# ROUGH SET ANALYSIS APPLIED TO THE STUDY OF AIR POLLUTANTS IN URBAN AREAS

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## ABSTRACT
This work shows the application of an innovative technique of quantitative analysis, the Rough Set Analysis, to the study of carbon monoxide (CO) and thin powders (TSP) concentrations in different areas of the town of Gela (Caltanissetta, Sicily, Italy). Apart from analysing the season variations in the considered pollutants emissions, the application of the Rough Sets methodology allows us to explain the air pollution caused by urban traffic, in terms of relationships between the above-mentioned substances and the meteorological substances which are mainly responsible for the their concentration. Moreover, such technique shows the results in terms of "if…, then…" sentences, which are easily comprehensible and lead to the making of preventive choices. The great flexibility of this methodology makes it suitable for useful applications in the future. It can also help to devise actions which aim at the improvement of the urban air quality management.

## INTRODUCTION
Air pollution in urban areas is one of the most important problems of the contemporary society. Indeed, nowadays most people live in medium-large towns and in many areas conurbations are growing; these are made up of big and small towns which are closer and closer and more and more interrelated. They can be considered as real mega-cities, even if they don't fall under the traditional administrative and statistical classification (1). As we know, the quality of the air is the result of a complex interaction between natural and anthropogenic environmental conditions, and such phenomenon is even more evident in those towns characterized by a mosaic of different areas (historical centre, modern quarters, parks, industrial area, agricultural suburbs etc.) with characteristic physical and environmental parameters (architecture, mobile and fixed emission, precipitations, etc.): each of them can be considered a distinct ecosystem.
The principle sources of urban air pollution are: industries, heating but above all transports, which produce most of the total suspended particles (TSP) (70-80%) and contribute to the urban emission of $NO_2$, for more than 60%, and CO, for more than 90% (2). Despite a general decrease in the fixed sources of emission in the last 20 years, the increase in the number of vehicles, though catalytic, and kilometres covered have counterbalanced the positive effect in a more or less remarkable way, in relation to the different pollutants (3-4). The phenomena of dispersion and dilution of the emissions are essential to the quality of the air and to diminish the effects of air pollution in urban areas, in order to protect the citizens health. Such phenomena are strongly related to meteorological variability conditions, in particular wind direction and speed, turbulence and stability of the atmosphere, air temperature and humidity (5-6). Given the importance of such meteorological variables, the main purpose of this work is to investigate, through a modern analytical methodology (the Rough Sets Analysis), the relations existing between the three major pollutants, which are commonly present in urban areas, and other parameters, at the time of their monitoring. In particular, we considered temperature, humidity degree, wind speed and monitoring time. The Rough Sets Analysis, is a quantitative methodology which was introduced by Pawlak, in the early eighties (7). It can provide an exhaustive explanation of phenomena which can be analysed as comprehensible decisional rules of the "if….then…" kind, through which the relations existing among the analysed variables are shown. Compared to other quantitative methodologies, this can be considered innovative because it allows you to analyse both quantitative and qualitative data and to

find the most significant information in order to explain the analysed problem, thus removing the superfluous or redundant data, without altering the quality of information (8-9). At the same time, the observation of some objective parameters, which are present in the rules, allows the decider to find the most significant relations among the variables considered, thus providing useful suggestions to improve the quality of the air. The interesting results obtained through previous applications of this method both to the same pollutants (10-13) and to other kinds of emissions (14), in high-risk industrial areas, led us to employ it for the analysis of urban areas air pollution as well.

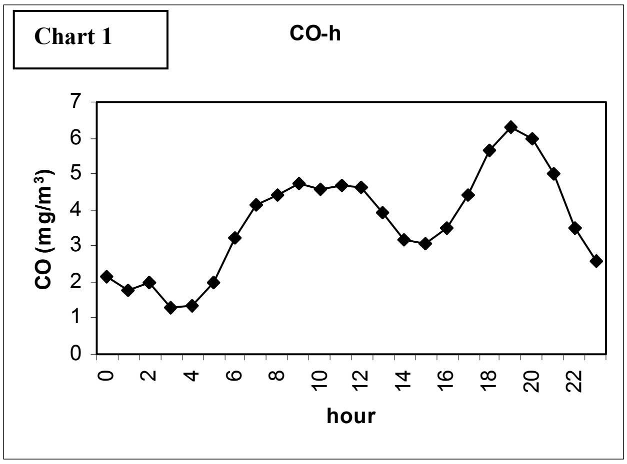
## ANALYSED DATA

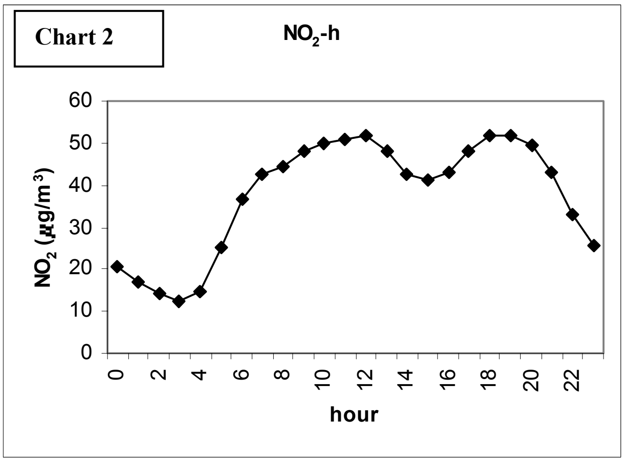
The urban area we studied is the town of Gela, in the province of Caltanissetta, in the southern part of Sicily, whose extension is about 4 kilometres. Gela is the fifth town in Sicily, as to the number of inhabitants (about 78.970 residents), and it has one of the biggest petrochemical industrial poles of southern Italy, which has exposed the environment of the area to serious risks. For this reason, a national decree has been recently passed, defining the features of those combustibles which can cause air pollution and the technological features of combustion plants (15). The monitoring net in Gela, a town with a high traffic volume (about 43.000 vehicles are present) was created in 1982 and, until 1992, was made up of 5 stations, while at present it has 9 stations (7 are scattered in the town territory and 2 in Niscemi, which is about 20 kilometres away). They continuously measure the principle pollutants (CO, $SO_2$, $NO_2$, $O_3$, $C_6H_6$, VOC) and some meteorological parameters, in conformity with the M.D. 20$^{th}$ May 1991, sending the hourly data to a processing centre (C.E.D., Data Processing Centre). In this work which analyse the air pollution, we carbon have considered three pollutants, representing the most important chemicals substances for the urban pollution (16): monoxide (CO), nitrogen dioxide ($NO_2$) and the total suspended particles (TSP). The reason of such a choice are various: indeed, the concentration of these substances (17-18) in the atmosphere is often high, exceeding the alarm thresholds which have been set and also because these pollutants are not season related and therefore can be measured during the whole year. They are compounds with different characteristics: CO is a primary pollutant, always present in the atmosphere, whose concentration are mainly due to car traffic and home heating; while $NO_2$ has both primary and secondary pollutant features, since it derives by photochemical processes, according to the atmosphere reactivity which is determined by particular meteorological conditions (19). The atmosphere particulate is completely different. Indeed, especially in its smallest dimension ($PM_{10}$ e $PM_{2,5}$), this is probably the most dangerous pollutant for the effects it has on human health (epidemiological studies have shown its strict relation to heart and breathing disease) (20-22), but it is also one of the most difficult pollutants to study, because of the variability and complexity of its composition (among its principle components we can find: sulphates, nitrates, minerals, ammonium, organic and elementary carbon, metals and bio-aerosol) (23).
The threshold values we considered are: for the particles 40 $\mu g/m^3$, which was established by the EC directive 1999, in force since 1$^{st}$ January 2005 (24), for $NO_2$ 40 $\mu g/m^3$ , in force since 1$^{st}$ January 2010, and for CO 10 $mg/m^3$ according to the recent MD of 2$^{nd}$ April 2002 n. 60 (25); such severe threshold values have been established by European and National laws, in order to protect human health in urban environment. In order to monitor the presence of the three pollutants we used different analytical methods, according to the pollutant considered: absorption in the infrared for CO, chemiluminescence for $NO_2$ , gravimetric analysis for TSP. We took into account a two year period: in fact we analysed the hourly average data in the years 2001-2002; the analysis has been carried out studying, , the exceedings in the attention level in relation both to the month and the hour, for the station n. 5 in Venezia street; this is at the entrance of the town, on the north ring road, which is an important junction and crossroads.

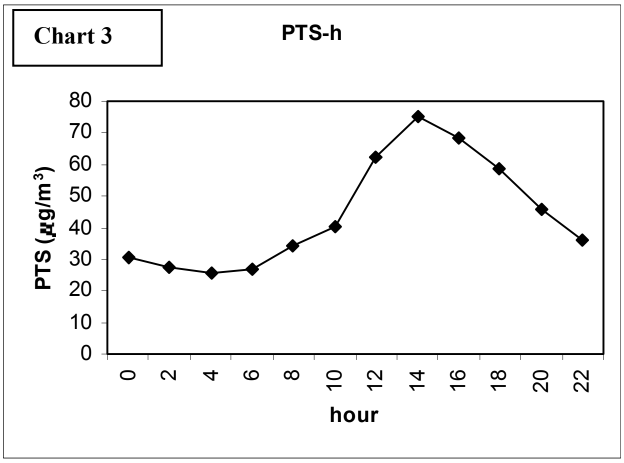
## RESULTS AND DISCUSSIONS

In order to study the trend of the emissions during the day, we calculated the hourly average concentrations of the polluting emissions distributed during the 24 hours (charts 1-3). Chart 1 shows that the CO hourly average data per day don't exceed the threshold limit established by the law (10 $mg/m^3$). In any time of the day, even if the highest quantity of this pollutant can be found in the hours between 8 a.m. and 2 p.m. and between 6 p.m. and 9 p.m.; during this latter interval, the concentrations are higher than in the previous one, while the lowest concentrations can be found between 10 p.m. and 5 a.m.

**Charts 1-2-3: hourly trends of CO, $NO_2$ e PTS average concentrations**




These results reflect some tests to other samples in different Italian towns (26). Chart 2, instead, shows the relation between the hours of the day and the arithmetic averages of $NO_2$; in this case the trend is bi-modal, and the exceeding of legal limits (40 $\mu g/m^3$) coincides with the rush hours, that is from 8 a.m. to 2 p.m. and 6 p.m. to 8 p.m.; while the lowest concentrations can be found at night, between 10 p.m. and 5 a.m. We can notice that such trend is very similar to that we observed for CO. However, unlike the latter, we can find here some values which exceed the legal thresholds (this happens, above all, during the hours with the highest percentage of car traffic, which probably is responsible for such emission). Chart 3 analyses the particles' trend during the whole day. We can notice that the legal alarm thresholds is exceeded many times (40 $\mu g/m^3$); the trend is rather constant from 10 p.m. till 11 a.m., while it is rising in the afternoon hours, with a peak at two p.m. (equal to 75 $\mu g/m^3$ about). Therefore it is clear that the fall in emission intensity due to a decrease in traffic during the night, allows the fraction of rough particles to sediment. As a consequence the concentration (27) of particles decreases and this means that their presence is related to the number of circulating cars. From the analysis of CO hourly average concentrations referred to the years 2001-2002, we noticed that the legal alarm and emergency thresholds were not exceeded (Chart 1). For this reason, we did not consider this pollutant for the application of the Rough Sets Analysis, since it doesn't show any difference in the values distribution, while we applied this methodology to the study of information concerning TSP and $NO_2$ . From the initial database provided by C.E.D of Gela, whose information concern the concentrations of the above-mentioned pollutants and the meteorological data concerning the town of Gela, we considered the data relating to 4 different times, homogenously distributed during the day (6 a.m., 12 p.m., and 6 p.m., midnight). The meteorological variables, which are considered as conditional attributes like the months and the hours of reading, are those which mainly influence the falling to the soil of the dangerous substances: wind speed, air temperature and humidity, daily measured at the above-mentioned hours. These data were then collected in six databases, each of them containing the information concerning the two-month periods of the two years considered. On applying the Rough Sets Analysis, we carried out two different elaborations. In the first one, $NO_2$ is considered as dependent variable (decisional criterion, D) and TSP as independent variable (conditional criterion, A); in the second one the particles are considered as decisional criterion, while $NO_2$ is considered as conditional criterion, in order to study the possible relations existing between the two substances.

As required by the Rough Sets Approach, which employs classical methodology and the dominance relation (8-9), the data concerning the meteorological variables have been suitably discretised in 4 classes of equal number, on the basis of the probability distribution obtained. As to the information concerning the pollutants, these have been discretised into three classes, taking into account the alarm and the emergency thresholds defined by the MD 60/2002 (25). Lastly the data concerning the months and the daily hours have been divided into 6 and 4 classes respectively.

The symbols used in the tables and their meanings are given as follows:

**R**= number of the rule; **A1** = Wind speed (m/sec): **1.**from 5,108 to 14; **2.**from 3,625 to 5,107; **3.** from 2,142 to 3,624; **4.** from 0 to 2,141. **A2** = TSP ($\mu g/m^3$): **1.** <= 40; **2.** from 40,01 to 50; **3.** > 50 (tab.1); **A2** = $NO_2$ ($\mu g/m^3$): **1.** <= 40; **2.** from 40,01 to 200; **3.** > 200 (tab.2) **A3** = Months **: 1**. January-February; **2.**March-April; **3.** May-June; **4.** July-August; **5.** September-October; **6.** November-December. **A4**= Hour of reading : **1.**= 0.00; **2.** = 6.00; **3.**= 12.00; **4.**= 18.00; **A5**= Air relative degree of Humidity (%): **1.**from 0 to 71,604; **2.** from 71,605 to 84,619; **3.** from 84,620 to 93,303; **4.** from 93,304 to 100. **A6** = Air temperature (°C): **1.** from 0 to 14,141; **2.** from 14,142 to 17,738; **3.** from 17,739 to 21,336; **4.** from 21,337 to 32.

The last column of the tables has been called D, which represents the decisional criterion $NO_2$ (Table 1) and TSP (Table 2). The decision classes are the same as the thresholds concerning the attribute A2. The interesting results we obtained are shown as tables (tables 1-2), in order to provide the reader with a concise and comprehensible representation of the decisional rules obtained with confidence equal to 100% (that is the certainty, from a probabilistic viewpoint, that we obtain a determined value of the decisional criterion, considering the values of the attributes and/or the conditional criteria that are present in the rules).

**Table 1: Rules obtained with decision attrib. D=$NO_2$**

| RULE | A1 | A2 | A3 | A4 | A5 | A6 | D |
|---|---|---|---|---|---|---|---|
| 1 | ≥ 3 | ≥3 | 1 | | | 1 | ≥2 |
| 2 | ≥ 3 | ≥2 | 1 | 4 | | 1 | ≥2 |
| 3 | ≥ 3 | ≥2 | 2 | 3 | | | ≥2 |
| 4 | | | 3 | 3 | 2 | 4 | ≥2 |
| 5 | ≥ 2 | ≥3 | 4 | 3 | | | ≥2 |
| 6 | ≥ 2 | ≥3 | 5 | 3 | | | ≥2 |
| 7 | ≥2 | ≥3 | 5 | 4 | | | ≥2 |
| 8 | ≥2 | | 5 | | 1 | | ≥2 |
| 9 | | ≥3 | 5 | | 3 | | ≥2 |
| 10 | ≥2 | ≥3 | 5 | | 2 | | ≥2 |
| 11 | ≥2 | | 5 | 4 | | 3 | ≥2 |
| 12 | | | 5 | 4 | 3 | 3 | ≥2 |
| 13 | ≥4 | ≥2 | 6 | | | | ≥2 |
| 14 | ≥4 | | 6 | 4 | | | ≥2 |
| 15 | ≥3 | ≥2 | 6 | 4 | | | ≥2 |
| 16 | | ≥2 | 6 | 4 | 4 | | ≥2 |
| 17 | ≥3 | ≥2 | 6 | | | 2 | ≥2 |

**Table 2: Rules obtained with decision attrib. D=PTS**

| RULE | A1 | A2 | A3 | A4 | A5 | A6 | D |
|---|---|---|---|---|---|---|---|
| 1 | ≥ 4 | ≥ 2 | 1 | 4 | | | ≥2 |
| 2 | ≥ 3 | | 1 | 4 | 3 | | ≥2 |
| 3 | | ≥ 2 | 2 | 3 | 3 | | ≥2 |
| 4 | | | 2 | | | 4 | ≥2 |
| 5 | | ≥ 2 | 3 | 3 | 4 | | ≥2 |
| 6 | | | 3 | 3 | 3 | 4 | ≥2 |
| 7 | | ≥ 2 | 5 | 3 | 4 | | ≥2 |
| 8 | ≥ 3 | ≥ 2 | 1 | | 3 | 2 | ≥3 |
| 9 | | | 1 | 3 | 4 | 2 | ≥3 |
| 10 | ≥ 3 | | 2 | | 3 | 3 | ≥3 |
| 11 | | ≥ 2 | 3 | | 4 | 4 | ≥3 |
| 12 | ≥ 4 | | 6 | 4 | 4 | | ≥3 |

This is how to read a rule: rule n. 1 of table 1 shows that: "if the wind speed is 3.62 m/sec. at maximum and if the particles' concentration is higher than 50 μg/m$^3$ (emergency threshold) and we are in January-February, with an air temperature ranging from 0° C and 14.14°C , then $NO_2$ is more than 40 μg/m$^3$ (alarm class)". As we can notice in the tables, the phenomenon of the two pollutants concentration is quite complex, since more attributes or criteria are necessary to describe each rule.
The rules concerning $NO_2$ concentration are described in table one. The class of this pollutant has values which are higher or equal to 2 (alarm), since we didn't find any rules with 100% confidence that can describe the pollutant in different classes. As the database has been split up into 6 subsets, according to the period, the Attribute 3-month is always present in the 17 rules found. However, the differentiated presence shows that the phenomenon of the pollutant concentration doesn't vary with the passing of time. Instead, the attribute which seems to have more influence on the description is the wind speed. Indeed, showing values inferior or equal to 3.6 m./sec., it indicates a negative correlation with the pollutant's values that can be found in the rules. On the other hand, there seems to be a positive relation between the particles and the $NO_2$ concentration, since like $NO_2$ , even the criterion A2 is on medium-high level. The relation with the hours of the readings is also significant, as A4 can be found in classes 3 and 4, that is between 12 p.m. and 6 p.m., when most of the vehicles are circulating. This result has been also confirmed by other studies in different urban areas (19). Instead the relations between $NO_2$ and air humidity (A5) and temperature (A6) have little relevance, since they describe the same decision class with different values. Unlike table 1, table 2 describes two different decisional classes (alarm and emergency), concerning the values of the particles; even in this case, the observations about the previous table in relation to the wind speed attributes, can be made in the analysis of the particles values, since we can find higher concentrations during the less windy periods, no matter what the months are (attribute 4), which are present in the description of the rules. This result can also be found in other kinds of analyses carried out in different urban areas. It is also interesting to notice that during the summer months (July-August) the particles concentration is not high (28), unlike the other months (29). The relation between $NO_2$ and TSP is again rather positive, with the only difference that, this time $NO_2$ represents the independent variable, and the particles represent the dependent variable. Now, the analysis of the particles through the conditional attribute, shows that the TSP has alarm or emergency values at 12 p.m. and 6 p.m. as we have already seen in $NO_2$ . But the most substantial differences concern the relation with humidity. Here the medium-high values of the conditional attribute in question point out that the particles are on alarm or emergency levels (in effect, as to Table 1 we didn't make the same considerations). Lastly, the air temperature attribute in itself cannot explain the TSP levels in Table 2, since the medium-high values of this decisional criterion are matched with temperature with different kinds of values.

## CONCLUSIONS

In order to provide a correct explanation of air pollution phenomena, it is fundamental to have a wide knowledge and a good ability in interpreting the meteorological variability, which has a primary importance in determining the pollutants concentrations and movements in metropolitan areas. In particular, this can be applied to urban areas like the one we have studied (Gela). During the nineties this town has implemented several PUTs (Urban Traffic Plan) in order to improve the quality of the traffic, respecting the laws which compel to minimize the emissions. This has resulted into the adoption of a series of physical and organizational interventions, aiming at suggesting people how to behave according to the town's needs. Considering the very complex reality of the area we have examined, we wanted to suggest that rather than stopgap measures (block or limits), which are useless to reduce the present pollution levels, it would be better to implement measures to improve the environment in big cities. These measures could include incentives to use public transport or private vehicles which employ with low carbon density fuel (LPG; methane), the optimisation of car pooling, incentives for the renewal of the car park, the rationalisation of the urban traffic, the extension of paying parking areas in order to discourage the use of private means of transport, the development of local infrastructures (regional railway) (30). All these measures aim at improving the conditions of car traffic (circulation and parking) and road safety (less car accidents), while reducing air and noise pollution and saving more energy. The attention to the quality of the air has become one the most important factors in order to protect and improve the quality of life in towns. The interesting decisional rules we have found can be very useful in order to plan measures to improve the quality of the air in the area. Moreover, they could turn useful in the presence of the most severe meteorological variables, which are mainly responsible for the accumulation of the pollutants we have analysed.

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