



**Oil/gas pre-treatment
plants and air quality
hazards**

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Oil/gas pre-treatment plants and air quality hazards: PM₁ measurements in Agri Valley (southern Italy)

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A PM₁ (i.e., aerosol particles with aerodynamic diameter less 1.0 µm) short term monitoring campaign was carried out in Agri Valley (southern Italy) in September 2012. This area is of international concern since it houses the largest European on-shore reservoir and the largest oil/gas pre-treatment plant (i.e., Centro Olio Val d'Agri – COVA) within an anthropized context. PM₁ measurements were performed in Viggiano, the nearest town to the COVA plant and one of the most populated town of the Agri Valley. During the study period, the PM₁ daily concentrations ranged from 1.2 to 8.4 µg m⁻³ with a mean value of 4.6 µg m⁻³. Regarding the PM₁ chemical composition, it can be observed that S and typical crustal elements were the most abundant constituents of the PM₁ collected. By applying the Principal Component Analysis, it was pointed out that crustal soil, biomass and wood burning, secondary atmospheric reactions involving COVA plant emissions and local soil particles, and traffic were the main sources contributing to the PM₁ measured in the area under study. Moreover, a possible contribution of the long-range transport of African dust was observed.

1 Introduction

In the last few years, sub-micrometric particles (referred to as PM₁, aerosol particles with aerodynamic diameter less than 1.0 µm) have become a major concern mainly due to their effects on human health (Galindo et al., 2013). In fact, unlike coarser particles (i.e., PM₁₀ and PM_{2.5}, aerosol particles with aerodynamic diameter less than 10 µm and 2.5 µm, respectively), PM₁ can penetrate more deeply into the human respiratory and circulation systems carrying harmful chemical species inside the human body (Mohiuddin et al., 2014). Among these species, trace elements play a key role since they have been related to both short- and long-term adverse human health effects such as chronic respiratory diseases, heart diseases, lung cancer, and damage to other organs (Dubey et al., 2012). About 70–80 % of the toxic trace elements, like cadmium (Cd), chromium

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(Cr) and lead (Pb), have been found in PM₁ (Cheng et al., 2011). Despite this, there is still a relatively limited amount of data for the sub-micrometer atmospheric particle fraction available at present (Mirante et al., 2013). As a consequence, the knowledge of the physicochemical features of the PM₁ and the identification of its origin have become a major concern especially in areas where population is potentially exposed to several PM₁ emission sources.

The present study enters this context and its purpose is to investigate the PM₁ concentration and chemical composition and identify the main sources contributing to its presence in the local atmosphere of a town located at about 2.4 km away from the biggest existing oil/gas pre-treatment plant within an anthropized context (Agri Valley – southern Italy). This plant produces the emission of particles mainly in the fine and sub-micrometric size ranges that should represent a real problem, also posing health risks to the population living close to it (Trippetta et al., 2013). The main goal of this study is that for the first time PM₁ measurements have been performed in a urban site located in the proximity of such a plant. In fact, although this plant has began to work in 2001, only few studies exist on the air quality in this area (i.e., Trippetta et al., 2013; Pavese et al., 2012). Moreover, the results obtained, besides contributing to improve the knowledge of the PM₁ composition, could be also useful to address other type of studies (e.g., epidemiological studies) and support the government and regulatory bodies in their decision-making processes like the development of effective emission reduction strategies or the authorization of this type of plants in anthropized areas. In fact, several oil/gas pretreatment plants will be built in similar areas (e.g., Centro Olio Tempa Rossa – Corleto Perticara – southern Italy) in the next future.

2 Materials and methodologies

2.1 Study area

The Agri Valley is characterized by a large environmental complexity with naturalistic aspects coexisting along with anthropogenic activities that have potentially high environmental impacts. In fact, on the one hand the Agri Valley is a farming and breeding area, rich of woods and characterized by a considerable biodiversity that is partly included in the protected area of the Appennino Lucano, Val d'Agri, Lagonegrese National Park. On the other hand, this area houses the largest European on-shore reservoir that, since its discovery in the first half of the past century, has produced a significant and steady increase in the anthropogenic activities linked with the extraction of the hydrocarbons (crude oil and gas). At present, there are 25 active productive wells (UNMIG, 2013) located in the upper part of the Agri Valley which are directly connected to a oil/gas pre-treatment plant identified as Centro Olio Val d'Agri (COVA). In this plant, oil stabilization and gas conditioning are performed before piping the crude oil to the refinery located in Taranto (Puglia Region – southern Italy) through a 136 km long oil-pipeline and introducing the gas into the Italian gas distribution network (Snam Rete Gas S.p.A.). The COVA plant is the largest existing oil/gas pre-treatment plant located in an anthropized area (the nominal treatment capacity of the entire plant is of $16\,500\text{ m}^3\text{ g}^{-1}$ of crude oil and $3\,100\,000\text{ Sm}^3\text{ g}^{-1}$ of associated gas) and the anthropogenic activity with the highest release of atmospheric pollutant emissions in the Agri Valley (Trippetta et al., 2013). In fact, the pre-treatment processes occurring in the COVA plant imply continuous gaseous and particulate atmospheric emissions from several thermo destroyers and a system of torches where control flames continuously burn. Therefore, it could give rise to a wide range of environmental and especially human health impacts due to its presence in an area where several small towns (from 1700 to 5400 inhabitants) are settled.

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2.2 PM₁ measurements

PM₁ measurements were performed in the suburb of Viggiano (40°20'8.59" N, 15°54'7.43" E, about 840 m a.s.l.) from 1 to 30 September 2012. This site was chosen since Viggiano is the nearest town to the COVA plant, at about 2.4 km away from it (Fig. 1), and one of the most populated town of the Agri Valley (about 3100 inhabitants). The PM₁ samples were collected using a low volume (16.7 L min⁻¹ flow rate) gravimetric sampler (TCR Tecora) equipped with a PM₁ cut-off inlet and polycarbonate filters (Ø = 47 mm). The sampling time was 24 h (starting from 12:00 p.m.), and each filter was humidity-conditioned in a filter-conditioning cabinet (approximately $T = 20 \pm 2^\circ\text{C}$ and $\text{RH} = 50 \pm 5\%$) before and after sampling for 48 h. The PM₁ mass was determined with a gravimetric method using an analytical microbalance with a sensitivity of $\pm 1\text{ }\mu\text{g}$.

To determine the PM₁ chemical composition, the filters were acidic digested following the chemical protocol described in Caggiano et al. (2001). The total concentrations of Al, Be, Ca, Cr, Fe, K, Li, Mg, Mn, Na, P, Ti, S and Zn were measured by Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES). Cd, Cu and Pb were measured by means of Graphite Furnace Atomic Absorption Spectrometry (GFAAS). The blank (reagent+beaker+blank filter) contribution was evaluated and the resulting values were subtracted from the ICP-OES and GFAAS measurements of real samples. For all elements blanks were found to be < 10 % of the measured values. The method detection limit (MDL) was used to determine the lowest concentration level that could be detected, statistically different from a blank. Ten blanks were prepared and analyzed and MDLs were determined by adding 3 standard deviations of the blank readings to the average blank values (Yatkin and Bayram, 2007). Moreover, the validity of the whole analytical procedure was checked using the National Institute of Standards and Technology (NIST) standard reference material Urban Particulate Matter, SRM 1648. The results show that the MDL and recovery percentage ranged from 0.00013 to 0.79 ppm and between 63 and 135 %, respectively.

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2.3 Meteorology

Measurements of meteorological parameters (atmospheric pressure, temperature, global radiation, relative humidity, rainfall, and local wind speed and direction) were provided by the “Protezione Civile Gruppo Lucano” which has a meteorological station operating in the same place where PM₁ measurements were collected. By analysing the daily mean values of the main meteorological parameters, it can be observed that the pressure ranged between 1005 hPa and 1022 hPa with a mean value of 1016 hPa. The daily mean temperature ranged between 13 °C and 26 °C with a mean value of 19 °C. The relative humidity ranged from 26 % to 86 % with the 90th percentile higher than 76 %, while precipitations were registered during 9 days with values ranging from 0.3 mm to 17.3 mm. Finally, as for the wind, its speed ranged from 0.7 m s⁻¹ to 3.8 m s⁻¹ with a mean value of 1.7 m s⁻¹ and all the values, except for one of them, were included in the second and third classes of the Beaufort scale. Regarding the local wind direction, its frequency count is reported in Fig. 2.

3 Results and discussion

3.1 Explorative statistical analysis

Table 1 reports a summary of the explorative statistical analysis carried out on PM₁ and trace element daily concentrations measured at Viggiano site in September 2012. As Table 1 shows, the PM₁ daily concentrations range from 1.2 to 8.4 µg m⁻³ with a mean value of 4.6 µg m⁻³ and are characterized by a nearly normal distribution (Fig. 3). By comparing the mean value of the PM₁ daily concentrations registered in Viggiano with those reported in other studies, it can be observed that it is generally lower than those found in other sites (Cusack et al., 2013; Onat et al., 2013; Perrone et al., 2013; Theodosi et al., 2011; Caggiano et al., 2010; Pérez et al., 2008a; Pérez et al., 2008b; Marengo et al., 2006; Gomišček et al., 2004) and, in particular, it is lower than the PM₁

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concentration mean value ($11.0 \pm 5.1 \mu\text{g m}^{-3}$) measured close to the COVA plant from July to November 2011 (Trippetta et al., 2013). Regarding the latter, this could be due to the combination of two factors: the geographical position of Viggiano with respect to the COVA plant and the wind features of the area. In fact, Viggiano is about 2400 m far from the COVA plant and the difference in height between the two locations is about 200 m. Moreover, the area under study is generally characterized by wind speed values that could favour the dispersion of atmospheric pollutants consequently reducing their concentrations in the local ambient air.

By considering the PM₁ chemical composition, Table 1 provides a summary of the explorative statistical analysis performed on trace element concentration data. As Table 1 shows, S, followed by typical crustal elements, are the most abundant constituents of the PM₁ collected in the study area. Regarding the frequency distribution, the results of the Shapiro–Wilk normality test ($p < 0.05$) point out that Be, Cr, Li and P are the only elements that approach a normal distribution. In fact, they are the only elements characterized by skewness values close to zero (values not shown). All the other elements are positively skewed towards the lower concentrations, as confirmed by the median concentrations lower than the corresponding mean concentrations.

3.2 Source identification

3.2.1 Enrichment Factor technique

The crustal Enrichment Factor (EF) technique was applied to the PM₁ chemical data to obtain preliminary information about elements originating both from natural processes and human activities (Mbengue et al., 2014; Hassan et al., 2013; Yongming et al., 2006). The enrichment factor for a generic X element with respect to a reference crustal Y element is defined as $EF_X = (X/Y)_{air}/(X/Y)_{crust}$, where EF_X is the enrichment factor of the X element, $(X/Y)_{air}$ is the concentration ratio of X to Y in the aerosol sample, and $(X/Y)_{crust}$ is the average concentration ratio of X to Y in the crust (Fang et al., 2006; Quiterio et al., 2004; Chao and Wong, 2002). In this study, the Earth crust chem-

ical composition was provided by Taylor and McLennan (1985) and Al was used as reference element assuming that its anthropogenic sources are negligible (Chithra and Shiva Nagendra, 2013). According to Song et al. (2012), the elements were classified into three types by the EFs as follows: crustal elements ($EFs < 10$), mixed elements ($10 \leq EFs \leq 100$) and elements of anthropogenic origin ($EFs > 100$).

Figure 4 shows the EF mean values of the different trace elements. As Fig. 4 shows, EF values lower than 10 were found for Ti, Mn, Fe, and K. This suggests that their main sources are of a crustal type (e.g., soil and re-suspended dust) and that anthropogenic activities give a negligible contribution to their atmospheric levels. Na, Mg, Ca and P EF mean values of 10, 12, 32 and 39, respectively, suggest that these elements are partly derived from anthropogenic sources and human activities. Finally, Cd, S, Li, Zn, Be, Pb, Cr and Cu are characterised by EF mean values higher than 100 indicating that these elements are of an almost total anthropic origin.

3.2.2 Weekday–weekend variation of the PM_{10} and trace element concentrations

The comparison between weekday (i.e., from Monday to Friday) and weekend concentrations is a methodology widely used to point out the contribution of local anthropogenic activities that could be characterized by a weekly pattern. Figure 5 reports the mean values of PM_{10} and trace element concentrations registered during weekdays and weekends. By calculating the average percentage variation in the PM_{10} and trace element concentrations between weekdays and weekends, it can be observed that except for Zn and Pb, the trace elements that on average show higher concentrations on weekends than weekdays are either of prevailing natural origin or are significantly affected by the contribution of natural sources (i.e., Ca and Mg). A possible explanation of the observed increases should be provided by considering the local meteorological features during the two considered periods. In fact, on weekends, the temperature shows slightly higher mean values while the relative humidity is on average lower. Moreover, only two rainy days out of 9 registered during the entire study period occur on weekends. Finally, no significant variation is observed in wind speed. All this implies that

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weekends are characterized by slightly dryer and warmer conditions that could facilitate the soil drying and the consequent re-suspension of soil and/or road dusts. The latter could be supported also by the higher concentration values of Zn and Pb that, when they are associated to crustal elements, are typical tracers of road dust contributions. As to S, the variation observed should be related to a change in the emissions of the COVA plant which is expected to be the main source of sulfur compounds in the study area with about 0.033 kt of SO₂ per year (average value referred to 2009–2011 period) emitted only by its thermosteers. These contribute approximately 95 % to the total emissions of SO₂ of the COVA plant during normal operating conditions (ENI, 2012).

3.2.3 Principal Component Analysis

In order to identify the main PM₁ sources, Principal Component Analysis (PCA) was used. PCA is a multivariate statistical technique widely applied to study the correlation structure among the different atmospheric pollutants and identify the source types that can give rise to their presence in atmosphere (Okubo et al., 2013; Yatkin and Bayram, 2007; Vallius et al., 2005; Quiterio et al., 2004; Diaz et al., 2002). In this study, each variable was normalized to unit variance and all the principal factors with eigenvalues > 0.8 were retained. For clarifying the meaning of the principal components (PCs), the retained factors were subsequently subjected to the VARIMAX normalized rotation. Chemical species were considered to identify source categories only when factor loadings were ≥ 0.5 (absolute value) (Caggiano et al., 2010; Callén et al., 2009). SPSS® for Windows version 12.0 was used for the multivariate statistical analysis.

By applying the PCA to the concentrations of the trace elements measured in PM₁, six significant components (PCs), explaining 81 % of data variance, were pointed out (Table 2).

PC₁ explains 22 % of data variance and is characterized by high loadings (loading absolute value ≥ 0.8) of Mn (0.96), Fe (0.92), and by moderate loadings (0.8 < loading absolute value ≤ 0.5) of Al (0.75), Na (0.69) and K (0.57). All these elements are abun-

dant in Earth's crust rocks and soils (Yu et al., 2013; Sudheer and Rengarajan, 2012) and their presence in the local atmosphere could be related to the re-suspension from fields or bare soils by local winds and to long-range transport of dust from the Saharan region whose occurrence is very frequent in Mediterranean countries during spring and summer months (e.g., Pey et al., 2013; Caggiano et al., 2011; Mona et al., 2006). The presence of K may also suggest the influence of the biomass and wood burning in this component. In fact, K is the most common inorganic species used to trace this kind of source (Cusack et al., 2013; Kim et al., 2010). Therefore, PC₁ identifies the PM₁ crustal fraction with a minor contribution of biomass and wood burning. This is consistent with the rural features of the area where farming is a bedrock of the local economy. Moreover, domestic fires, mainly related to cooking and heating, often occur and open burning of grass and forest is a common practice used for clearing field waste in farming and ranching.

PC₂, which explains 15% of data variance, is characterized by high loadings of Ca (0.81) and S (0.80), and by moderate loadings of Ti (0.77) and Mg (0.65). Sulfate particles recorded in this area are mainly formed by secondary atmospheric reactions of sulfur gaseous compounds emitted from the COVA plant and particles coming from the local soil (Lettino and Fiore, 2013). Calcium sulphates (mainly formed as gypsum) and magnesium sulphates, as well as mineral particles including Ti in their composition, may be also related to the long-range transport of African dust (Dall'Osto et al., 2010). Therefore, PC₂ identifies secondary atmospheric reactions involving COVA plant emissions and local soil particles with a possible minor contribution of natural emissions from long-range transport of African dust.

PC₃ explains 13% of data variance and is significantly characterized by Zn (0.85) with moderate contributions of Be (0.59) and Na (0.57). Zn is considered a good marker for tyre wear emissions (Salvador et al., 2007) as well as tailpipe emissions due to its use in motor oil (López et al., 2011). Moreover, Zn and Na have been found in particulate matter released during wood combustion, especially barks combustion (Jöller et al., 2007). Regarding Be, the EF analysis results indicates that its origin is almost

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total anthropic, so its presence in this component should be related to contributions of anthropogenic sources identified as fossil fuel combustion and vehicle emissions (Duan et al., 2012). Based on this, PC₃ can be classified as mixed including contributions coming from traffic and combustion processes (wood and fossil fuels).

PC₄ explains 12 % of the data variance and is significantly related to Cd (0.82), and to a lesser extent to Pb (0.64) and Mg (0.56). Cd is generally related to exhaust emissions from gasoline, lubricating oils and abrasion of tyres and brake linings. Regarding Pb, although the European Union member countries, including Italy, have phased out leaded gasoline since 1994 banning it in 2002, Pb is already widely used in a number of car components, including lead wheel weights, solder in electronics and lead-acid batteries. The wear of such components may generate particles containing Pb (Song et al., 2012). Finally, Mg, when associated with traffic tracers, is one of the potential markers of resuspended road dust. Based on this, PC₄ can be related to resuspension of road dusts from paved or non-paved roads (Lim et al., 2010).

PC₅, explaining 11 % of the data variance, is significantly characterized by Li (0.85), with moderate contribution of Cr (0.55). Li and Cr are found in vehicle exhaust and coal fly ash (Chandra Mouli et al., 2006). Therefore, PC₅ can be classified as mixed including contributions coming from traffic and coal combustion processes. PC₅ also includes P (−0.66) but the negative sign of the loading might indicate an independent behavior of P with respect to the other two elements included in this component. This could probably be due to different sources of this element such as resuspension of soil particles containing both naturally occurring and fertilizer derived P, primary biogenic aerosols and combustion sources (fossil fuel, biomass burning, biofuels) (Lettino and Fiore, 2013; Mahowald et al., 2008).

Finally, PC₆ explains 8 % of data variance and is exclusively related to Cu (0.87). Cu is a good tracer of traffic emissions and is generally associated to brake wear abrasion (López et al., 2011). Wood combustion, waste incineration and oil combustion also contribute to its presence in atmosphere (Al-Masri et al., 2006). Moreover, Cu is also associated to industrial emissions (Mbengue et al., 2014). Due to the variety of

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sources that could contribute to the presence of Cu in atmosphere and the potential presence of all of these sources close to the sampling site, this component is classified as “unidentified”.

3.2.4 Trace element concentrations and local wind direction

The consistence of the sources identified by the PCA with the features of the area under study was evaluated by analysing the variability of the trace element mean concentrations as a function of the local wind direction (Fig. 6). It should be noted that, since the winds came mainly from the sectors from SSE to NW, the directional contributions of most of the source factors were dominated by these wind sectors.

As Fig. 6 shows, four groups can be defined as a function of the concentration variability degree with respect to the wind directions:

1. no variability;
2. low variability;
3. moderate variability;
4. high variability.

The first group includes Be, Cr and Li. These are the only three elements that do not show any variability as a function of the wind direction indicating sources uniformly distributed over the entire study area, a feature that belongs to the identified sources of these elements in the study area (i.e., vehicle emissions and fossil fuel combustion).

The second group includes Ca, Cd, Mg, Na, P and Pb. All of them do not show a marked increase along a specific direction. The observed low variability is consistent with the multiple sources of these elements identified in the area under study that is wood combustion processes and/or soil and road dust resuspension. All of them have in common a certain feature: they are characterised by a good spatial distribution.

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The third group includes all the elements of prevailing natural origin (i.e., Al, Fe, K, Mn and Ti). All these elements are characterized by a quite similar variability and show inputs coming from preferential directions. In particular, the major sources of Al, Fe, Mn and Ti are in the south-west and west directions where cultivated and uncultivated soils are located with contributions from NNE as well. The latter are probably related to resuspension of dust from a soccer field made of bare artificial soil not covered by grass. K is the only element of prevailing natural origin that moves slightly away from this behavior. In fact, it shows fairly homogeneous contributions from all the directions except for a concentration peak observed along the NW direction. The uniformity of the contributions could be explained by considering that, in addition to crustal soil, domestic fires and open burning of grass and forest contribute to the presence of this element in the local atmosphere. These sources are widespread over the entire area and this could justify its behaviour. Instead, the peak observed along the NW direction can be due to a forest fire occurred just along this direction during the study period.

The last group includes Cu, S and Zn. Cu shows a marked peak along the WSW direction and very low contributions from all the other directions indicating the presence of a specific source for this element that has not been identified yet. Regarding S, it is interesting to note that the highest S concentrations are registered when wind comes from the SSW direction. The COVA plant is located just along this direction and, considering that sulfur is known to be a typical tracer of refinery operations and residual oil combustion in all PM size ranges (Saffari et al., 2013), this confirms the occurrence of secondary atmospheric reactions of sulfur gaseous compounds emitted by the COVA plant and mineral aerosols. Finally, the major sources of Zn are in the NW direction. Along this direction, the urban center of Viggiano is located. Viggiano is the closest place to the sampling site where the major contributions from traffic and residential wood burning are expected and this could explain the observed variability.

4 Conclusions

For the first time PM₁ measurements have been performed in an urban centre located close to an oil/gas pre-treatment plant. In particular, PM₁ and trace element concentrations were measured in Viggiano (Agri Valley – southern Italy) in September 2012.

During the study period, the PM₁ daily mean concentration is 4.6 µg m⁻³ resulting lower than those found in other sites. By considering the PM₁ chemical composition, S, followed by typical crustal elements (i.e., Ca, Fe, Mg, Na, Al, and K), were the most abundant constituents among the inorganic species measured. The investigation of the main PM₁ emission sources performed by the integrated use of complementary tools such as the enrichment factor technique, principal component analysis, and the analysis of the concentration variability as a function of the different days of the week and of the wind data highlights that emissions of crustal type, biomass and wood burning related emissions, secondary atmospheric reactions involving COVA plant emissions and local soil particles, and both direct and indirect traffic related emissions can contribute to the PM₁ measured in the area under study. Moreover, a possible contribution of the long-range transport of African dust is observed. The results obtained give a realistic picture of the emission features of the area where anthropogenic activities both typical of little urban settlements and related to industrial plants where oil/gas processing occurs are inserted in a rural context.

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Table 1. Explorative statistical parameters of PM₁ and trace element daily concentrations registered at Viggiano site in September 2012. The number of observations is 30. Legend: *m* = mean value, *sd* = standard deviation, *md* = median value, *min* = minimum value, *max* = maximum value. The PM₁ and trace element daily concentrations are expressed in μgm^{-3} and ngm^{-3} , respectively.

	<i>m</i>	<i>sd</i>	<i>md</i>	<i>min</i>	<i>max</i>
PM ₁	4.6	1.7	4.4	1.2	8.4
Al	156.1	177.2	79.0	26.7	730.9
Be	1.2	0.1	1.2	1.1	1.4
Ca	1500.5	1097.8	1145.0	331.4	5408.7
Cd	0.6	0.2	0.5	0.3	1.2
Cr	38.1	3.6	38.3	26.5	46.0
Cu	16.9	38.6	8.6	0.4	204.7
Fe	277.8	294.2	182.6	108.1	1531.3
K	105.8	87.5	73.2	33.1	347.7
Li	33.0	7.3	34.4	11.0	46.1
Mg	264.2	101.4	235.1	107.1	598.0
Mn	4.0	3.0	3.0	1.4	16.2
Na	239.8	99.1	219.5	115.1	590.3
P	38.3	19.7	35.7	6.1	79.8
Pb	5.3	3.2	4.7	1.2	15.0
S	3523.2	6161.8	1545.6	642.8	25 888.3
Ti	15.1	16.7	8.5	3.6	67.4
Zn	97.7	150.8	25.0	4.3	638.6

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Table 2. PCA results after the normalized VARIMAX rotation for chemical element concentrations in PM_{10} . Loadings and percentage of explained variance (P%) are reported. Loadings < 0.5 are not reported.

PC ₁ P% = 22		PC ₂ P% = 15		PC ₃ P% = 13		PC ₄ P% = 12		PC ₅ P% = 11		PC ₆ P% = 8	
Al	0.75	Ca	0.81	Zn	0.85	Cd	0.82	Li	0.85	Cu	0.87
Mn	0.96	S	0.80	Be	0.59	Pb	0.64	P	−0.66		
Fe	0.92	Ti	0.77	Na	0.57	Mg	0.56	Cr	0.55		
Na	0.69	Mg	0.65								
K	0.57										

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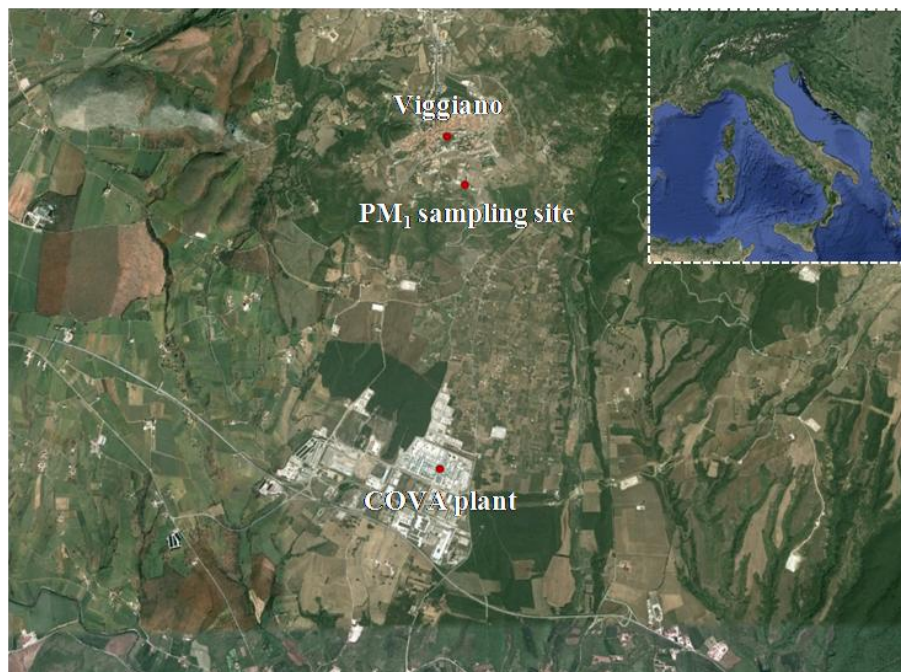



Fig. 1. Location of the PM₁ sampling site. The image also reports the location of the Centro Olio Val d'Agri (COVA) plant and the urban area of Viggiano. Aerial photography to courtesy of Google Earth (<http://earth.google.com/>).

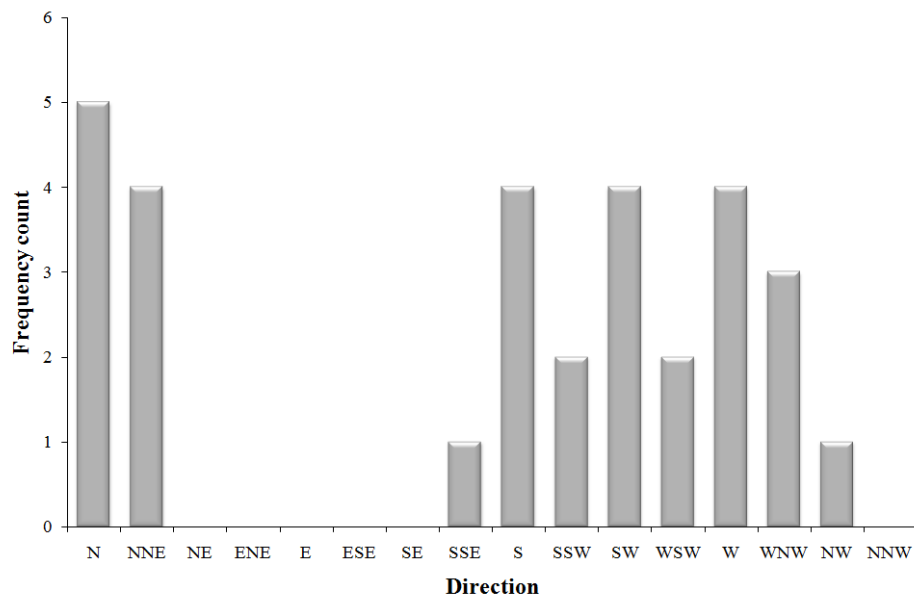
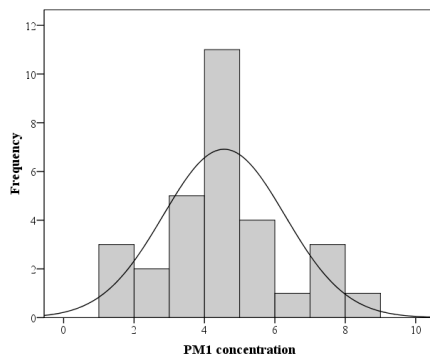
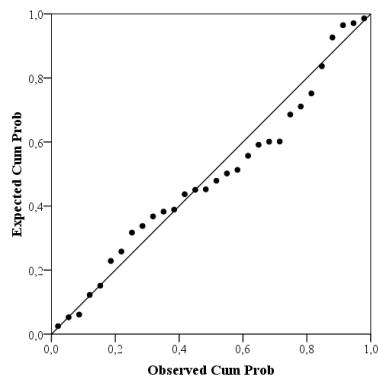


Fig. 2. Frequency count of the local wind direction.



(a)



(b)

Fig. 3. (a) Frequency and **(b)** normal P-P plot of the PM₁ daily concentration data recorded in Viggiano in September 2012. The black line represent the normal fit.

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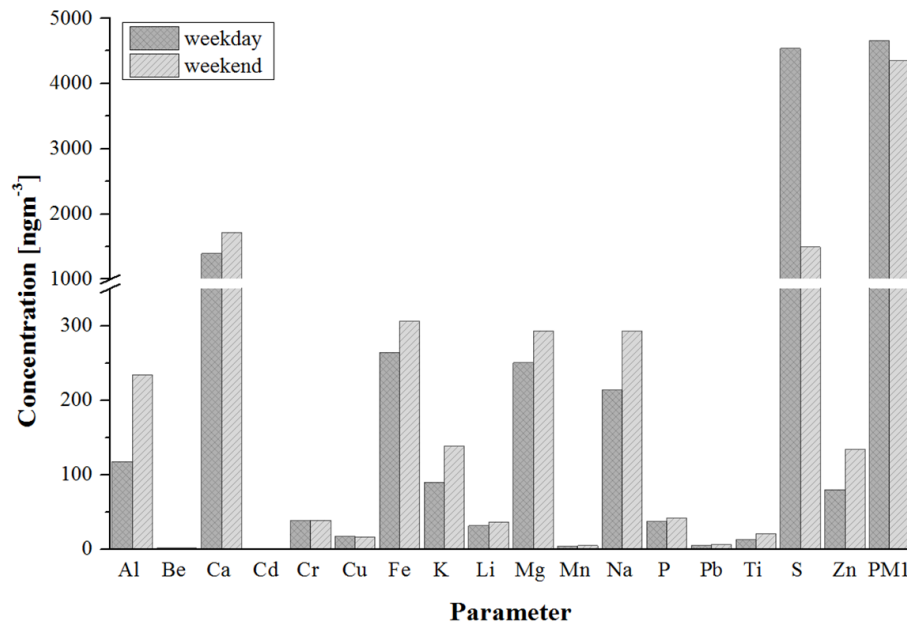


Fig. 5. Mean values of the PM₁ and trace element concentrations registered during weekdays (i.e., from Monday to Friday) and weekends.

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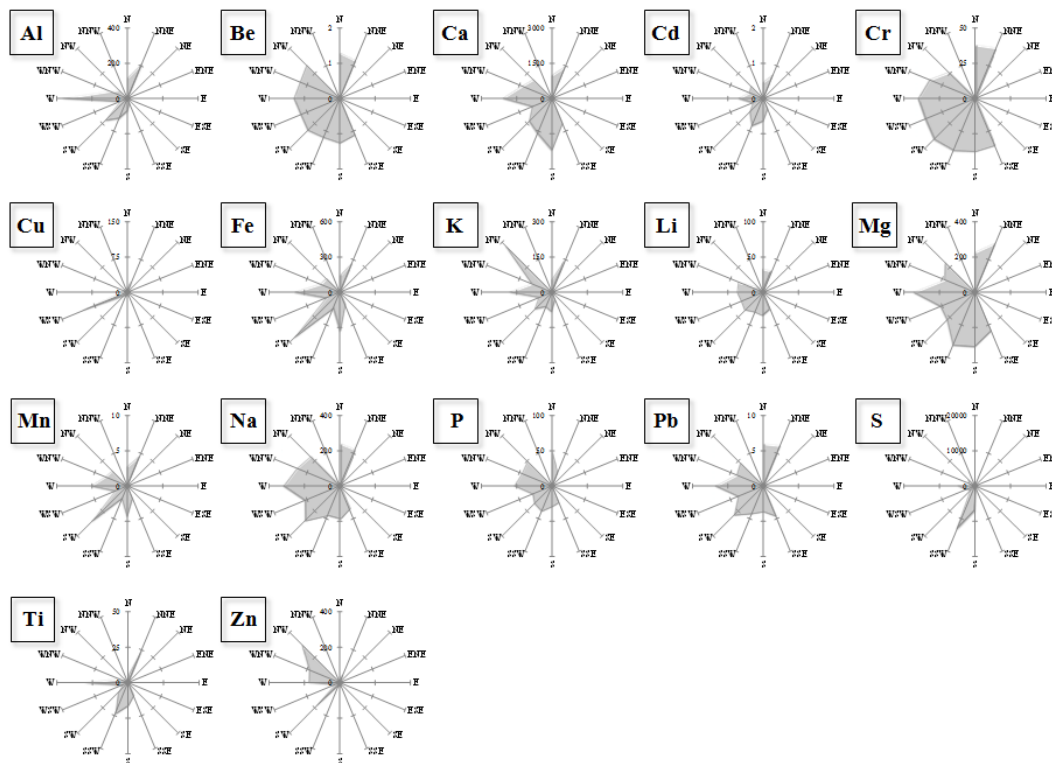


Fig. 6. Mean values of the trace element concentrations (ngm^{-3}) as a function of the local wind direction.

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