

Evaluation of the air pollution in a Mediterranean region by the air quality index

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Abstract The increasing expansion of the cities together with activities carried out on the environment by men have contributed to the deterioration of air quality. Air quality index measures how much air is free from pollution. Being aware of the healthiness of the breathed air is a right for the people. Public authorities must constantly inform the population on air quality status. Even though several pollutants are monitored by the air quality monitoring networks, providing a significant amount of data, their interpretation and presentation to the population by the public authorities is a difficult task. Some countries, for several years, have adopted evaluation procedures through daily indices that succinctly describe the air quality status in different areas of the city. The use of an index which is able to give a simple and quick information to the population represents a possible solution for the public authorities. Concerning a Mediterranean area, it has not yet been possible to adopt a single indicator to be used for informing the population. In this work, the air quality status is highlighted by the air quality index (AQI) whose purpose is to inform, in a simple and immediate way, the population. Analyzing the AQI's trend from 2013 to 2015, it was possible to assess the air quality status, obtaining an overall

scenario for the purpose of protecting human health and the ecosystems. We point out that this kind of research could be applied to every region or municipality.

Keywords Air quality · Monitoring networks · Mediterranean area · Applied mathematics · Protection of human health

Introduction

Measures aimed to contain and reduce air pollution require a joint and coordinated action by all States, through a policy, which safeguards human and environmental health. Actions aimed to the optimization of the available energy sources, to the employment of renewable sources, to the reorganization of urban traffic mobility, and to the containment of industrial emissions by more sustainable technology and manufacturing processes could reduce the incessant human activities exerted by mankind on the environment (Lanzafame et al. 2015; Monforte 2017a, b; Brusca et al. 2017). Factors like industry, traffic, and domestic heating systems represent the major sources of the atmospheric inlet of harmful pollutants, especially in large urban areas with high population density (Rocha et al. 2016; Caramagna et al. 2015; Brusca et al. 2016). The consequences of air pollution on the health of the population cause a decrease of the life expectation of about 2 years in the most polluted areas, not considering the harmful effects on the ecosystem (Setälä et al. 2013; D'Amato

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et al. 2010; Kampa and Castanas 2008; Dockery and Stone 2007; Ostro et al. 2006). Furthermore, some pollutants are among the main causes of harmful phenomena, such as eutrophication waters, photochemical smog, reducing agricultural yields, reduced forest growth, and climate impacts (Duro et al. 2014, 2016a, b, 2017; Ragusa and Rapicavoli 2017). Public information plays a key role on the air quality status influencing the policies of each State. Several pollutants are monitored by the air quality monitoring networks, providing a great mass of data (Lanzafame et al. 2016; Famoso et al. 2017). One of the first synthetic indices, adopted by the United States Environmental Protection Agency (US-EPA), was the Pollution Standards Index (PSI) (Ott and Hunt Jr 1976). Subsequently, the EPA replaces the PSI index with the air quality index (AQI), which incorporates two new sub-indices, one for ozone at ground level and one for fine particulate (Fitz-Simons 1999). It is calculated considering the typical pollutants from combustion processes (carbon monoxide (CO), particulate matter (PM₁₀), sulfur dioxide (SO₂)), in addition to secondary pollutants (nitrogen dioxide (NO₂), ozone (O₃)). The concentrations of these five pollutants are converted into a single number that assumes values from 0 to 500. This interval is divided into six classes, each of them represents a category of air quality (Kassomenos et al. 1999; Kyrkilis et al. 2007; Bishoi et al. 2009). Some States use a modified version of AQI (Poupkou et al. 2011); others make use of environmental sustainability indexes, where air pollution is only one of the parameters to be considered (Werner et al. 2002; Quénot et al. 2006). In the Italian scenario, it has not adopted, in all regions, a single indicator to be used to inform population (Strano et al. 2015; Murena et al. 2003). In this work, the procedure for AQI calculation used by the US-EPA has been applied, adapting it to the Italian regulations in order to define the air quality status in an Italian area located in the middle of Mediterranean, specifically Sicily, from 2013 to 2015. It was used as a reference scale with five categories (Murena 2004) rather than six as required by the EPA to calculate AQI. Using data obtained from ten monitoring stations belonging to the regional network and some owned by the provincial and municipal networks, it was possible to analyze the trend of the “adapted AQI” (AQI_{ad}). Location of the monitoring stations did not change during the 3 years of analysis (Famoso et al. 2015). By daily trend analysis of the AQI_{ad}, it was possible to obtain, in terms of frequency, the predominant category and to compare

areas of purpose of the study, obtaining an overall scenario on the air pollutant status for protecting human health and the ecosystems.

Materials and methods

How to calculate the air quality index

The air quality index (AQI) is a dimensionless quantity defined in order to synthetically represent the overall air pollution status. AQI considers pollutants that cause health acute effects (PM₁₀, CO, NO₂, O₃, SO₂). The choice to include only pollutants that have acute effects comes from the fact that this index is formulated with the aim of giving daily instructions to the population in order to avoid short-term health effects (Lelieveld et al. 2015; Norris et al. 1999). For converting the concentrations of pollutants in AQI, a piecewise linear function of the concentration of the pollutant considered is used as shown in Eq. (1) (Bruno and Cocchi 2002):

$$I_{p,s} = \frac{I_{\text{high}} - I_{\text{low}}}{C_{\text{high}} - C_{\text{low}}} (C_p - C_{\text{low}}) + I_{\text{low}} \quad (1)$$

where $I_{p,s}$ is the sub-index for p th pollutant in s th station, C_p is the daily concentration of pollutant p , C_{low} is the concentration breakpoint that is $\leq C_p$, C_{high} is the concentration breakpoint that is $\geq C_p$, I_{low} is the breakpoint index corresponding to C_{low} , I_{high} is the breakpoint index corresponding to C_{high} . Equation (1) has to be applied for each p th pollutant measured by s th station. AQI value for s th station is represented by the highest value present between the sub-indices considered; by the relation (2), we obtain the value of the AQI:

$$\text{AQI}_S = \max(I_{O_3}, I_{PM10}, I_{CO}, I_{SO_2}, I_{NO_2}) \quad (2)$$

The numerical value of the AQI_{ad} may fall within five different categories of air quality, in a range from 0 to 100, instead of six and range from 0 to 500 as required by AQI. The AQI, used by the EPA, is hardly applicable to the Italian legislative context. It contains an excess of categories for the highest levels of concentration and a deficit for the lower ones (Murena 2004); it was necessary to apply a measurement scale in accordance with the Legislative Decree no. 155/2010, which transposes the European Directive 2008/50/EC. For example, a concentration of PM₁₀ of 51 $\mu\text{g}/\text{m}^3$ corresponds to an exceeded daily limit value, according to the Legislative

Decree no. 155/2010. Instead, if we calculate the AQI as in EPA, as shown in Table 1, the value that we obtain falls in the “Good” category, giving a wrong information about the air quality.

Table 2 shows the categories, the ranges, and the breakpoints adopted for AQI_{ad} calculation; to the categories, it has been associated with different colors in order to make this information easily understandable for the population.

The first two levels are established by Directive 2008/50/EC, while the second two come from epidemiological studies on single pollutants. In correspondence to the above reported concentration level, the following pollution categories have been defined. In the “Good” category, concentrations are under the limit value laid down by the Directive 2008/50/EC for the protection of vegetation. In the “Low pollution” category, concentrations are under the limit value laid down by the Directive 2008/50/EC for the protection of human health; these values are in agreement with the guidelines proposed by the WHO for individual substances based on effects other than cancer or odor/annoyance (World Health Organisation (WHO) 2000). In the “Moderate pollution” category, concentrations are above the limit value laid down by the Directive 2008/50/EC; current knowledge does not allow to define the long-term effects on the population. In the “Unhealthy for sensitive groups” category, concentrations can cause effects, in the short period, to particularly vulnerable groups (children, elderly, asthmatics) (Gilli et al. 2002; WHO 2000). In the “Very unhealthy” category, concentrations are able to cause effects, in the short term, to the entire population (Gilli et al. 2002; WHO 2000).

Data sources

The air quality in the Mediterranean area of Sicily is controlled by a regional monitoring station system managed by “Agenzia Regionale per la Protezione dell’Ambiente” (ARPA). In this work, the data of pollutant concentrations measured by ten monitoring stations located in Sicily from 2013 to 2015 was used. The monitoring stations are classified according to the type of area: urban, suburban, and rural. In this work, the authors consider urban and suburban monitoring stations. The urban ones are located in predominantly built areas and with a high man-made environment rate; while suburban monitoring stations are located in built areas but with a low man-made environment rate. Each station is equipped with several analyzers for measuring a single pollutant (SO₂, PM₁₀, CO, O₃) or a grouping of them (NO₂, NO, NO_x). In details, NO₂ analyzer was a Philips chemiluminescence NO/NO_x model 200E according to UNI EN 14211:2005. The measurement principle is based on the oxidation of nitrogen monoxide molecules by ozone which produces a characteristic luminescence intensity proportional to the concentration of NO. The SO₂ analyzer was a Philips pulsed fluorescence model K50206/00 as per UNI EN 14211:2005. Measurements were based on pulsed fluorescences. Ultraviolet radiation is filtered, focused, and channeled into a fluorescence chamber. Simultaneously, an environmental air sample is injected into the chamber. The ultraviolet radiation excites the SO₂ molecules leading to higher energy levels. Subsequently, the excited SO₂ molecules emit a characteristic radiation which, when properly filtered, is fed into a photoamplifier tube which transforms the data into an optical/electrical type. The PM₁₀ is measured by a PMx monitor model “Swam 5A” manufactured by FAI instruments.

Table 1 EPA’s table of breakpoints

O ₃ (ppb) C _{low} -C _{high} (avg 8 h)	O ₃ (ppb) C _{low} -C _{high} (avg 1 h)	PM ₁₀ (µg/m ³) C _{low} -C _{high} (24 h)	CO (ppm) C _{low} -C _{high} (avg 8 h)	SO ₂ (ppb) C _{low} -C _{high} (avg 1 h)	NO ₂ (ppb) C _{low} -C _{high} (avg 1 h)	AQI I _{low} -I _{high}	AQI category
0–59	–	0–54	0.0–4.4	0–35	0–53	0–50	Good
60–75	–	55–154	4.5–9.4	36–75	54–100	51–100	Moderate
76–95	125–164	155–254	9.5–12.4	76–185	101–360	101–150	Unhealthy for sensitive groups
96–115	165–204	255–354	12.5–15.4	186–304	361–649	151–200	Unhealthy
116–374	205–404	355–424	15.5–30.4	305–604	650–1249	201–300	Very unhealthy
–	405–504	425–504	30.5–40.4	605–804	1250–1649	> 300	Hazardous

Table 2 AQI_{ad}'s table of breakpoints

AQI _{ad} Category	AQI _{ad} Value	O ₃ (μg/m ³)	O ₃ (μg/m ³)	PM ₁₀ (μg/m ³)	CO (mg/m ³)	SO ₂ (μg/m ³)	NO ₂ (μg/m ³)
	<i>I_{low} - I_{high}</i>	<i>C_{low} - C_{high}</i> (avg 1 hr)*	<i>C_{low} - C_{high}</i> (avg 8 hr)**	<i>C_{low} - C_{high}</i> (24 hr)***	<i>C_{low} - C_{high}</i> (avg 8 hr)	<i>C_{low} - C_{high}</i> (avg 1 hr)	<i>C_{low} - C_{high}</i> (avg 1 hr)
Good	0 - 25	-	0 - 65	0 - 20	0 - 4	0 - 20	0 - 40
Low pollution	26 - 50	0 - 180	66 - 120	21 - 50	5 - 10	21 - 125	41 - 200
Moderate pollution	51 - 70	181 - 240	121 - 180	51 - 144	10.1 - 11.6	126 - 250	201 - 400
Unhealthy for sensitive groups	71 - 85	241 - 324	181 - 223	145 - 238	11.7 - 15.5	251 - 500	401 - 950
Very Unhealthy	86 - 100	325 - 600	224 - 500	239 - 500	15.6 - 30	501-1000	951 -1900

*Maximum daily average hourly; **maximum moving average on 8 h according to the procedure indicated on Legislative Decree 155/2010; ***daily value acquired during 24 h

Measurement is gravimetric using the mass measurement of attenuation through β -rays using a source of low-activity ¹⁴C. Reference method for sampling and measuring PM₁₀ is described in EN 12341:1999 "Air quality; determination of the PM₁₀ fraction of suspended particulate matter; reference method and field test procedure to demonstrate reference equivalence of measurement methods." A Philips Gas Filter Correlation (GFC) CO analyzer was used as per UNI EN 14626:2005. The measuring principle is based on the absorption of infrared radiation (IR) by molecules of CO, whose intensity variation is proportional to the CO concentration. This IR absorption is governed by the Beer-Lambert law which defines how much light of a specific wavelength is absorbed by a particular gas molecule. The Ozone photometric analyzer was an API model 400A. The basic principle on which the ozone analyzer M400E is based is the Beer-Lambert equation. It defines the amount of

light at a specific wavelength that is absorbed by a particular gas molecule at a certain distance and at a given temperature and pressure. The reference method for sampling and measuring O₃ is described in EN 14625:2005.

The choice of the stations to be included for the AQI_{ad} calculation was performed in order to obtain a maximum spatial coverage without overlap. Table 3 shows the identification of each station; Fig. 1 shows the spatial location.

Results and discussion

To obtain the daily AQI_{ad} from pollutant concentrations measured by monitoring stations, Eqs. (1) and (2) have been applied. The location of the monitoring stations was kept unchanged from 2013 to 2015. This choice gives the opportunity to evaluate, in terms of frequency, the

Table 3 Identification and spatial location of each stations

ID station	Name station	Location	Altitude (m.a.s.l.)	Zone
MLZ	Milazzo	38° 11' 29.16" N-15° 14' 56.78" E	26	Suburban
MSB	Misterbianco	37° 30' 56.40" N-15° 00' 38.50" E	177	Urban
POL	Priolo	37° 09' 31.45" N-15° 11' 38.81" E	16	Suburban
RGS	Ragusa	36° 55' 34.21" N-14° 42' 54.98" E	596	Urban
GLA	Gela	37° 04' 06.14" N-14° 15' 31.97" E	9	Urban
ENN	Enna	37° 33' 51.80" N-14° 16' 54.50" E	920	Urban
SCD	San Cataldo	37° 29' 08.71" N-13° 59' 21.41" E	606	Urban
TRM	Termini	37° 58' 40.43" N-13° 41' 16.55" E	103	Suburban
PRT	Partinico	38° 02' 58.90" N-13° 07' 07.20" E	182	Urban
TPN	Trapani	38° 00' 44.53" N-12° 32' 48.82" E	7	Urban

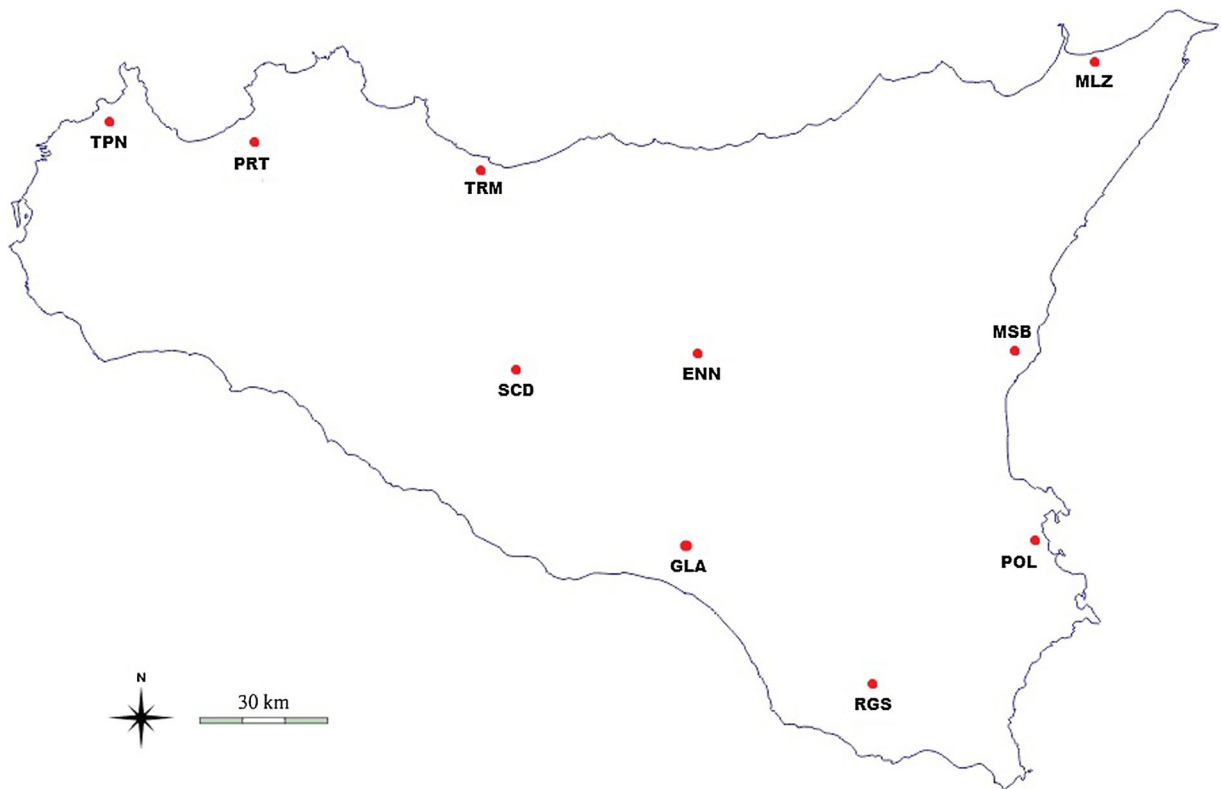


Fig. 1 Spatial location of the monitoring stations

prevailing AQI_{ad} category in each station during this period. Table 4 shows the frequencies calculated for each category as a function of the number of days, while Fig. 2 shows the summary of data expressed as a percentage.

As shown in Table 4, the dominant categories in all the considered stations are the “Low pollution”

followed by “Moderate pollution”; in this latter case, the concentration values are above the limit value set by the Directive 2008/50/EC. It is the second most present category during the period 2013–2015 in six out of 10 stations. In the remaining four stations, the second category “Unhealthy for sensitive groups” is present in five

Table 4 AQI_{ad} category frequencies for each station

ID station	No. of days	Frequency category [%]				
		Good	Low pollution	Moderate pollution	Unhealthy for sensitive groups	Very unhealthy
MLZ	1086	3.60	83.88	12.52	–	–
MSB	1084	1.20	95.75	3.05	–	–
POL	1078	15.03	75.52	9.27	0.18	–
RGS	1021	28.11	71.80	0.09	–	–
GLA	1000	0.10	96.10	3.60	0.20	–
ENN	1061	3.00	81.53	15.47	–	–
SCD	701	10.13	86.59	3.28	–	–
TRM	1076	1.96	96.28	1.58	0.18	–
PRT	1089	1.57	95.68	2.57	0.09	0.09
TPN	1044	1.82	94.34	3.54	0.20	0.10

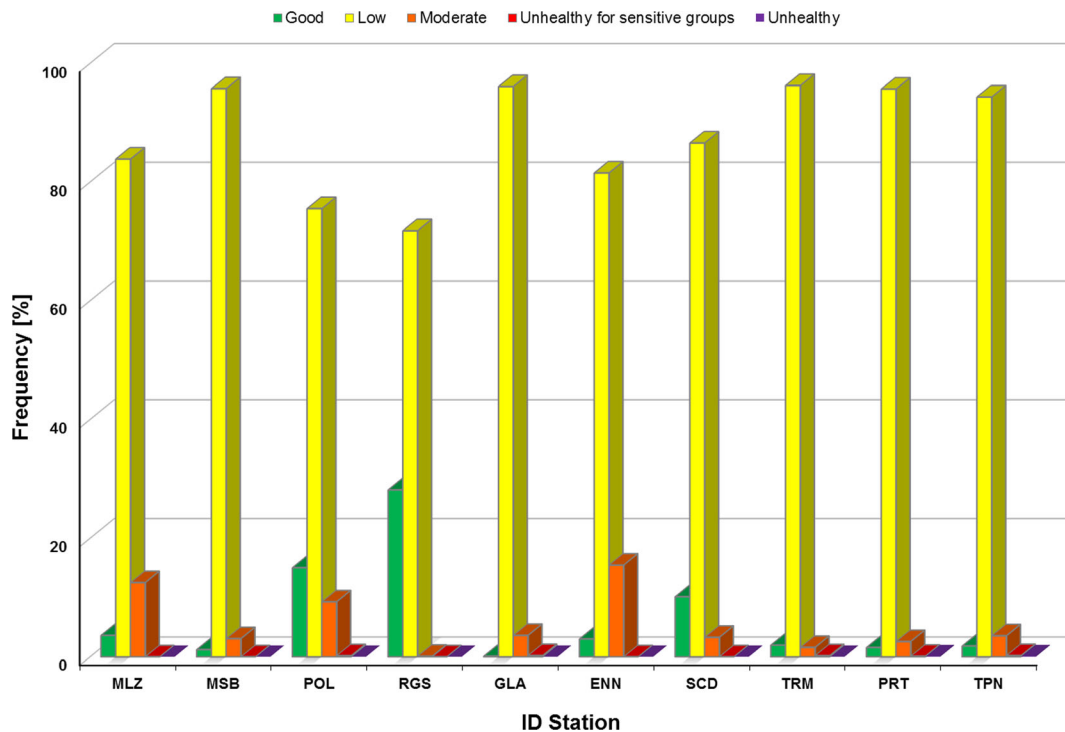


Fig. 2 Summary of frequencies

out of 10 stations with very low percentages, reporting sporadic events caused by human activity but also natural causes, whereas Sicily is often affected by Saharan dust phenomena (Cuspilici et al. 2017). A similar situation was observed for the “Very unhealthy” present in two out of 10 stations. The AQI_{ad} daily trend was analyzed for all stations; results are shown in Figs. 3 and 4. The trends show an increase from April to August followed by a decrease from September to March. This seasonal periodicity is mainly due to high concentrations of ozone, a secondary pollutant, which is highly sensitive to solar radiations. The analysis of the AQI_{ad} trend showed a deterioration of the air quality in the analyzed area, during the summer. Given the cyclic nature with which the phenomenon occurs, a prior information notice to population, especially for sensitive groups, was released, and it may reduce exposure and, hence, mitigate the short-term effects on health.

Conclusion

In this work, the air quality index (AQI), used by the United States Environmental Protection Agency, was adapted to Italian legislative context (decree 155/2010)

implementing rules of the Directive 2008/50/EC. The AQI_{ad} was used to define air quality status in a big region of the Mediterranean area. Using concentrations of the pollutant provenience from ten monitoring stations, it was possible to assess the air quality status from 2013 to 2015. The choice of stations to be included for the AQI_{ad} calculation was performed to ensure maximum territorial coverage without overlap. The stations belong to monitoring networks of the “Agenzia Regionale per la Protezione dell’Ambiente” (ARPA). The frequencies of the categories provided by the AQI_{ad} were obtained for each monitoring station. These data made it possible to identify the main category and, therefore, to define an overall scenario of the air quality status. As for the AQI_{ad} daily trend, it was noted an increase during the period April–August; after this period, a decrease occurred. This seasonal cycle, largely due to an excess of secondary pollutants such as ozone, is present in the majority of stations. This study suggests the chance of knowing in advance the AQI_{ad} value; it is a useful support for the public authorities and for the healthcare system. If this approach was taken into consideration, it would represent a preventive measure able to reduce the exposure of those categories of people particularly at risk. Future developments aim therefore

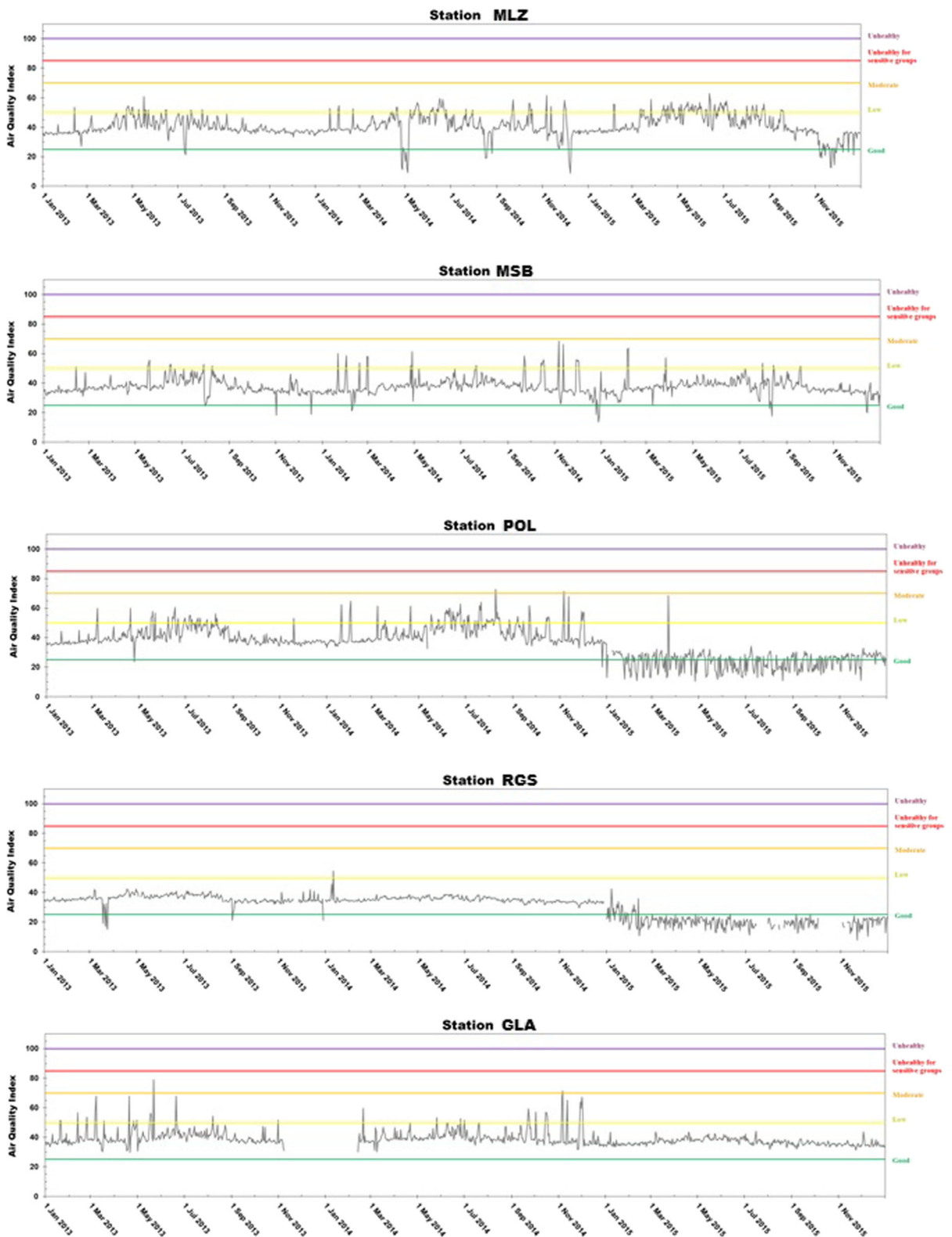


Fig. 3 AQI_{ad} trend stations MLZ, MSB, POL, RGS, GLA

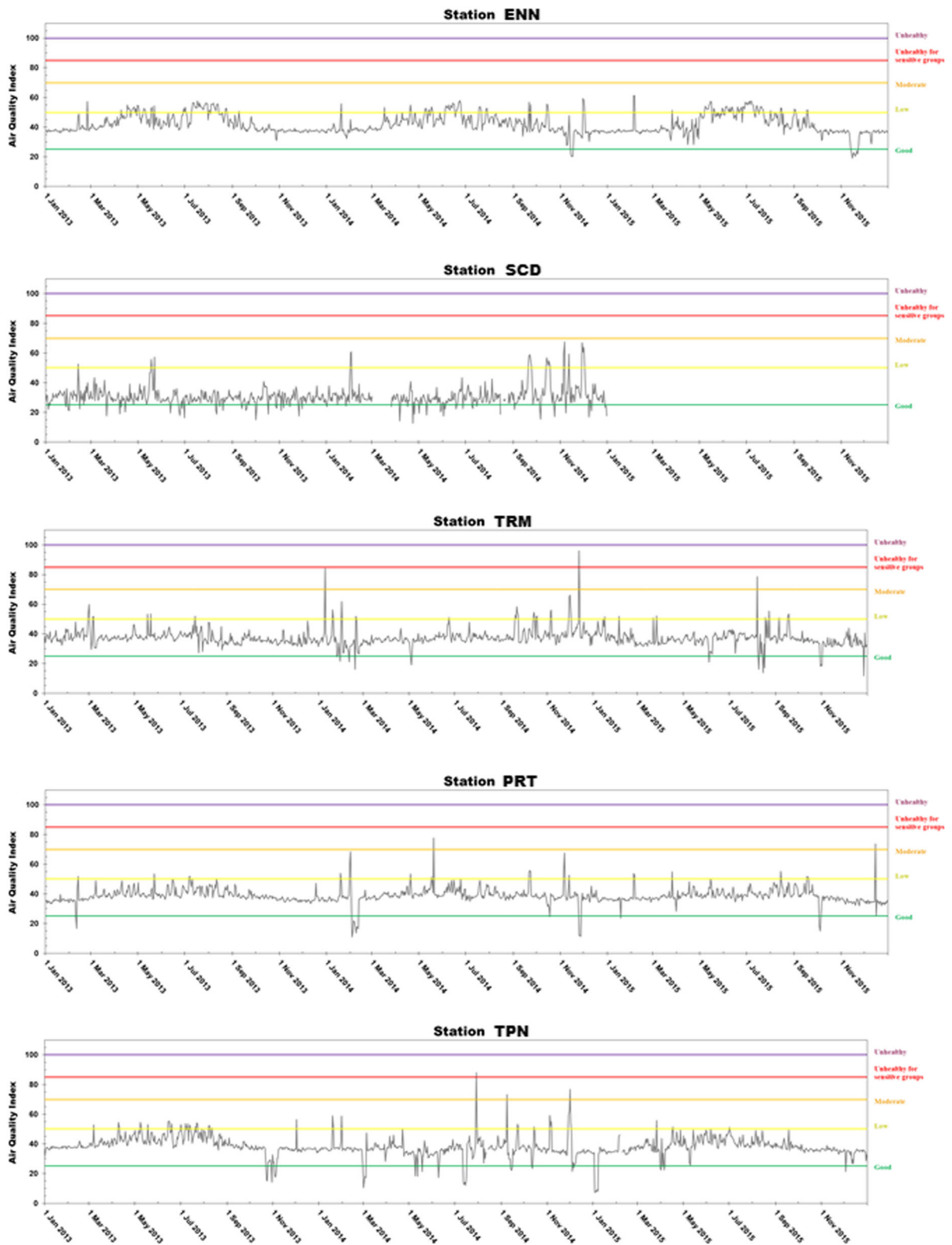


Fig. 4 AQI_{ad} trend stations ENN, SCD, TRM, PRT, TPN

to the creation of a short-term forecasting model of the air quality index. The forecasting model has to be implemented taking also into account the meteorological parameters, because they play a leading role in the distribution of atmospheric pollutants, in addition to a quantitative assessment about conditions of daily urban traffic.

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