

Analysis of Air Quality in the Outdoor Environment of the City of Messina by an Application of the Pollution Index Method

G. Cannistraro, L. Ponterio

Abstract—In this paper is reported an analysis about the outdoor air pollution of the urban centre of the city of Messina. The variations of the most critical pollutants concentrations (PM_{10} , O_3 , CO , C_6H_6) and their trends respect of climatic parameters and vehicular traffic have been studied. Linear regressions have been effectuated for representing the relations among the pollutants; the differences between pollutants concentrations on weekend/weekday were also analyzed. In order to evaluate air pollution and its effects on human health, a method for calculating a pollution index was implemented and applied in the urban centre of the city. This index is based on the weighted mean of the most detrimental air pollutants concentrations respect of their limit values for protection of human health. The analyzed data of the polluting substances were collected by the Assessorship of the Environment of the Regional Province of Messina in the year 2004. A statistical analysis of the air quality index trends is also reported.

Keywords—Environmental pollution, Pollutants levels, Linear regression, Air Quality Index, Statistical analysis.

I. INTRODUCTION

NOWADAYS the deterioration of air quality of urban areas has become a global problem. A variety of air pollutants released in the centre of cities have known or suspected harmful effects for human health and for environment. Emitted pollutants are mainly the products of combustion from space heating, power generation or from motor vehicle traffic. They may not only damage near their sources but they can travel long distances, chemically reacting in the atmosphere to produce secondary pollutants such as acid rain or ozone. In both developed and developing countries, the major problem to urban air quality is posed by traffic emissions. Petrol and diesel engine motor vehicles emit a wide variety of pollutants, mainly carbon monoxide (CO), oxides of nitrogen (NO_x), volatile organic compounds ($VOCs$) and particulates. Changes in urban atmosphere composition are caused largely by traffic-induced pollutants and the problem begins more critical considering its dependence from meteorological parameters. For example, photochemical reactions resulting from the action of sunlight on NO_2 and $VOCs$ concentrations lead to the formation of ozone O_3 , a secondary long-range pollutant, which may impacts in areas often far from the original emission sources. Acid rain is

another long-range event caused by vehicle NO_x emissions. Due to environmental policies, the levels of pollutants from industrial and domestic sources, together with their impact on air quality, tend to be steady-state or diminishing over time in urban areas; whereas traffic pollution problems are worsening world-wide. The pollution from motor vehicles is of great importance in developing countries with problems such as increasing vehicle fleets, infrastructural limitations, absence of emission control technologies of vehicle engines and poor maintenance or vehicle regulation.

This study examines the behaviour of pollutants concentrations collected every hour and every day in the year 2004 in the urban centre of the city of Messina. Analyzed pollutants are particulate with diameter less than $10\ \mu m$, benzene, carbon monoxide, nitrogen dioxide and ozone; almost all are traffic-induced primary pollutants, ozone and nitrogen dioxide are secondary pollutants, they are formed by photochemical reactions. Pollutant data were monitored by the Assessorship of Environment of Province of Messina, in four monitoring stations equipped with analyzers, situated in central areas of the city (Table I and figure n. 1).

Pollutants correlations with temperature and with vehicular traffic were observed, the relations among pollutants were

TABLE I
MONITORING STATIONS AND RELATIVE POLLUTANT ANALYZERS

Site number	Monitoring Stations	Pollutant Analyzer
1	Caronte	CO , PM_{10} , O_3 , C_6H_6
2	Archimede	CO , PM_{10}
3	Bocchetta	CO , PM_{10} , C_6H_6
4	Università	CO , C_6H_6

studied and linear regressions were effectuated. The differences between pollutants levels on weekday and on weekend were also examined. Pollutant data was also used for improving a method for calculating a pollution index useful for informing population about the quality of breathing air and its damages for human health.

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Fig. 1 Localization of the monitoring stations

II. POLLUTANTS TRENDS WITH TEMPERATURE

Relations between collected pollutants concentrations and temperature changes have been studied. It resulted that ozone concentrations increased with external air temperature with highest concentrations occurring in the afternoon. For tropospheric ozone formation depends largely by solar irradiation [1],[2]. In fact ozone is produced by photochemical reactions involving other pollutants, with a process that generally require a few hours after the emissions, and that is more effective when sunlight is intense and air temperatures

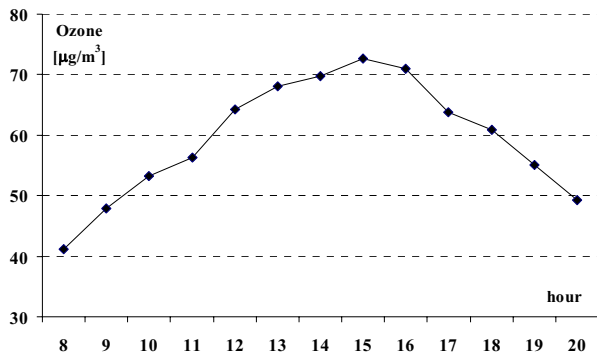


Fig. 2 Diurnal profile of ozone (monthly mean values per hour) in April 2004, Caronte station.

are warm. In figure n. 2 the diurnal profile of ozone levels from 8:00 to 20:00 is represented; maximum ozone concentrations have been observed between 14:00 h and 16:00 h, with the peak value at 15:00 h. Also before the sunrise, between 3:00 h and 5:00 h, high levels of ozone were revealed. Moreover highest ozone concentrations were during spring and summer months, when solar irradiance is higher, how showed in figure n. 3, in which the year profile of

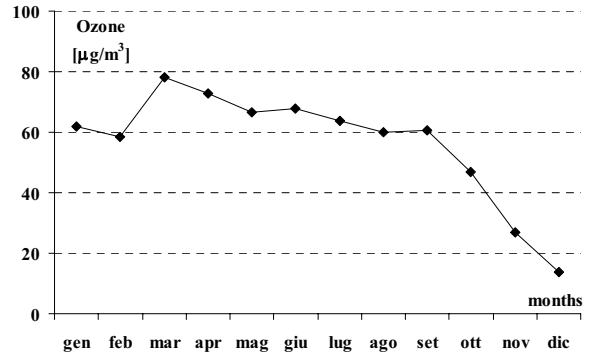


Fig. 3 Ozone Monthly hourly mean values at 15:00 h during the year 2004, in the "Caronte" station.

monthly means of ozone levels at 18:00 h is reported. Ozone levels decreased from September to December, according to temperature decrements. However have been also monitored high values of ozone levels in March and April (fig.n.3). This anomalous trend can be explained by the pollutant emissions from the conditioning plants.

Nitrogen dioxide dependence with temperature has been also studied; it presents an opposite trend as to ozone, in fact if temperature increases it decreases. Probably for nitrogen dioxide molecules dissociates to form ozone at high temperatures by photochemical reactions [3]. Primary pollutants such as benzene and carbon monoxide, were compared with temperature but the results had no significance; on the contrary their influence with vehicular traffic, reported below, revealed very interesting.

III. POLLUTANTS TRENDS WITH VEHICULAR TRAFFIC

The city of Messina is interested by an enormous commuter traffic, from the hinterland to the city, and from Sicily to remaining Italian regions. The gases emitted by motor-vehicles are the main source of pollution in the urban centre. The study of the trends of primary pollutants during rush-hours confirms the relations between pollutants and motor vehicle traffic. Observing the monthly mean day for traffic-induced pollutants, such as particulate PM₁₀, benzene and carbon monoxide, reported in fig. n.4, peak values can be noted during the morning rush-hour, from 07:30 h to 08:30 h, and during the evening rush-hour, from 19:30 h to 20:30 h.

Particularly, in the "Università" station the pollutants reveal peak values in three rush-hours, from 08:30 h to 09:30 h, from 13:00h to 14:00 h and from 19:30 h to 20:30h (fig. n.5). It is due to the particular kind of urban traffic interesting that area; in fact this zone is the site of the Court and of the University, so it is interested by a great commuter traffic in this hours.

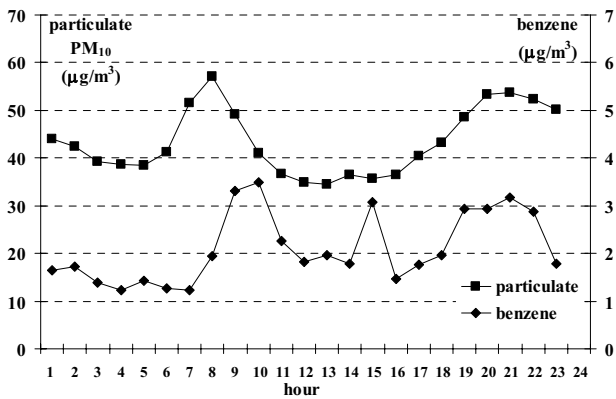


Fig. 4 Monthly mean day in the “Bocchetta” station in February 2004 for particulate PM₁₀ and benzene

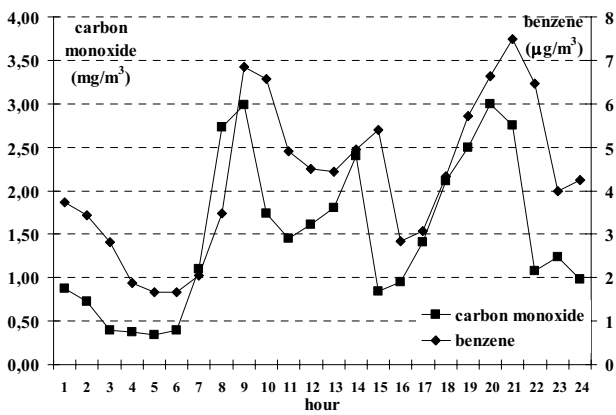


Fig. 5 Monthly mean day in the “Università” station for benzene and carbon monoxide in February 2004

IV. WEEKEND-WEEKDAYS DIFFERENCES

The analysis of the data revealed also that the “ozone weekend effect” occurred in the urban centre of Messina. This phenomenon happens when ozone concentrations on weekends are higher than weekdays (fig. n. 6); although during weekends ozone precursor species concentrations were lower. This phenomenon has been observed in many industrialized areas in the world, and in many urban centres, like in Southern California [4], in Toronto [2] and New York City [5].

On the contrary, primary pollutants concentrations, benzene, carbon monoxide and particulate, decreased during weekends; this is due to the low vehicular traffic circulating in the urban centre of Messina in this period.

V. CORRELATION ANALYSIS

The relation among tropospheric ozone and nitrogen dioxide has been investigated, under the hypothesis that most of the vehicular traffic coming from the “Caronte” docking passes across the “Bocchetta”.

The correlation among the two pollutants resulted negative with a correlation coefficient=-0,85; maybe it can be explained by the photochemical reaction of nitrogen dioxide,

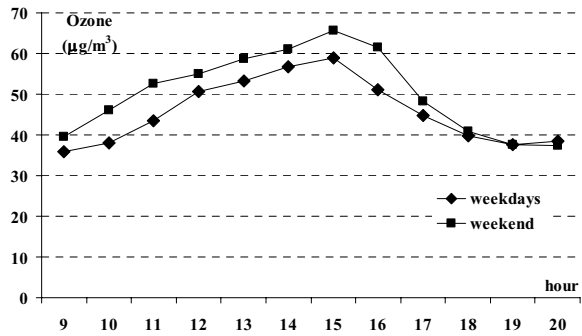


Fig. 6 Comparison among monthly means of ozone concentrations during weekdays and ozone concentrations during weekend in January 2004 in the “Caronte” station from 09:00 h to 20:00 h

which at high temperatures contributes to form tropospheric ozone. Similar results have been obtained in other studies reported in literature [6]. Has been calculated the regression line relative to the relation between ozone and nitrogen dioxide (fig. n. 7), that is reported below:

$$[NO_2] = -0,42 * [O_3] + 36,21 \tag{1}$$

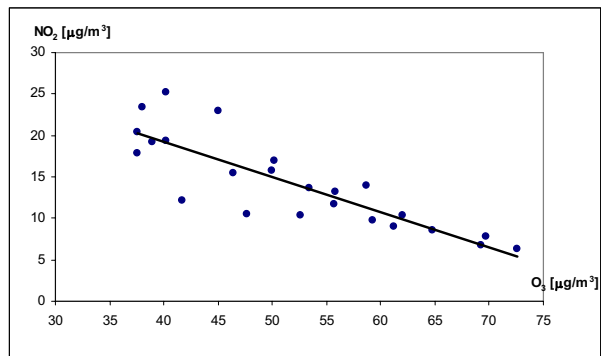


Fig. 7 Correlation among ozone monthly mean concentrations and nitrogen dioxide monthly mean concentrations - Regression line

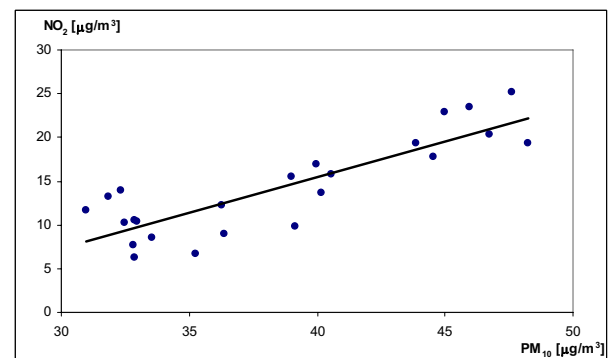


Fig. 8 Correlation among particulate monthly mean concentrations and nitrogen dioxide monthly mean concentrations - Regression line

The relations among traffic-induced primary pollutants have been analyzed; the correlations particulate-nitrogen

dioxide, particulate-benzene and carbon monoxide-benzene, are reported in fig. 8, 9, 10. A positive correlation between particulate and nitrogen dioxide resulted with an high correlation coefficient 0.85. The calculated equation of regression line is the following:

$$[NO_2] = 0,81*[PM_{10}] - 16,96 \tag{2}$$

Positive correlations resulted also by the analysis of particulate and benzene and by the analysis of carbon monoxide and benzene and relative regression lines have been obtained (fig. n.9 and fig. n. 10)

The relative equation of the regression lines was:

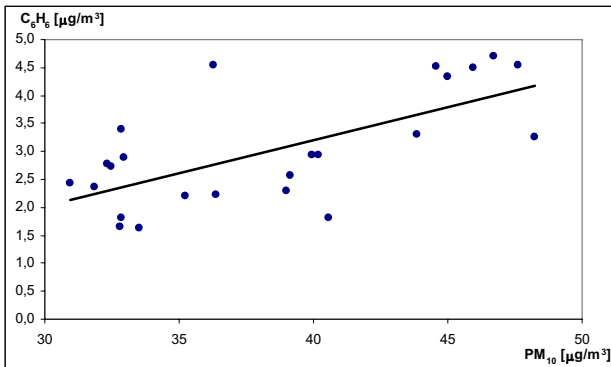


Fig. 9 Correlation among particulate monthly mean concentrations and benzene monthly mean concentrations and regression line

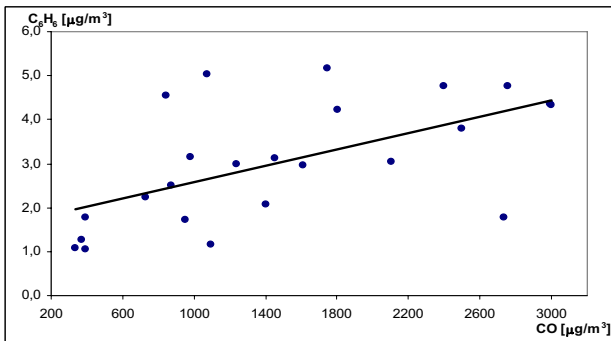


Fig. 10 Correlation among carbon monoxide monthly mean concentrations and benzene monthly mean concentrations and regression line

$$[C_6H_6] = 0,12*[PM_{10}] - 1,52 \tag{3}$$

with correlation coefficient 0.67,

$$[C_6H_6] = 0,000932*[CO] - 1,65 \tag{4}$$

with correlation coefficient=0.59

The analysis revealed that carbon monoxide and particulate didn't result strictly correlated with motor vehicle in the same manner like benzene. For carbon monoxide and particulate the analysis revealed a correlation coefficient lower than that obtained in the first two analyses, maybe it was due to the presence of other sources of carbon monoxide and particulate, such as air-conditioning systems for the former.

VI. THE POLLUTION INDEX METHOD

Nowadays, especially in industrialized countries, people need to know information about the quality of the air that they are breathing. The pollution index method here studied is based on a simple indicator of the air quality in an urban context that is useful for communicating to citizens information about the state of air quality of a waste urban area [7, 8]. This index estimates the air quality by means of a series of pollutants critical in the Italian urban contexts. The calculation of the Pollution Index is based on the weighted mean value of the sub-indexes of the most critical pollutants. It is expressed by a numerical index ranging from 1 to 7; an highest value of the index represents an highest value of environmental pollution, and, of course an highest health risk. By the correlation with the limit values of the pollutants in the ambient air, this index represents the trend of air quality of a certain urban zone. The seven levels of the index express also the satisfaction degree of the people and the protection degree of human health (Table II).

TABLE II
VALUES, INDEXES AND HEALTH RISKS FOR THE AQI

NUMERIC VALUE	QUALITY INDICATOR	NUMERIC INDEX	HEALTH RISKS
0 ÷ 50	OPTIMUM	1	No risks for people
51 ÷ 75	GOOD	2	No risks for people
76 ÷ 100	MODERATE	3	No risks for people
101 ÷ 125	MEDIOCRE	4	Generally there aren't risks for people. People with asthma, chronic bronchitis or cardiopathy may feel light respiratory symptoms only during an intense physical activity
126 ÷ 150	NOT MUCH HEALTHY	5	There risks for people with heart-diseases, olds and children
151 ÷ 175	UNHEALTHY	6	Many people may feel light adverse symptoms, however reversible. Weak people may feel gravest symptoms.
> 175	VERY UNHEALTHY	7	People may feel light adverse effects for health. There are more risks for olds, children and people with respiratory diseases.

VII. CALCULATION OF THE INDEX

The Pollution Air Quality Index is calculated by the formula:

$$I_{IQA} = \frac{I_1 + I_2}{2}$$

The two sub-indexes I_1 e I_2 are calculated for the two most critical pollutants, presenting the highest value. The sub-indexes of NO_2 , PM_{10} , C_6H_6 are calculated by the following formula:

$$I_X = \frac{V_{max hX}}{V_{rijX}} * 100$$

where: I_X = air quality index of the X pollutant;

$V_{max hX}$ = highest value of the mean values of the x pollutant during an hour, monitored from 01:00 to 24:00 by all the monitoring stations of the area;

V_{rifX} = limit value of the x pollutant during an hour for protection of human health [9].

While the sub-indexes of O₃ and CO are calculated by the

following formula: $I_X = \frac{V_{\max 8hX}}{V_{rifX}} * 100$

where: I_X = air quality index of the X pollutant;

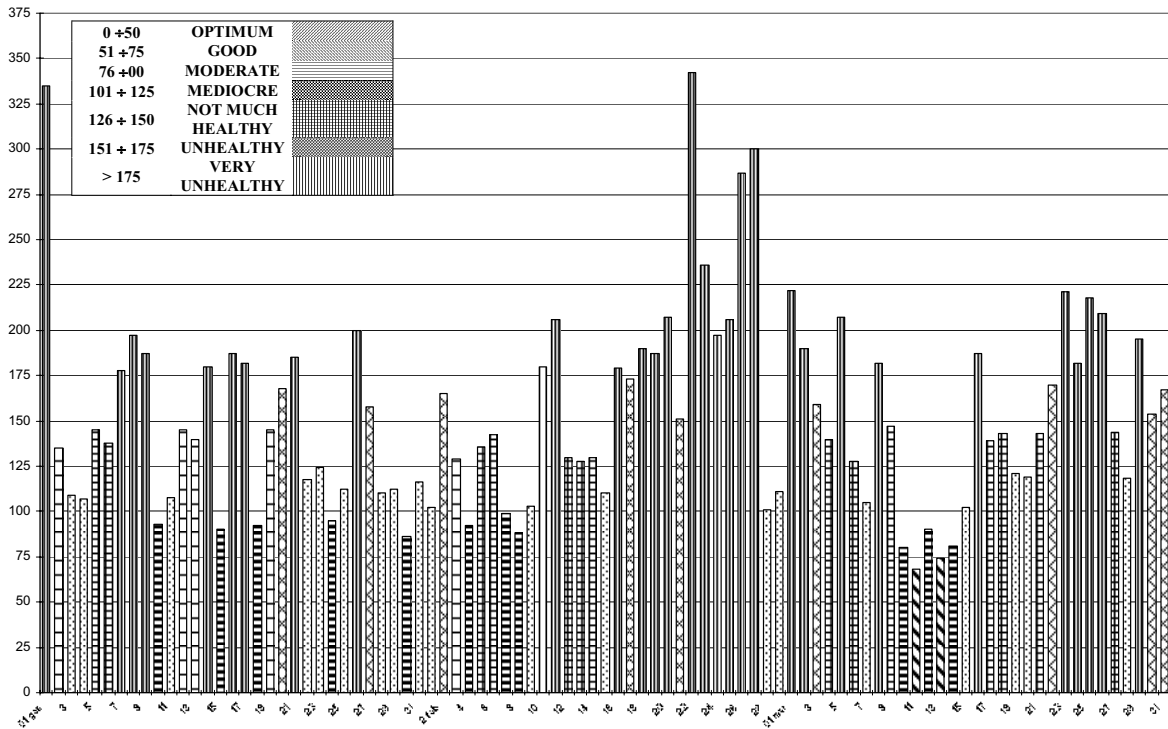


Fig. 11 Values of the Air Quality Index in the Caronte monitoring station from January to March 2004.

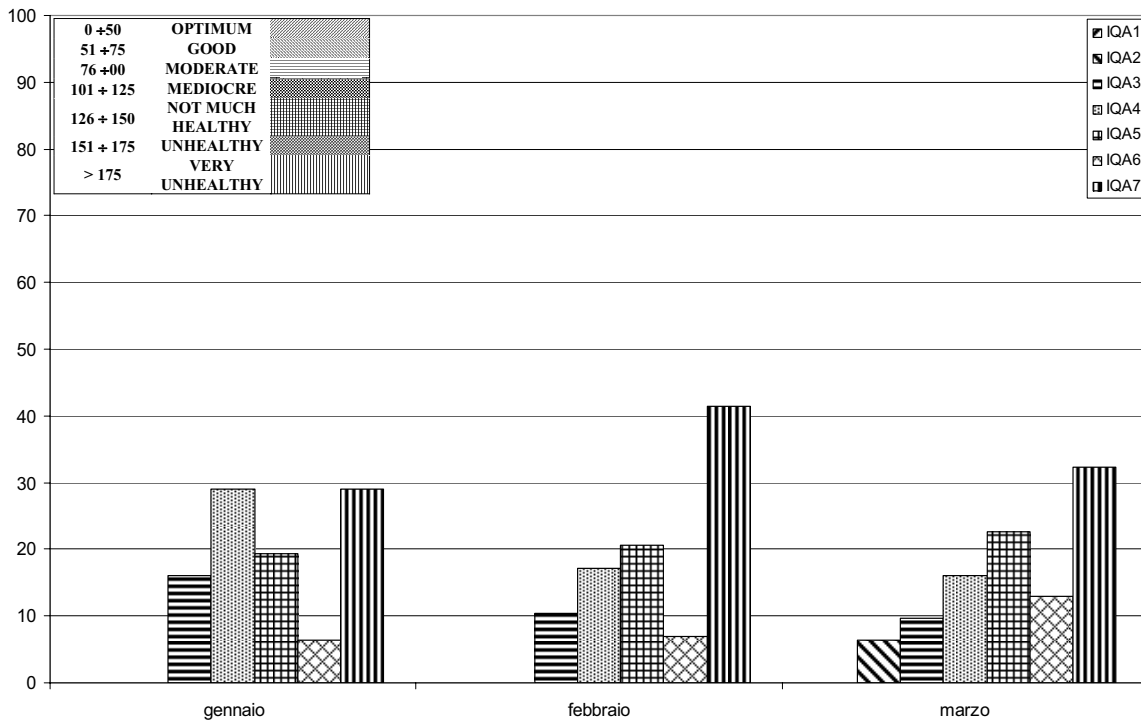


Fig. 12 Statistical analysis of Air Quality Index in the monitoring station "Caronte" from January to March 2004.

$V_{\max 8hX}$ = highest value of the mean values of the X pollutant during an hour, monitored from 01:00 to 24:00 by all the monitoring stations of the area;

V_{rifX} = limit value of the X pollutant during an hour for protection of human health [9].

VIII. A CASE STUDY: THE CITY OF MESSINA

The method of the Pollution Index has been applied in the urban centre of the city of Messina. The analyzed data were collected in the year 2004 by the Assessorship of the Environment of the Regional Province of Messina in four monitoring stations situated in areas mostly interested by road traffic. The chosen areas were: the area of the docking of the Shipping Society "Caronte", the area surrounding the urban centre, the area near the highway connecting Messina with the other cities of Sicily, and a central zone surrounding the University and the Court of Messina. The four monitoring stations were named in the order Caronte, Archimede, Boccetta and Università (Table I and fig. 2).

IX. EVALUATION OF THE AIR QUALITY INDEX IN THE CITY OF MESSINA

Each monitoring station served to collect the hourly means concentrations of pollutants from 1:00 h to 24:00 h, for every day of the year 2004. For every day of the year has been calculated the highest daily value of the hourly means of each pollutants; by the reference limit value according to the actual legislation, the D.M. 2002, n. 60 and the Directive 2002/3/CE

[10], have been calculated the sub-indexes. Using the mean value of the two highest sub-indexes, indicating the two most critical pollutants, has been evaluated the pollution index for each day in the year 2004.

X. VALUES OF THE AIR QUALITY INDEX IN THE MONITORING STATIONS AND ANALYSIS OF THE RESULTS

In the "Caronte" monitoring station high values of the Pollution Index have been registered in the months from January to March (fig. n. 11) and from October to December. The situation during the months from January to March is also reported in a statistical analysis, in fig. n. 12. From this analysis it is possible to see, for example, how the level 7, the most harmful for human health, was exceeded in a percentage of 40% during February. This is due to the enormous fluxes of heavy and light motor vehicle passing from this station during the winter period. Also in the Boccetta monitoring station the most critical period for air pollution air was represented by the months January, February and March (Fig. n. 13). It is also possible to see this from the results of the statistical analysis in this paper reported (Fig. n. 14).

XI. CONCLUSIONS

Pollutants concentrations monitored in the urban centre of the city of Messina have been studied in this paper. The analyzed pollutants were particulate with diameter less than $10\mu\text{m}$, benzene, carbon monoxide, nitrogen dioxide and ozone; almost all are traffic-induced primary pollutants, ozone and nitrogen dioxide are secondary pollutants, formed by

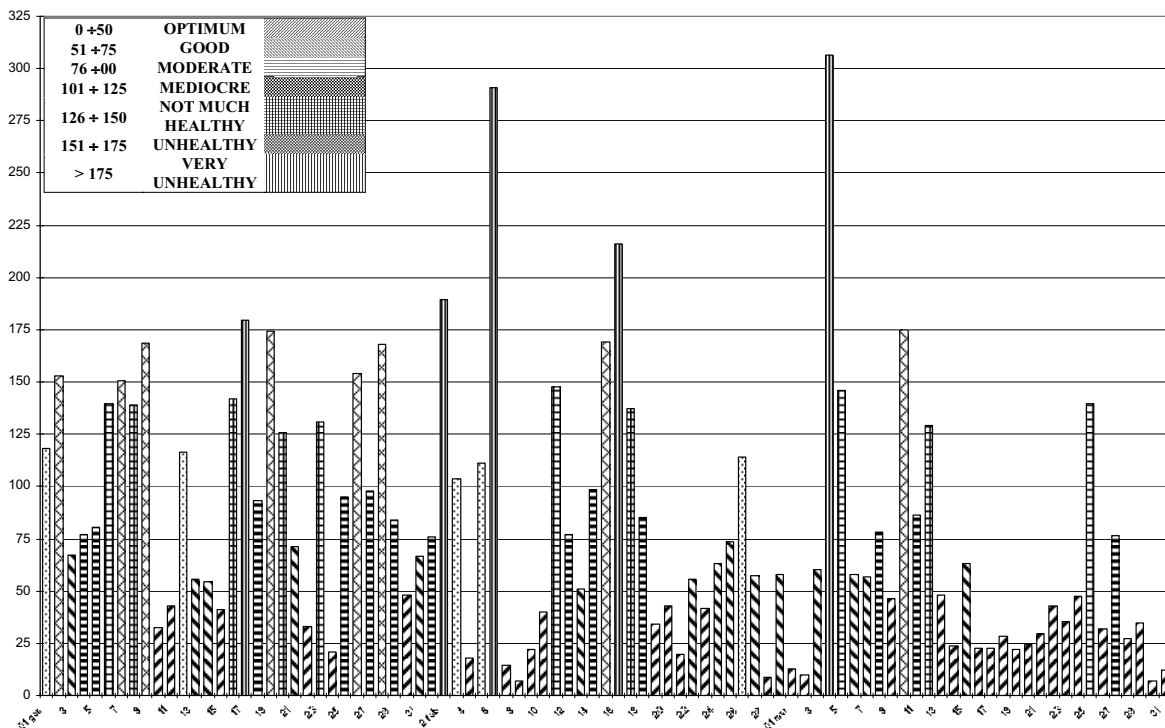


Fig. 13 values of the Air Quality Index in the Boccetta monitoring station from January to March

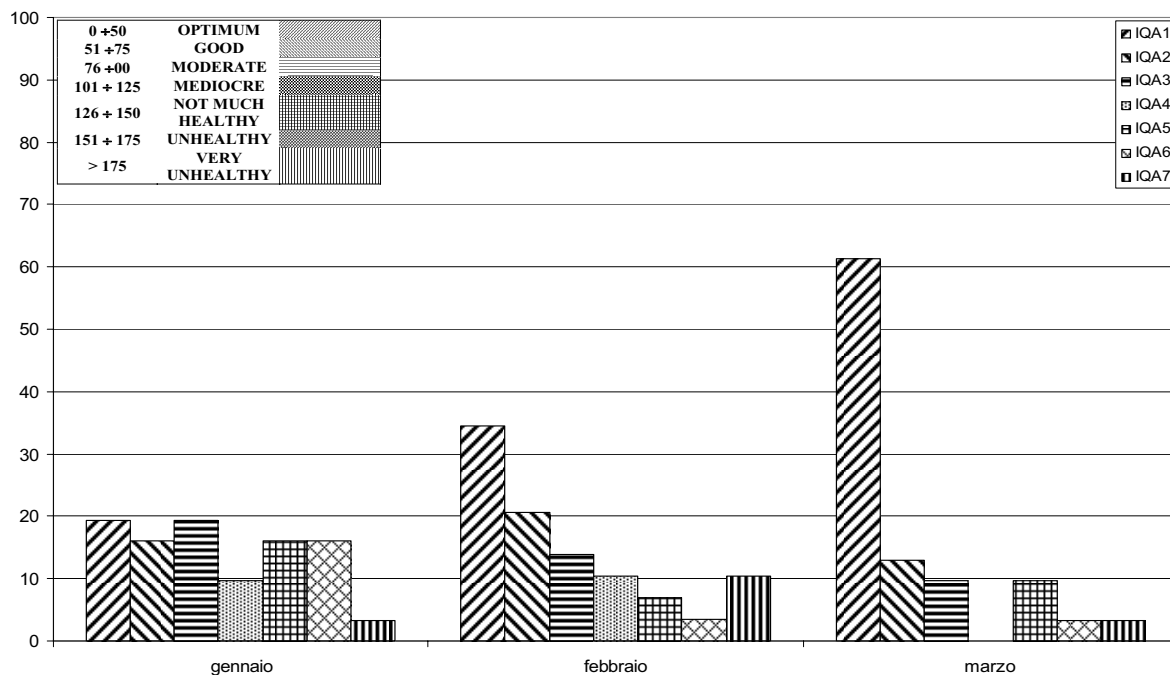


Fig. 14 statistical analysis of the data in the monitoring station Boccetta from January to March 2004

photochemical reactions. The relations between the pollutants and the external air temperature have been analyzed. Ozone revealed to be a temperature-dependent pollutant, with the observation of ozone concentrations increasing with temperature. This trend has been studied both during a day and during a year. Also nitrogen dioxide revealed to be a temperature-dependent gas, its molecule dissociates to form ozone with solar irradiation. The analysis of the relation between ozone and temperature revealed an high correlation negative coefficient; has also been calculated the regression line. The analysis of the data revealed the occurrence of the phenomenon named "ozone weekend effect" in the urban centre of Messina. Elevated ozone concentrations occurred on weekends relative to weekdays despite the weekends had lower measured ambient levels of ozone precursor species. The dependence between the primary pollutants, particulate, benzene and carbon monoxide, emitted by motor vehicles, has been revealed from the analysis of their behaviour during the morning rush-hours. Peak values can be noted during the morning rush-hour, from 07:30 h to 08:30 h, and during the evening rush-hour, from 19:30 h to 20:30h. In the monitoring station named "Università" peak values occurred also from 13:00h to 14:00 h due to the kind of urban traffic. The relations between primary pollutants have been observed and relative regression lines have been calculated. A positive correlation between particulate and nitrogen dioxide resulted with an high correlation coefficient 0.85. From the linear regression study of carbon monoxide and benzene has been obtained a correlation coefficient lower. Also from the linear regression study of particulate and benzene. Carbon monoxide and particulate didn't result strictly correlated with motor vehicles like benzene; maybe by the presence of other sources of pollution in the ambient air of the city of Messina. In order to study the air pollution in some crucial areas of the city of

Messina, has been improved the method of a Pollution Index, weighted mean of the most critical air pollutants, carbon monoxide, benzene, particulate matter PM_{10} and ozone. This index may be useful for communicating to citizens information about the state of air quality of a waste urban area. The highest values of the Pollution Index were relative to the urban areas interested everyday by an enormous road traffic, such as the area near the docking of the shipping society and the area near the highways. High values of pollution have been calculated in the winter period, that is the most critical period for road traffic in the city. A statistical analysis of the index trends was also effectuated.

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