Environmental Assessment of a Wide Area Under Surveillance with Different Air Pollution Sources

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Abstract— **Campania region, Southern Italy, is a wide and critical area affected by environmental problems and characterized by different levels and sources of air pollution. The main tasks of the paper are: first, the compilation of the emission inventory of this Region, and second, the evaluation of air quality and the individuation of agglomerates and zones characterized by similar air quality levels. For the first task, the atmospheric emission inventory was performed by using a bottom-up approach, focusing at regional level instead of national; the pollutants produced from different sources were achieved through direct measures for the most important industries, while for diffused sources the emissions were estimated. Emissions from road transport sector, that are the most difficult to calculate depending on many variables, were estimated with a technique that implements the COPERT methodology. For the second task, in order to calculate the polluting concentrations and to assess the air quality state all over the Region, the analysis was carried out by using the Gaussian model ISC. The environmental zoning has assembled all communes in macro areas, revealing four reclamation zones and one observation zones, for which reorganization strategies will be necessary to the aim to catch up the established limits. This modelling approach can be considered as an important assessment tool for the local environmental authorities, because it can be applied in order to evaluate the compliance of air quality with the limit values and the influence of various emission categories on air quality.**

Index Terms—**dispersion models, emission inventory, environmental zoning, road transport sector.**

I. Introduction

A simplified and robust approach to assess the air quality state and the amounts of pollutants emitted from several sources in an Italian critical region was needed for use in environmental risk assessment. The improvement of the environment is chief objective of the Europeans politics; the most recent European and Italian legislative decrees that have regulated the environmental matter are oriented to planning and determination of the more opportune strategies for health safeguard and for ecosystem protection. It appears understandable, therefore, that the environmental programming must use appropriate cognitive instruments to estimate the air quality state and the origins of air pollutions in order to support prevention and reorganization decisions. In this context, the inventory of emission sources and the environmental zoning of the territory are fundamental cognitive element for the planning activity and for air quality management.

In Campania region, Southern Italy, there were identified four National Interest Priority Sites (NIPSs), with different levels and sources of pollution. In this area a high level spotted air contamination is moreover due to the legal and outlaw industrial and municipal wastes dumping, with hazardous consequences also on the quality of the air and water table. Moreover there is a general perception of health risks due to the contamination of human food and air due to surface depositions of particles from waste combustion; recent studies carried by the International Society of Doctors for the Environment evidenced a significant increase of human cancers in two provinces of this region.

This study is characterized principally from two phases. The first objective was to produce an air pollutants emission inventory for the Region Campania (Italy), with a bottom-up approach, focusing at regional level instead of national, then including local and definite parameters. This inventory expressly include a distribution in space, with communal disaggregation, for all the emissive sources, classified in different categories. Among these, two categories of emission sources were taken into account in great detail: mobile sources (meaning the road traffic) and stationary sources (mainly industry and power plants). These sources, in fact, represent in many European country the lion part of the anthropogenic emissions for the contaminants considered in this paper: carbon monoxide, nitrogen oxides, particulate matter (PM_{10}), and volatile organic compounds.

The emissions from the most important industrial systems were estimated with the availability of direct measures, while for the main diffused sources the pollutant emissions were calculated on the basis of opportune activity indicators for each specific emissive activities and of pertinent emission factors. In this study emissions from road traffic, that in Europe are almost always an important fraction of the total emissions, were estimated as accurately as possible implementing the COPERT methodology [1].

In general, an atmospheric emission inventory can be described as a collection of data related to the emissions of pollutants into air. These data must include the chemical identity of the pollutants, a quantification of the human or natural activity responsible for the emission, the emission factors or the information needed for their calculation, the location and the temporal variation of the emissions for each

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activity [2]. On the other hand, emission inventories are also important cognitive element in order to organize the input data for atmospheric dispersion models which, according to the Directive, can be used to estimate air quality under well-specified conditions, that is the object of the second phase of this paper. Besides, these dispersion models and emission projection scenarios are the only tools existing to forecast the agreement of future limit values established by laws.

The second phase of this study fits exactly in this context and consists in the definition of the air quality state all over the territory of the Region Campania by integration of the available data resulting from the emissions inventory with a dispersion model. This analysis was carried out by using the well-known Gaussian model ISC, that has determined the pollutant concentrations due to the principal industrial systems (namely punctual sources) and to the main diffused sources [3]; validation of these estimated concentrations was done by reference to real measurements [4]. Subsequently, through the comparison of the resulting air quality state with the actual air standards, the regional territory was subdivided in zones (environmental zoning). All the results obtained in this study for Region Campania are important tools for studying air quality and to set up plausible remediation strategies in areas characterized by nonattainment of the limit values established by legislation.

II. Theory

A. *The Emission Inventory*

The emission inventories are becoming more and more important in order to achieve the requirements of the European Directives regarding air quality. Emission inventories, in fact, are useful tools to identify the zones for which a non-respect of the limit values is predicted [5], since they give direct information of the emissive pressure that insists over a territory. Such inventories constitute a technological, economic and territorial data collection, which concurs to individualize the pollution sources (industrial, civil, transports, etc.), their localization with spatial disaggregation (regions, provinces and towns), the amount and typology of the polluting substance. At European level the emission inventories are compiled following the CORINAIR methodology [6]. The activities responsible for the emissions are grouped according to the SNAP97 (Selected Nomenclature for Air Pollution, version 1997) codes.

The emissions of the main air pollutants in this study were estimated from fuel combustion sources and non-combustion sources as part of anthropogenic activities: transformation (power) sectors (electricity and heat production, oil refineries, and other energy and transformation industries); industry sectors (including iron and steel, chemical and petrochemical, non-ferrous metals); transport sectors (including aviation, roads, railways, and shipping); and other sectors (including agriculture, commerce and public, residential and domestic). In this study the amounts of pollutants emitted from various sources in the zone under investigation were obtained through direct and continuous measures where possible, otherwise through estimates. The direct measure of the emissions, generally, were carried out only for the principal industrial systems. The industrial sources, usually schematized as punctual sources, generally refers to larger industrial facilities that are governed by permits or regulations; questionnaires were sent to the main industries to get data on possible point sources. For all other sources, called diffused sources, emissions of a particular species were estimated as a product of the activity data, emission factors, and removal efficiency of emission controls [7]. Region specific emission factors for several emission species from subdivided source sectors were compiled from a wide range of literature, such as AP-42 [8], the IPCC Guideline [9] and the EMEP/CORINAIR Emission Inventory Guidebook [6]; these emission factors were then used to estimate emissions in Campania.

Among the diffused sources, a considerable fraction of the emissions in industrialized countries is due to road transport sector, in particular in urban areas, despite extensive actions world-wide to decrease these emissions during the last two decades [10]. In spite of their importance, the emissions estimate from road transport are very difficult to calculate because they depend on many variables, characterized by a high degree of uncertainty. The uncertainties are both inherent to the emission factor equations (which depend on pollutant, vehicle type, fuel type, inspection and maintenance programs) and are also due to the several variables required for their estimation (fuel consumption, total mileage, driving patterns, climatic factors) and the uncertainties of all these variables. For this reason in this study emissions from road traffic were estimated as accurately as possible, implementing the COPERT methodology, the most usually employed software in Europe for official national inventories of emissions from road traffic [11].

This methodology [12] permits the estimation of the emissions for 230 vehicle categories belonging to the five main classes: passenger cars, light duty vehicles, heavy duty vehicles, urban buses and coaches, and two wheelers. Vehicles belonging to such main classes are then distinguished according to the fuel type, the EU Directives to which they conform in terms of emissions, the cylinder capacity and other variables. COPERT calculates the total emissions of exhaust gases by summing emissions from three diverse sources, namely the thermally stabilized engine operation (hot emissions), the warming-up phase (cold start emissions) and due to evaporation. Since vehicle emissions depend on the engine operation, exhaust emissions are calculated as a function of average speed and for three driving conditions: urban, rural and highway [13].

The COPERT methodology can be employed to calculate a traffic emission inventory with both a top-down approach and a bottom-up approach. For countries for which the needed input data aren't accessible at low level, it is more suitable the top-down approach that first estimates a global (national level) value before refining the results by distributing them over the different regions to be modeled, with the help of available proxy data. For countries where the required input is attainable at smaller levels it is appropriate to make use of this data and then to apply a bottom-up approach that considers first the single emissions to finally combine them in the last step and obtain the global emissions. In this study the COPERT methodology was used with a bottom-up approach; however, application of the methodology at higher spatial resolution can be done only when more full and detailed data are available.

B. The Dispersion Model

The dispersion models are calculation tools that allow to describe in simplified way the phenomena of the pollutant dispersion in atmosphere. The inputs of the model are the meteorological data (opportunely processed) acquired from the weather stations, and the polluting emission (from inventory); the output will be the concentration of the same pollutant in a specified point of the territory object of the simulation. The choice of the models to use for the simulation of the pollutant dispersion depends on various factors, the main ones are: the detail and the accuracy of the available database (emission inventory, meteorological factors, air quality data), the morphological complexity of the investigated area, the characteristics of the emissive sources, field of application (urban, rural or industrial), the detail of the results that are desired to obtain [14].

The model proposed for the specific requirements of this analysis is the well-known Gaussian model ISC (Industrial Source Complex). Although the fundamental assumption of the Gaussian approach, that is the normal distribution of the concentrations, comes true in absolutely ideal conditions of atmosphere homogenous turbulence, the models that are based on this hypothesis are instruments of widest employment because they are characterized from a simple and practical use. On the other hand, the Gaussian method sure turns out not much suitable to deal situations characterized from not homogenous atmospheres, complex orography and unstable pollutants.

The ISC Short Term model provides options to model emissions from a wide range of sources that might be present at a typical industrial source complex. The basis of the model is the straight-line, steady-state Gaussian plume equation, which is used with some modifications to model simple point source emissions from stacks, emissions from stacks that experience the effects of aerodynamic downwash due to nearby buildings, isolated vents and multiple vents.

For the specific requirements of this analysis the ISC model was used in the long-term version. The ISC long-term model makes the same basic assumption as the short-term model, and uses input meteorological data that have been summarized into joint frequencies of occurrence for particular wind speed classes, wind direction sectors, and stability categories. In the long-term model, the area surrounding a continuous source of pollutants is divided into sectors of equal angular width corresponding to the sectors of the seasonal and annual frequency distributions of wind direction, wind speed, and stability

III. Results and Discussion

A. The Emission Inventory in Campania

The objective of this phase was to produce an air pollutants emissions inventory. In this study, as also above exposed, the amounts of pollutants emitted in Region Campania from the principal industrial systems (schematized as punctual sources) were obtained through direct measures. These direct measure of the emissions were performed by the same main industries that subsequently sent extended and detailed data on possible point sources (the main stacks). These territorial data collection concurred to individualize the industrial pollution sources, their localization with spatial disaggregation and the amount and typology of the polluting substance. The maps of Fig. 1 and Fig. 2 show the emissive levels of CO and NO_X for the main industrial systems in the Region with their spatial localization.

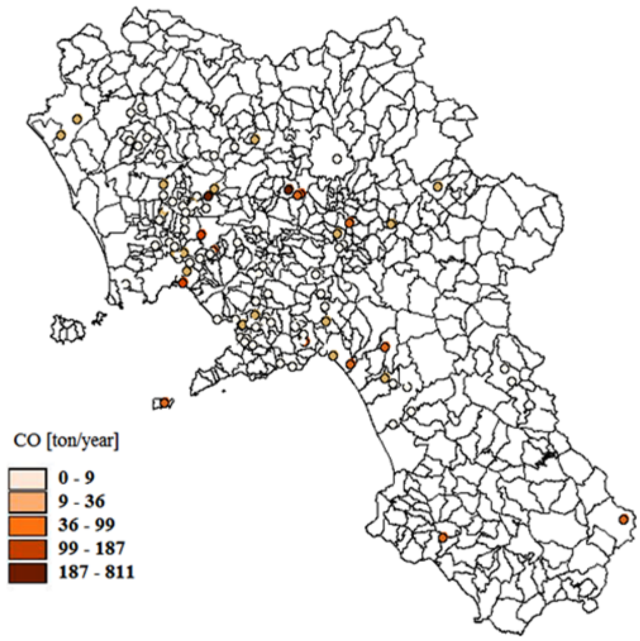

Fig. 1. Localization of the different industrial sources in Campania and their emissive levels of CO

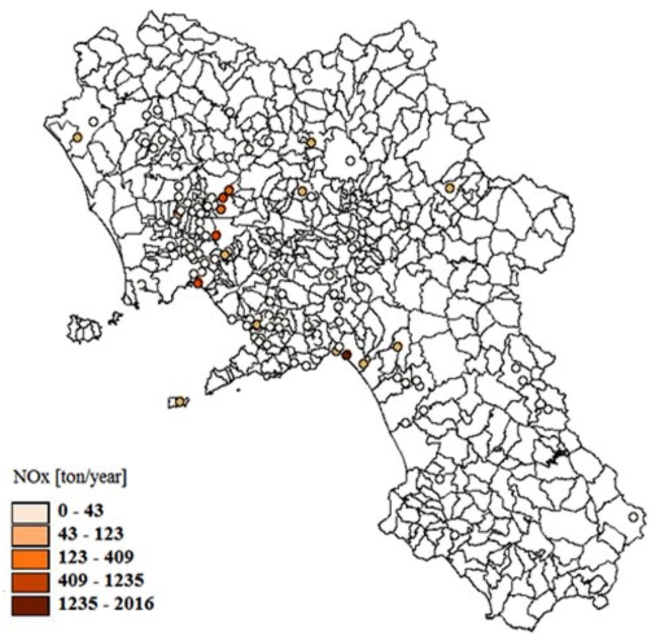

Fig. 2. Localization of the different industrial sources in Campania and their emissive levels of NO_X

These sources included above all industrial boilers and power plants running on fuels as diverse as natural gas, liquefied petroleum gas, coal, and diesel. The emissions were calculated for every single source and, in the following step, all the emissions from sources located in the same municipality were added. It's manifest that the most important industries are located mainly in the industrial area around Napoli and Caserta and its surroundings.

For the diffused sources (small industries, heating systems, natural sources, urban road traffic) the emissions were estimated on the basis of opportune activity indicators and fixed emission factors concerning specific emissive activity in this region, collecting information, mainly statistical, also from a lot of other agencies or institutions. Since the substantial contribution to total emissions in Italy and in each European country is due to vehicle traffic, and then in order to quantify in detail the environmental impact attributable to the road transport, particular attention was focused on this sector (SNAP Sector 07). For the road transport sector, in this study, the COPERT methodology was used with a bottom-up approach, focusing at municipal level instead of national, then including local and specific parameters relating to vehicular fleet, driving patterns, medium trips, average vehicle speed and fuel consumption.

The collection of these necessary input data to calculate the emissions from road transport in the Campania Region (Italy) has required the support of agencies and institutions. Data about the number of vehicles regularly registered were provided by ACI (the Italian Automotive Association) and were adjusted through percentage reductions to be applied to vehicles PRE EURO, necessary to represent vehicles of this category actually circulating in Italy [15]. The values of others variables, such as the average speed on each road type and the percentage of mileage traveled on each of road type, were acquired from ISPRA (the Italian Institute for Environmental Protection and Research) studies on transportation [16] . The emissions due to cold starts were estimated considering minimum and maximum temperatures for each month in Campania Region.

Total emissions calculated for the road transport sector and for all the other SNAP Sectors in Campania are summarized in Table I. This Table shows the amount of the main air pollutants (CO, VOC, NO_X and PM_{10}) emitted from diffused and punctual sources, expressed in tons per year, and disaggregated for CORINAIR sectors of activity.

The analysis of these results show clearly that for Region Campania a considerable part of total emissions is due to contribution of road traffic; the road transport sector contributes for about 49% and 41% of CO and NO_X total emissions respectively, while regarding the total emission of VOC and PM_{10} it's responsible for about 12% and 24% of these pollutants. In Region Campania, as in other regions of southern Italy, in fact, the replacement of vehicle fleet is very tardy if compared to other Italian regions, resulting in clear consequences on air quality [17]. On the other hand, in relation to the composition of diesel passenger cars, more promising results were noticed; the diesel passenger cars, in fact, are on average newer than the gasoline passenger cars.

TABLE I
TOTAL EMISSIONS OF MAIN AIR POLLUTANTS OVER CAMPANIA DISAGGREGATED FOR CORINAIR SECTORS

SNAP SECTOR	CO [t]	COV [t]	NOx [t]	PM_{10} [t]
Combustion in energy and transformation industries	176	87	1627	143
Nonindustrial combustion plants	5805	538	2082	1488
Combustion in manufacturing industries	4268	405	9121	1345
Production processes	529	2419	558	818
Extraction and distribut. of fossil fuels/geother. energy	49	1900	48	5
Solvent and other product use	0	38334	5	1
Road transport	45817	9493	32466	2122
Other mobile sources and machinery	33077	10783	34106	2606
Waste treatment and disposal	172	875	37	51
Agriculture	808	10625	15	84
Other sources	2959	5016	1	175
Total	*93660*	*80476*	*80066*	*8838*

To summarize the main results of the other sectors, in Campania CO is mainly emitted by road transport sector, followed by non-road traffic, namely aviation and shipping (35%), natural gas and GPL combustion in the residential sector (6%), and industrial sources burning oil, natural gas or GPL (5%). Gasoline passenger cars provide more than 46% to the total emissions of CO from the road traffic, due to their large total mileage respect to other vehicle class (27%), and to the fact that in urban environment they travel at low average speed, consequently combustion is not efficient [18,19]. About NO_X emissions, non-road traffic was the largest emissive sectors (43%), while industrial oil and natural gas use emits for about 11%.

Examination of sector contributions to PM_{10} emissions reveals that emissions from non-road traffic sector contributed 29%, while oil and GPL combustion in the residential sector, and industrial sources (burning oil, coal or GPL) emit for about 17 % and 15%, respectively. About PM_{10} emissions, in Campania there is an evident reducing rate of emissions from coal and oil combustion in the domestic sector and a growing rate of emissions from diesel passenger cars [20]. About VOC emissions, solvent and paint use, non-road traffic and agriculture sectors contributed 48%, 13% and, 13% respectively, to the totals.

All results, from punctual and diffused sources, were finally combined in ArcGIS® to produce maps of the emissive levels obtained in Region Campania with spatial disaggregation of municipal type. This was done by adding the values pollutant by pollutant in order to get the total emissions for each town of the region.

In Fig. 3 and Fig. 4, with regard to the emission inventory of CO and NO_X drawn up for Campania from all sources and activity sectors, the final results are shown; the total value of the main polluting emissions are disaggregated for municipality.

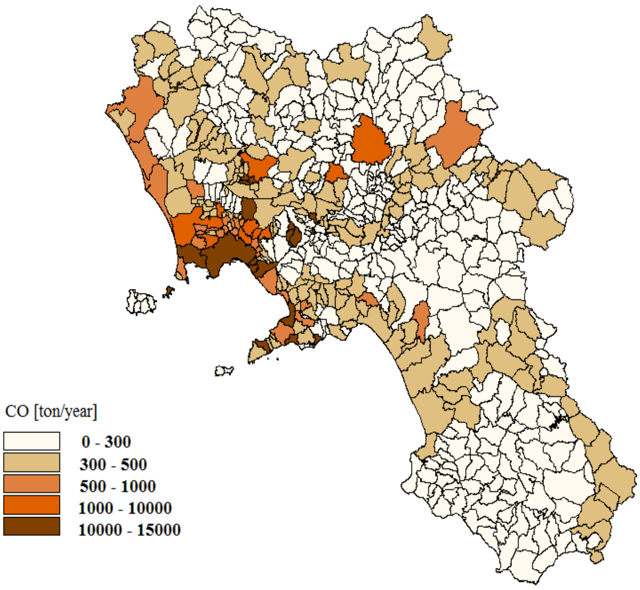

Fig. 3. Distribution of CO total emission over Campania with communal spatial disaggregation

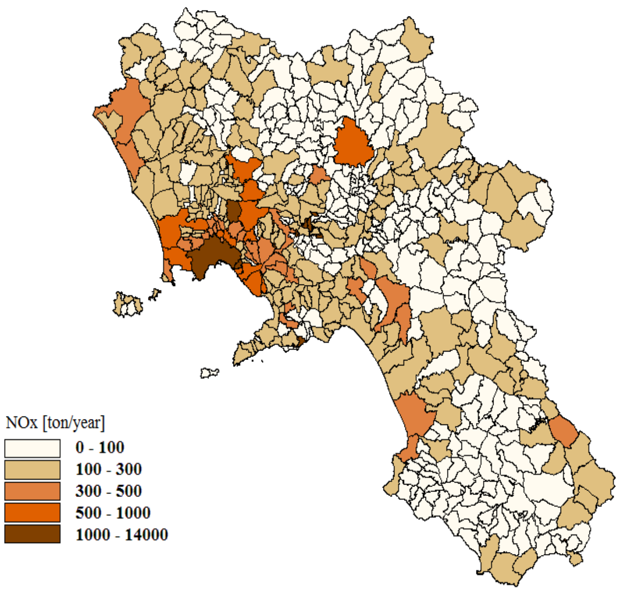

Fig. 4. Distribution of NO_X total emission over Campania with communal spatial disaggregation

About the spatial distribution of the emissive levels, the maximum values of the emission density were estimated in Naples and Caserta surroundings. The main sources of atmospheric pollution located in these areas are: vehicle traffic (also due to a dense network of road and motorways around these two main cities), non-road traffic (harbors and airports) due to a system of maritime connections and an airport, industries (located mainly in the industrial area around Naples and Caserta and its surroundings) burning natural gas, oil and coal that emit mainly CO, NO_X and PM_{10}

This emission inventory is very useful since it gives a direct indication of the pressure insisting over the regional territory, helping in the identification of areas with similar pollution problems. These results, in fact, can be used to study future scenarios that include the impacts of changing populations and of new commercial developments (i.e., to predict environmental changes). Such information is also very helpful for assigning impact significance, prescribing mitigation measures, and designing and developing environmental management plans and monitoring programs.

B. The Model Prediction of Pollutants Dispersion

As shown in the previous paragraphs, predicting the ambient air quality impacts of pollutant emissions requires an assessment of the transport, dispersion, chemical transformation, and removal processes that affect pollutant emissions after their release from a source. In order to define the air quality state all over Campania region, under well-specified conditions resulting from the available data of the emission inventory, the analysis was carried out by using the Gaussian model ISC [21]. The gas atmospheric dispersion was analyzed on maps with meshes of 1 km x 1 km, characterized by receptors positioned at 2 m altitude. Under these conditions the application of the model determined the pollutant concentrations due to the principal industrial systems (namely punctual sources) and to the main diffused sources all over the territory. The main results of the simulations provided by the model are shown in the map of Fig. 5, in which it's possible to gain the estimated concentrations of NO_X in every mesh of the reticulum of the Naples-Caserta zone since, as already presented, the main sources of atmospheric pollution and the maximum values of the emission density are located in these areas.

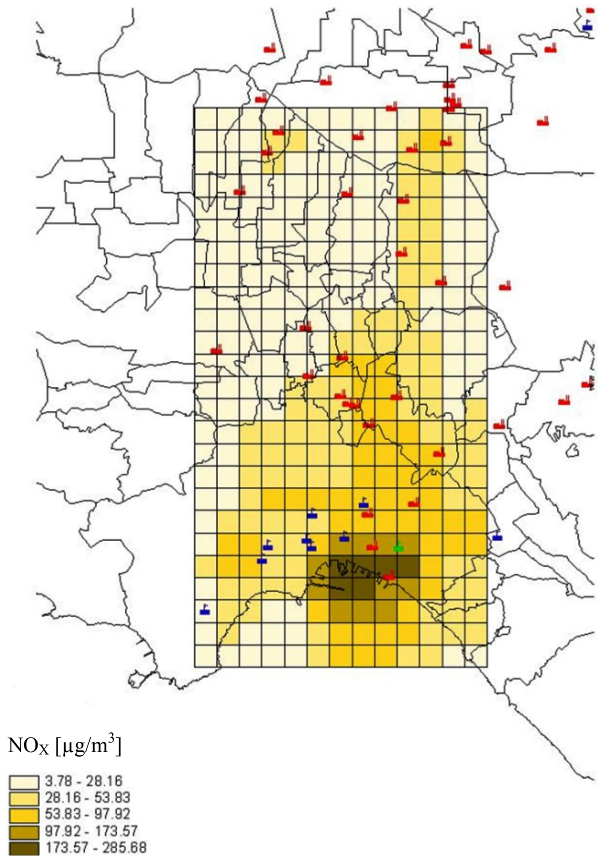

Fig. 5. NOx concentrations [$\mu g/m^3$] estimated through ISC dispersion model

The legend in the bottom left-hand corner show the average values of the estimated pollutant concentrations under the actual on-site meteorological conditions. The meteorological data needed to run these simulations like wind speed and direction, temperature, humidity, properly processed, were collected at the Naples airport weather station (green symbol in the figures); atmospheric stabilities (Pasquill's classification of stabilities, A–F) were compiled from the hourly wind speeds, cloud cover and solar insolation.

Validation of these results was done by reference to real measurements. Initially a set of air monitoring stations were selected as significant in order to generalize the measures detected from these stations all over the regional territory [22]. Subsequently these stations, representative of the most polluted areas of the territory (and located in the figures with blue symbols), were attributed to specific meshes 1 km x 1 km of the same reticulum used for the spatial dispersions of the pollutant emissions. For these meshes, the real measured concentrations were compared with predicted values of the models, so calculating the percentage differences that were always below 15 %, then acceptable [23].

Ultimately, by application of simulation model all over the regional territory and for all pollutants, the territory environmental zoning was obtained (shown in Fig. 6), through the comparison between the air quality present background (that it's emerged by means of the estimate mathematical model) and the existing law standards, therefore individualizing the more critical zones of the Region in which the value of the pollutants exceeds the limit fixed from the environmental legislation in force, definite reclamation zones. In this figure, it's remarked as the Campania territorial zoning has assembled all communes in macro areas, revealing four reclamation zones and one observation zone, for which reorganization strategies will be necessary to the aim to catch up the established limits.

Starting from these results it will be possible to formulate remediation plans in the zones for which a nonrespect of the limit values is foreseen, while maintenance plans must be set up for the rest of the regional territory. In this way, the atmospheric emission inventories and the territory environmental zoning become a primary and essential cognitive element for the air quality management and they are also necessary to set up remediation programs in areas characterized by pollution problems.

IV. Conclusions

The main aim of this study was to supply a valid environmental programming instrument in order to characterize and individualize the major responsible sources of air pollution in Region Campania (Italy). This paper has described, in a first step, the pollutant emission inventory estimated for each activity of this Region, producing maps with spatial disaggregation of municipal type. In a second phase, this study has explained the territory environmental zoning, estimating the air quality state to local scale through the use of a dispersion model, and assembling all communes in macro areas, so revealing four reclamation zones and one observation zone

The analysis of the results shows clearly that for Region Campania a considerable part of total emissions is again due to contribution of road traffic. All the results obtained in this study, besides, are important tools for studying air quality in Region Campania and in order to set up possible remediation plans in areas of this region characterized by nonattainment of the limit values established by legislation. In fact, the same procedures and simulation models can be used to examine strategies oriented to the air quality improvement; so new emissive background will be defined according to the adoption of new environmental laws and to the virtual implementation of low environmental impact technologies in the several analyzed fields (transports, productive activities, energy, etc.).

Future changes in pollutant emissions and in the air quality will be affected intensely by the evolution in anthropogenic emissions, that are always regulated by economic growth, environmental policy, and future application of emissions controls. However, despite substantial advancements in fuel and engine technology to curb car exhaust, the deteriorating air quality in urban areas are still largely dominated by traffic emissions [24]. For this reason, the decline in pollutant emissions and concentrations in Region Campania could occurred as a result of the adoption of ever more stringent emission control standards on mobile source pollutants and the implementation of technologies (e.g., catalytic converters) and government programs (e.g., periodic inspection and maintenance of on-road vehicles) to achieve standards.

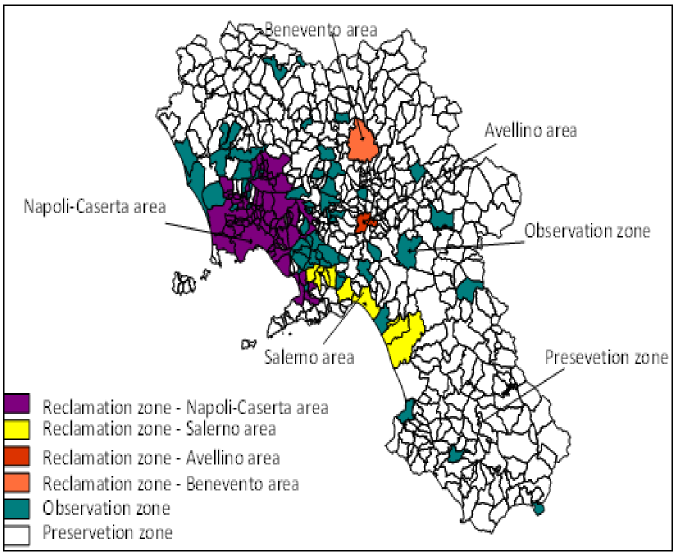

Fig. 6. Environmental zoning of Region Campania

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