoso		24%		n.d.						n.d.		n.d.
Pietrasanta		34%		n.d.						n.d.		n.d.
Seravezza		10%		n.d.						n.d.		n.d.
Stazzema		2%		n.d.						n.d.		n.d.
Piombino				n.d.					11%	n.d.		n.d.
Grosseto				n.d.						n.d.	6%	n.d.

Fig.2 LI- La Pira

Station ID (fig.8) 18, 1, 24

Comune / Stazione	PI-Montecerboli M2	PI-Montecerboli M3	AR-CasaStabbi M2	AR-CasaStabbi M3	SI-Poggibonsi M2	SI-Poggibonsi M3
Anghiari				9%		n.d
Barberino Val D'Elsa					25%	n.d
Bibbiena				46%		n.d
Caprese Michelangelo			1%	66%		n.d
Casole d'Elsa		94%				n.d
Castel Focognao				28%		n.d
Castel San Niccolo'				29%		n.d
Castellina in Chianti		2%				n.d
Castelnuovo di Val di Cecina	2%	94%				n.d
Chianni		26%				n.d
Chitignano			<1%	100%		n.d
Chiusdino		73%				n.d
Chiusi della Verna			3%	63%		n.d
Colle di Val d'Elsa		35%			5%	n.d
Gambassi Terme		10				n.d
Lajatico		39				n.d
Montecatini Val di Cecina		23%				n.d
Montemignaio				46%		n.d
Monteriggioni		56%				n.d
Monteverdi Marittimo		4%				n.d
Monticiano		18%				n.d
Montieri		4%				n.d
Murlo		3%				n.d
Ortignano Raggiolo				11%		n.d
Pieve Santo Stefano				5%		n.d
Poggibonsi					67%	n.d
Pomarance	12%	95%				n.d
Poppi				33%		n.d
Pratovecchio				42%		n.d
Radicondoli		90%				n.d
San Gimignano		22%			8%	n.d
Soviciille		6%				n.d
Stia				19%		n.d
Subbiano			57%	51%		n.d
Talla				20%		n.d
Volterra		17%				n.d

Fig.3 AR-Casa Stabbi

Fig. 4 LU-Capannori

Comune / Stazione	PI-Passi M2	PI-Passi M3	PI-S.Croce M2	PI-S.Croce M3	LU-S.Concordio M2	LU-S.Concordio M3	LU-Capannori M2	LU-Capannori M3
Altopascio	14%	1%	35%			n.d.	59%	77%
Bientina	27%	30%	35%			n.d	11%	
Buggiano						n.d.		13%
Buti						n.d.	10%	
Calci	8%					n.d.	1%	
Calcinaia	94%		54%			n.d.		
Capannori			9%	13%	13%	n.d.	97%	14%
Cascina	79%		97%			n.d.		
Castelfiorentino*			6%			n.d.		
Castelfranco di Sotto	25%	65%	66%			n.d.	15%	35%
CerretoGuidi		71%				n.d.		
Chiesina Uzzanese						n.d.		100%
Collesalvetti*			23%			n.d.		
Crespina*			22%			n.d.		
Empoli		4%	19%			n.d.		
Fauglia*			19%			n.d.		
Fucecchio	49%	92%	74%			n.d.		
Larciano	16%	2%				n.d.		
Lari			27%			n.d.		
Lucca	15%		6%	31%		n.d.	46%	92%
Massarosa	41%					n.d.		
Monsummano Terme			12%			n.d.		12%
Montecarlo						n.d.	99%	51%
Montecatini Terme						n.d.		11%
Montopoli in Val d'Arno		100%	33%			n.d.		
Palaia *		18%				n.d.		
Pescia						n.d.	13%	5%
Pieve a Nievole			16%			n.d.		48%
Pisa	47%		16%			n.d.		4%
Ponsacco			81%			n.d.		
Ponte Buggianese	7%	3%	54%			n.d.		48%
Pontedera	43%	13%	52%			n.d.		
Porcari			22%			n.d.	100%	96%
S.Croce sull'Arno	71%	100%	95%			n.d.		12%
S.Maria a Monte	71%	97%	31%			n.d.		
S.Miniato		70%	12%			n.d.		
San Giuliano Terme	22%		13%	<1%		n.d.		
Vecchiano*	100%		6%			n.d.		
Viareggio	55%					n.d.		
Vico Pisano	37%					n.d.		
Villa Basilica*						n.d.	5%	
Vinci			7%			n.d.		

Municipality out zone boundaries

Fig. 5 AR-Acropoli

Station ID (fig.8) 2

Comune / Stazione	Ar-Acropoli M2	Ar-Acropoli M3
Arezzo	20%	10%
Castiglion Fiorentino		7%
Cortona		1%

Station ID (fig.8) 6, 3, 4, 7

Comune / Stazione	FI-Scandicci M2	FI-Scandicci M3	FI-Bassi M2	FI-Bassi M3	FI-Boboli M2	FI-Boboli M3	FI-Signa M2	FI-Signa M3
Bagno a Ripoli	15%	3%	5%		5%	3%		
Calenzano	1%			5%				
Campi Bisenzio	65%						18%	7%
Carmignano*							3%	16%
Empoli*		13%						6%
Fiesole*	7%		44%	14%	1%			
Firenze	92%	16%	55%	29%	65%	33%		10%
Impruneta*	75%	16%			8%			
Lastra a Signa	64%	33%					10%	28%
Montemurlo*				13%				
Montespertoli*	1%							
Poggio a Caiano*								96%
Prato*				8%			<1%	
Quarrata*								35%
Scandicci	100%	47%			7%			23%
S. Casciano in Val di Pesa*	23%							
Sesto Fiorentino	49%		1%					
Signa	75%	64%					92%	74%

*** Municipality out zone boundaries**

Fig 6 FI-Bassi

Station ID (fig.8) 22, 23, 21

Comune / Stazione	PT-Montale M2	PT-Montale M3	PT-Signorelli M2	PT-Signorelli M3	PO-Roma M2	PO-Roma M3
Agliana	100%	n.d		n.d		
Calenzano		n.d		n.d		10%
Campi Bisenzio		n.d		n.d		14%
Firenze		n.d		n.d		16%
Montale	18%	n.d		n.d		
Montemurlo	22%	n.d		n.d		
Pistoia	10%	n.d	12%	n.d		
Prato	14%	n.d		n.d	29%	37%
Quarrata	39%	n.d		n.d		

*** Municipality out zone boundaries**

Fig 7 PO-Roma

Results

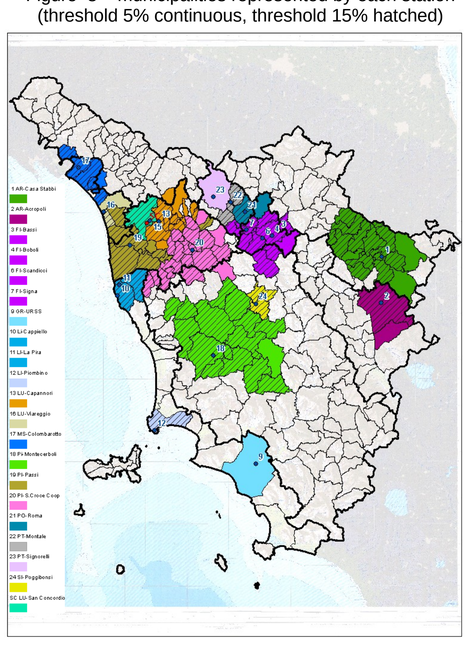
Table 1 – choice criteria in the case of multiple attribution

Municipality	Multiple attribution	Proximity	Accordance M2-M3	Higher Coverage	zone consistency	Spatial continuity	Final Attribution	Notes
Altopascio	13,19,20	x	x	x			13	
Bagno a Ripoli	3,4,6	x	x				4	
Bientina	13,19,20	x	x	x			20	
Calcinaia	19, 20			x			19	
Calenzano	3, 21		x	x	(x)		3 (21)	Station 21 could be validated, being the municipality part of Firenze agglomerate
Campi Bisenzio	6,7,21	x	x	x			7	
Capannori	13, 20	x	x	x			13	
Cascina	19, 20	x					19	
Castelfranco di Sotto	13,19,20	x	x	x			20	
Collesalvetti	11, 20	x	x	x			11	
Colle Val d'Elsa	18, 24	x		x			18	
Empoli	6,7,20	x	x	x			20	
Fiesole	3, 6		x	x			3	
Firenze	3,4,6,7,21				x		3/4/6/7	Municipality of Firenze is considered to be represented by every monitoring station of the agglomerate
Fucecchio	19, 20	x	x	x			20	
Impruneta	4, 6		x	x			6	
Larciano	19					x	20	In this case, spatial continuity based on models results for adjacent municipalities was considered more relevant of models results for the municipality itself
Lastra a Signa	6, 7		x	x			6	
Livorno	10, 11	x	x	x			10/11	Both sites are located in the municipality of Livorno and represent different air quality characters inside the urban area (residential and industrial)
Lucca	13,19,20,SC	x	x	x		SC	13,(SC)	
Montemurlo	19, 20	x					20	Confirmed by sampling campaing data
Monsummano Terme	13, 20						13/20	Both site could be taken in accont (see map)
Pieve a Nievole	13, 20	x		x			13	
Pisa	19, 20	x		x			19	
Pistoia	22, 23	x		x			23	
Prato	3, 21	x	x	x			21	
Ponte Buggianese	13, 20							Both site could be taken in accont (see map)
Pontedera	19, 20	x	x	x			20	
Porcari	13, 20	x	x	x			13	
Quarrata	7, 22						22	Sampling campaign data
San Gimignano	18, 24	x		x			18	
San Giuliano Terme	19, 20	x		x			19	
Santa Croce sull'Arno	13, 19, 20	x	x	x			20	
Santa Maria a Monte	19, 20	x	x	x			20	
Scandicci	4, 6, 7	x	x	x			6	
Signa	6, 7	x	x	x			7	
Vecchiano	19, 20	x		x	(x)		19, (16)	
Viareggio	16, 19	x					16	

Table 2 – municipalities represented by each station (multiple attribution highlighted)

ID STAZIONE	COMUNE	M2	M3	M2UM3 >15%	M2UM3 >5%
1	Anghiari		9%		U>5%
1	Bibbiena		46%	U>15%	U>5%
1	Caprese Michelangelo	1%	66%	U>15%	U>5%
1	Castel Focognao		28%	U>15%	U>5%
1	Castel San Niccolo'		29%	U>15%	U>5%
1	Chitignano		100%	U>15%	U>5%
1	Chiusi della Verna	3%	63%	U>15%	U>5%
1	Montemignaio		46%	U>15%	U>5%
1	Ortignano Raggiolo		11%		U>5%
1	Pieve Santo Stefano		5%		U>5%
1	Poppi		33%	U>15%	U>5%
1	Pratovecchio		42%	U>15%	U>5%
1	Stia		19%	U>15%	U>5%
1	Subbiano	57%	51%	U>15%	U>5%
1	Talla		20%	U>15%	U>5%
2	Arezzo	20%	10%	U>15%	U>5%
2	Castiglion Fiorentino		7%		U>5%
3	Fiesole	44%	14%	U>15%	U>5%
3	Firenze	55%	29%	U>15%	U>5%
3	Calenzano		5%		U>5%
4	Bagno a Ripoli	5%	3%		U>5%
4	Firenze	65%	33%	U>15%	U>5%
6	Firenze	92%	16%	U>15%	U>5%
6	Impruneta	75%	16%	U>15%	U>5%
6	Lastra a Signa	64%	23%	U>15%	U>5%
6	S. Casciano in Val di Pesa	23%		U>15%	U>5%
6	Scandicci	100%	47%	U>15%	U>5%
6	Sesto Fiorentino	49%		U>15%	U>5%
7	Campi Bisenzio	18%	7%	U>15%	U>5%
7	Carmignano	3%	16%	U>15%	U>5%
7	Firenze		10%		U>5%
7	Poggio a Caiano		96%	U>15%	U>5%
7	Signa	92%	74%	U>15%	U>5%
9	Grosseto	6%	n.d.		M2 5%
10	Livorno	88%	19%	U>15%	U>5%
11	Collesalvetti	3%	24%	U>15%	U>5%
11	Livorno	22%	29%	U>15%	U>5%
12	Piombino	18%	n.d.	M2 15%	M2 5%
13	Altopascio	59%	77%	U>15%	U>5%
13	Buggiano		13%		U>5%
13	Buti	10%			U>5%
13	Capannori	97%	14%	U>15%	U>5%
13	Chiesina Uzzanese		100%	U>15%	U>5%
13	Lucca	46%	9%	U>15%	U>5%
13	Monsummano Terme		12%		U>5%
13	Montecarlo	99%	51%	U>15%	U>5%
13	Montecatini Terme		11%		U>5%
13	Pescia	13%	5%		U>5%
13	Pieve a Nievole		48%	U>15%	U>5%
13	Ponte Buggianese		48%	U>15%	U>5%
13	Porcari	100%	96%	U>15%	U>5%
13	Villa Basilica		5%		U>5%
16	Camaiore	7%	n.d.		M2 5%
16	Viareggio	34%	n.d	M2 15%	M2 5%
17	Carrara	98%	45%	U>15%	U>5%
17	Fosdinovo		33%	U>15%	U>5%
17	Massa	53%	9%	U>15%	U>5%
17	Montignoso		24%	U>15%	U>5%
17	Pietrasanta		34%	U>15%	U>5%
17	Seravezza		10%		U>5%
18	Casole d'Elsa		94%	U>15%	U>5%
18	Castelnuovo di Val di Cecina	2%	94%	U>15%	U>5%
18	Chianni		26%	U>15%	U>5%
18	Chiusdino		73%	U>15%	U>5%
18	Colle di Val d'Elsa		35%	U>15%	U>5%
18	Gambassi Terme		100%	U>15%	U>5%
18	Lajatico		39%	U>15%	U>5%
18	Montecatini Val di Cecina		23%	U>15%	U>5%
18	Monteriggioni		56%	U>15%	U>5%
18	Monticiano		18%	U>15%	U>5%
18	Pomarance	12%	95%	U>15%	U>5%
18	Radicondoli		90%	U>15%	U>5%
18	San Gimignano		22%	U>15%	U>5%
18	Soviciille		6%		U>5%
18	Volterra		17%	U>15%	U>5%
19	Calci		8%		U>5%
19	Calcinaia		94%	U>15%	U>5%
19	Cascina		79%	U>15%	U>5%
19	Larciano		16%	U>15%	U>5%
19	Massarosa		41%	U>15%	U>5%
19	Pisa		47%	U>15%	U>5%
19	San Giuliano Terme		52%	U>15%	U>5%
19	Vecchiano		100%	U>15%	U>5%
19	Vico Pisano		37%	U>15%	U>5%
20	Bientina	30%	55%	U>15%	U>5%
20	Castelfiorentino		6%		U>5%
20	Castelfranco di Sotto	65%	66%	U>15%	U>5%
20	CerretoGuidi	71%		U>15%	U>5%
20	Crespina		22%	U>15%	U>5%
20	Empoli	4%	19%	U>15%	U>5%
20	Fauglia		19%	U>15%	U>5%
20	Fucecchio	92%	74%	U>15%	U>5%
20	Lari		27%	U>15%	U>5%
20	Monsummano Terme		12%		U>5%
20	Montopoli in Val d'Arno	100%	33%	U>15%	U>5%
20	Palaia	18%		U>15%	U>5%
20	Ponsacco		81%	U>15%	U>5%
20	Ponte Buggianese	3%	54%	U>15%	U>5%
20	Pontedera	13%	52%	U>15%	U>5%
20	S.Croce sull'Arno	100%	95%	U>15%	U>5%
20	S.Miniato	70%	12%	U>15%	U>5%
20	S.Maria a Monte	97%	31%	U>15%	U>5%
20	Vinci		7%		U>5%
21	Calenzano		10%		U>5%
21	Prato	29%	37%	U>15%	U>5%
22	Agliana	100%	n.d	M2 15%	M2 5%
22	Montale	18%	n.d	M2 15%	M2 5%
22	Montemurlo	22%	n.d	M2 15%	M2 5%
22	Quarrata	39%	n.d	M2 15%	M2 5%
23	Pistoia	12%	n.d		M2 5%
24	Barberino Val D'Elsa	25%	n.d	M2>15%	M2 5%
24	Poggibonsi	67%	n.d.	M2>15%	M2>5%
SC	Lucca	31%	n.d.	M2>15%	M2>5%

Figure 8 – municipalities represented by each station (threshold 5% continuous, threshold 15% hatched)



The combined application of different methods to characterize spatial representativeness of PM10 lead to some interesting results. Models (M2 and M3), being developed independently, in many cases fit to the same result. The most relevant example is given by the site of Casa Stabbi. This monitoring station is the reference for PM10 regional background. It is classified as Rural and its representativeness was expected to be wide. Method 2 (ß indicator) gave a very small area (2 km radius), while method 3 gave a wide land coverage (see Fig. 3). The reason why the ß indicator fails concerns the circularity of buffers: increasing radius buffer, the percentage of natural area (almost 100% in the nearest surroundings) slightly decrease as the circle includes an urban area. This suggests that the site can be assumed representative of the entire regional land use classified as natural (CORINE classes:311 to 521). The shape area resulting from method 3 confirms this assumption; in fact as it is clearly evident from fig.3 all urban areas are cut out of the resulting representativeness. The representativeness of the monitoring station of Casa Stabbi has been extended to the all natural areas. The attribution of spatial representativeness of investigated sites to the whole municipal surfaces is clearly an approximation; this choice was made to simplify air quality management, necessarily made at an administrative level.
The overlapping of regional background level to the resulting areas of fig.8 improves the description of the regional coverage obtained at municipal level. In fact natural areas, not concerned by urban or suburban background values, are subtracted to municipal area (see fig. 9) and more properly referred to the regional background. Moreover some areas of NO DATA (ex. Mountains or hills) find their proper description in regional background values, and areas not covered by regional network can be more precisely identified.

First application of results to assess population exposure to 2014 monitoring data

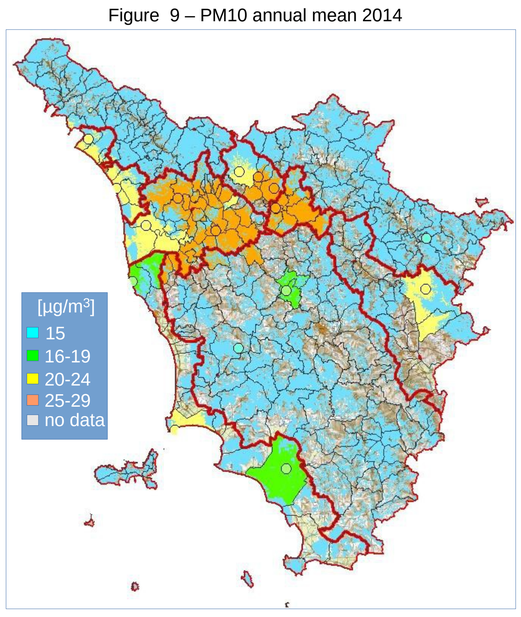
On the basis of 2014 annual means (fig.9) and population census (ISTAT 2001) exposure of population to PM10 levels was estimated.

Results are shown in table 4.

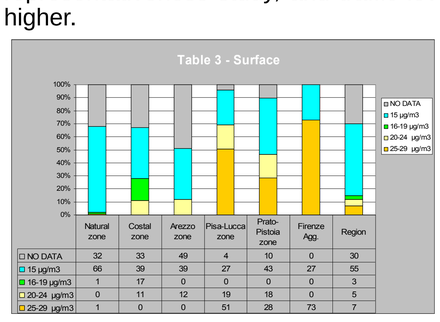
Through the application of models, M2 and M3, 70% of regional surface and 71% of regional population result represented by monitoring data.

It is remarkable that the legal limit of 40 µg/m³ was nowhere exceeded in 2014, as it is also significant that only 22% of population is resident in areas under the OMS reference value of 20 µg/m³ as annual mean.

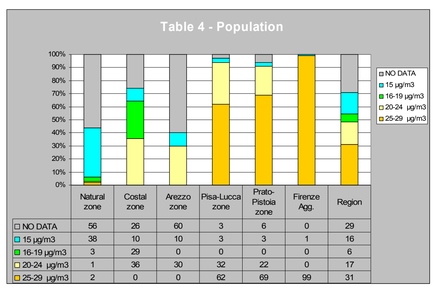
Figure 9 – PM10 annual mean 2014



It must also be reminded that only background stations are considered in this representativeness study, and traffic levels in urban areas may be considerably higher.



	Natural zone	Costal zone	Arezzo zone	Pisa-Lucca zone	Prato-Pistoia zone	Firenze Agg.	Region
NO DATA	32	33	49	4	10	0	30
15 µg/m3	66	39	39	27	43	27	55
16-19 µg/m3	1	17	0	0	0	0	3
20-24 µg/m3	0	11	12	19	18	0	5
25-29 µg/m3	1	0	0	51	28	73	7



	Natural zone	Costal zone	Arezzo zone	Pisa-Lucca zone	Prato-Pistoia zone	Firenze Agg.	Region
NO DATA	56	26	60	3	6	0	29
15 µg/m3	38	10	10	3	3	1	16
16-19 µg/m3	3	29	0	0	0	0	6
20-24 µg/m3	1	36	30	32	22	0	17
25-29 µg/m3	2	0	0	62	69	99	31

[1] Janssen, S., Dumont, G., Fierendis, F. and Mensink, C. (2008), Spatial interpolation of air pollution measurements using CORINE Land Cover data. Atmospheric Environment 42, 4884-4903.
[2] Piersanti A., Ciancarella L., Cremona G., Righini G., Vitali L. (2013), Rappresentatività spaziale di misure di qualità dell'aria. Valutazione di un metodo stima basato su fattori oggettivi. Rapporto Tecnico RT/2013/1/ENEA, ENEA. http://openarchive.enea.it//handle/10840/4475
[3] Vitali L., Ciancarella L., Cionni G., Cremona G., Piersanti A., Righini G. (2013): Rappresentatività spaziale di misure di qualità dell'aria. Valutazione di un metodo di stima basato sull'analisi dei campi di concentrazione simulati dal modello nazionale MINNI, Rapporto Tecnico RT/2013/3/ENEA, ENEA.

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