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Air Quality Monitoring Network for Tracking Pollutants: the Case Study of Salerno City Center

Daniele Sofia, Aristide Giuliano*, Filomena Gioiella

Sense Square srl, Corso Garibaldi 33, Salerno, 84123, Italy
aristidegiuliano@sensesquare.eu

In urban cities it is common to find a series of substances in atmosphere responsible to cause damages to human health. These substances are constantly produced by human activities and they focus mainly on urban and/or metropolitan areas. Low-cost sensors have a great potential to revolutionize the way to monitor the exposure of the population to the atmospheric pollution because they offer the ability to collect temporal and spatial data. In fact, one of the challenges associated with these data coming from this kind of source is to try to make them more general by combing them in the form of a network. In this work a dispersion model is used to test the distribution of dusts (2.5 μm) at the level of the individual points of network. The chosen monitoring area is in a seaside town of South Italy. The monitoring network is composed by three sensory systems located in some relevant points for anthropic activity. We have applied an interpolation model to determine the areas of greatest pollution concentration in the monitored area. The model simulated the pollution movements at the level of the individual monitoring points. Furthermore the model has also considered the meteorological conditions.

1. Introduction

Nowadays in urban cities a series of substances are found in atmosphere responsible to cause damage to human health. These substances are continually produced by human and industrial activity and they are localized mainly in metropolitan areas. Among the atmospheric pollutants responsible of direct damages to human health, the particulate matters are more dangerous especially the powders with diameter less than 10 μm, PM 10 and less than 2.5 μm, PM 2.5. These substances are mainly concentrated in metropolitan area and their amounts are frequently higher than the threshold values imposed by local regulations. The possible causes lied in the vehicular traffic, the industrial plants emissions and heating of buildings. People are worried about the effects on human health of possible atmospheric pollution caused by the gaseous emissions of combustion plants (Giuliano et al., 2018). Therefore accurate measurements of the pollutants concentrations are essential not only from an environmental point of view, but also for economical reasons since a part of taxation may be dependent on the emission values (Salehi Kahrizsangi et al., 2015; Sofia et al., 2013). In literature some models for assessing city environment exposure are described such as proximity-based models, interpolation models, land use regression models, line dispersion models, integrated emission-meteorological models and hybrid models combining personal or household exposure monitoring with one of the preceding methods (Jerrett et al., 2005). Unfortunately, the development of air quality monitoring networks is hindered by the high costs and large dimensions of nodes (monitoring stations) that make impossible to install them in particularly critical locations (such as densely populated urban centers). Moreover, the reduced number of data makes the forecasting models more generic for a large territory losing the peculiarity of air pollution linked to a single and restricted area. Recent advances of tunable all solid state laser systems and Lidar technique (Light Detection and Ranging) opened new perspectives in the 3D-analysis of atmospheric pollution dynamics. However, 3D mappings of concentrations of pollutants have been obtained, allowing a direct access to the physical and chemical dynamics of air pollution (Frejafon et al. 1998). Besides their detection, these species have to be tracked along neighboring areas by the use of dispersion models (Lauret et al., 2016). Furthermore, low-cost sensors offer the ability to collect temporal and spatial data and they have

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a great potential to revolutionize the way to monitor the exposure of the population to the atmospheric pollution (Cariou et al., 2016).

In this work an analysis of the data obtained after the installation of monitoring networks in a seaside town of South Italy (Salerno) was carried out. In particular, we focalized on one of the most dangerous pollutant for human health that can be found in atmosphere, the PM 2.5. In fact, due to their small diameter, the fine particulate matter may cause greater adverse human diseases especially at cardiovascular and respiratory level. Therefore the objective of monitoring campaign is to inform citizens about the air that they breathe and consequently promote actions to reduce air pollution.

In this paper, a Gaussian dispersion model of pollutions was proposed in order to validate the results obtained after air monitoring in three relevant points for anthropic activity (Ciarlo et al., 2017) where sensory systems of the monitoring network are previously located. The first objective is to examine the monitoring area in terms of PM 2.5 concentration in order to obtain the areas exposed to higher concentrations and to find the sources of pollution. The second objective is to understand the effect of distributed to concentrated sources.

2. Materials and Methods

2.1 Monitoring stations

The stations for air quality monitoring systems are composed by sensors able to detect fine powders concentration (PM 2.5). They are combined with temperature, humidity, pressure and wind direction sensors in order to simplify the elaboration of pollution dispersion model. In particular, the fine powders sensors are based on the use of laser source that crosses an air flow sampled from the outside. The air arrives through a suction system in the measuring chamber. When a particle crosses the beam, it switches the invested light in all the surrounding space (laser scattering), with an intensity and spatial distribution that depends on the diameter of the particle.

2.2. Sensor Networks

As shown in Figure 1, the three selected points are: Teatro Verdi (1), Duomo (2) and Portanova (3). These points have been selected in areas that are heavily affected by human activity to assess the population's exposure to PM 2.5.

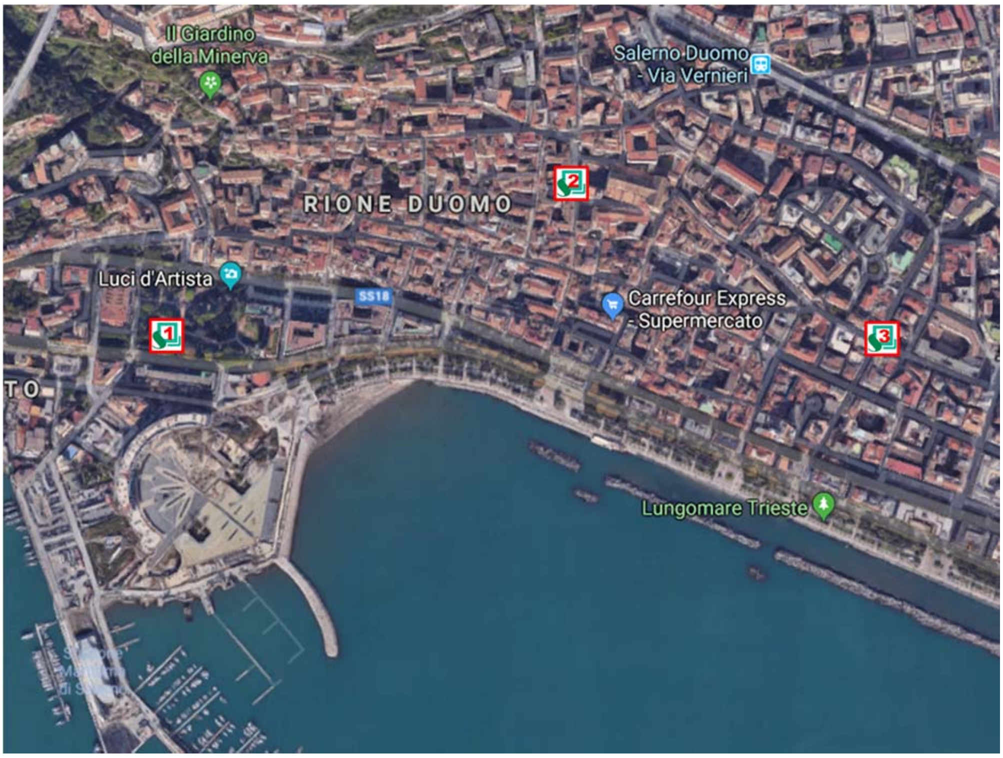

Figure 1: Air quality monitoring station network with spatial and temporal high resolution localized in Salerno city: 1) Teatro Verdi, 2) Duomo, 3) Portanova.

2.3. Model description

In this work, we used the Operational Street Pollution Model (OSPM) in order to test the model in single monitored streets (Silver et al., 2013). Briefly, the main components of the OSPM are summarized as follows. For the pollutant PM 2.5, the concentrations are modeled as Eq(1):

$$C = C_{bg} + Q_{trf}\,(C^*_{dir} + C^*_{rec}) \tag{1}$$

where:

- C: concentration at the receptor point (μg m^{-3});
- C_{bg}: background concentration (μg m^{-3});
- Q_{trf}: emissions from traffic per street length (μg m^{-1} s^{-1});
- C*: a function of meteorology, traffic speed and volume and street geometry (units: s m^{-2}). This is composed of the direct (C^*_{dir}) and recirculation (C^*_{rec}) components.

The concentrations of PM 2.5 represented the pollutants obtained by vehicular and high temperature combustions (industrial or heating emissions).. In the C* term the C^*_{dir} is calculated assuming a Gaussian plume as Eq(2):

$$C_d = \sqrt{\frac{2}{\pi}}\frac{Q}{W\,\sigma_w}\ln(\frac{\sigma_z}{h_0}) \tag{2}$$

where Q is the rate of release of emissions in the street, W is the street width, σ_z is the vertical dispersion parameter at the receptor point, h_0 is a constant indicating the height of initial pollutant dispersion and σ_w is the vertical velocity fluctuation considering the mechanical turbulence generated by wind and vehicular traffic in street (Wei and Qin., 2010).

The contribution from the recirculation vortex (C^*_{rec}) is calculated by a box model as Eq(3):

$$C_r = \frac{Q}{W}\frac{L_r}{\sigma_{wt}\,L_t + \; u_t L_{s1} + u L_{s2}} \tag{3}$$

where L_r, L_t, L_{s1} and L_{s2} are dimensions of the recirculation zone and σ_{wt} is the ventilation velocity of the canyon (Wei and Qin, 2010). In particular, the recirculation vortex forms only under certain conditions, governed by the wind speed and direction, as well as the canyon geometry. Furthermore, in order to determine the size of the recirculation zone the wind speed and direction are considered as meteorological parameters. The wind direction and speed are considered as follows: on the windward side, C* consists of the recirculating component (possibly with a contribution from the direct component, depending on the length of the recirculation zone) while on the leeward side C* is the sum of the direct and recirculating components. Both sides account for the urban background. The function C* also has a contribution from traffic-produced turbulence, which depends on the speed and volume of the traffic, as well as the frontal area of the vehicles. Meandering of the wind direction is also accounted for in C*, as the wind direction is not expected to remain constant during the 24 h time steps.

2.4. Model inputs

The number of cars, vans, trucks and buses were available for three points for each hour of all days. We also considered the proportion of cold starts and the mean travel speeds at each hour of the day. Vehicle emission factors and vehicle fleet composition are based on the European COPERT IV emission model (EEA, 2009). As background concentrations, we considered the diffusion dispersion coefficients due to vehicular traffic.

3. Results

First of all, an improvement of traditional laser scattering technique is realized. In Figure 2 and in Table 1 a data comparison between the “traditional” technology (i.e. gravimetric technique) and laser scattering is performed.

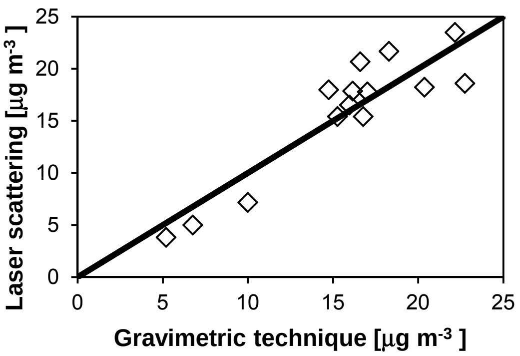

Figure 2: Comparison between the "traditional" technology (i.e. gravimetric technique) and laser scattering improved by Sense Square.

Table 1: Data comparison between gravimetric and laser scattering technique.

Gravimetric	4.2	6.06	6.01	15.26	14.74	14.74	15.96	16.77	17.02	17.02	18.29	20.37	22.75	22.17
Scattering	3.8	5.98	7.16	15.41	15.24	15.97	16.52	15.41	17.77	17.77	21.66	18.22	21.59	23.48

The results showed a good correlation between two technologies with a relative average error between 2 and 7%. The error of this typology of apparatus (laser scattering) is generally due to humidity level of sampled air, which causes the sensor to overestimate the concentrations of fine particles. The monitoring campaign period in Salerno city lasted two months (November-December 2016). In Figure 3 a significant part of this monitoring campaign are reported. In particular, from the data obtained during the monitoring campaign, we have chosen one of the weekends with greater impact and their recorded data are compared with weekdays ones. The experimental results are related to the anthropic activities in the monitored area. In particular, the graphs showed the PM 2.5 particle distribution obtained by using the software R the statistical model Kriging during the most successful days with the sensor networks mentioned above. The greater PM 2.5 concentration from the south-east of the city center is recorded in Figure 3a corresponding to a day of the weekend. On the contrary, at the midweek no PM 2.5 accumulation is found in any part of the monitored territory (Figure 3b).

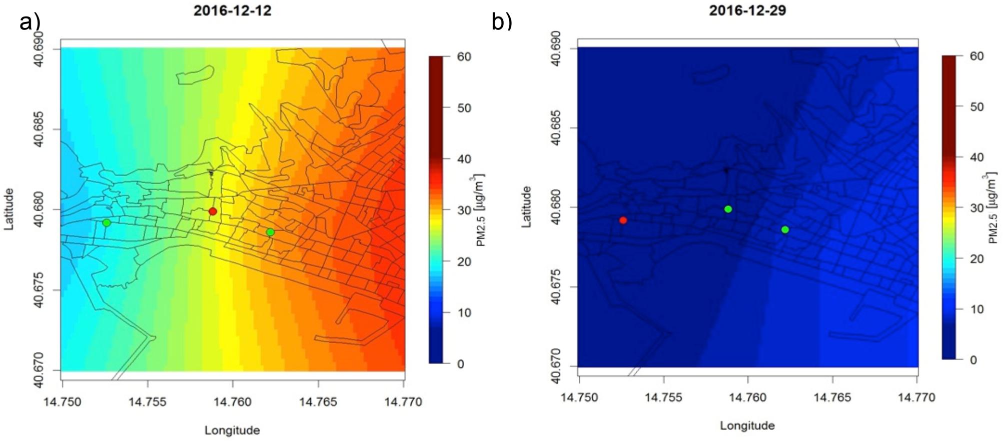

Figure 3: PM 2.5 concentrations in a weekend (a) and weekday (b).

The maximum-recorded concentration during the weekend is equal to 50 µg m^{-3} while a low concentration between 0 and 18 µg m^{-3} is recorded during the midweek (the Figure 3b is all blue). The higher PM 2.5 concentration recorded during the weekend is in agreement with the greater intense anthropic activity of the weekend compared to weekday in the analyzed zone. In particular the maximum concentration of the midweek day is 62% lower than the weekend.

More in detail, a concentration profile of PM 2.5 in three selected points is shown in Figure 4 a, b, c.

The measurements of PM 2.5 concentrations are made every 2 minutes in a time frame from 11 a.m. to 11 p.m. The three graphs show a concentration decrease of dusts during the night period and a peak corresponding to the beginning of the anthropic activities. Furthermore it is recorded a concentration reduction of investigated particles during working hours and subsequently a progressive increase due to the vehicular traffic after the working activities. In all the graphs there is the presence of the double peak at similar times corresponding to the beginning and the end of the work activities; in all cases there is a reduction in the average concentration at night. More in detail, in Figure 4 a, b in addition to the maximum peak we also note a higher concentration of the PM 2.5 probably due to the urban orography of the monitored points.

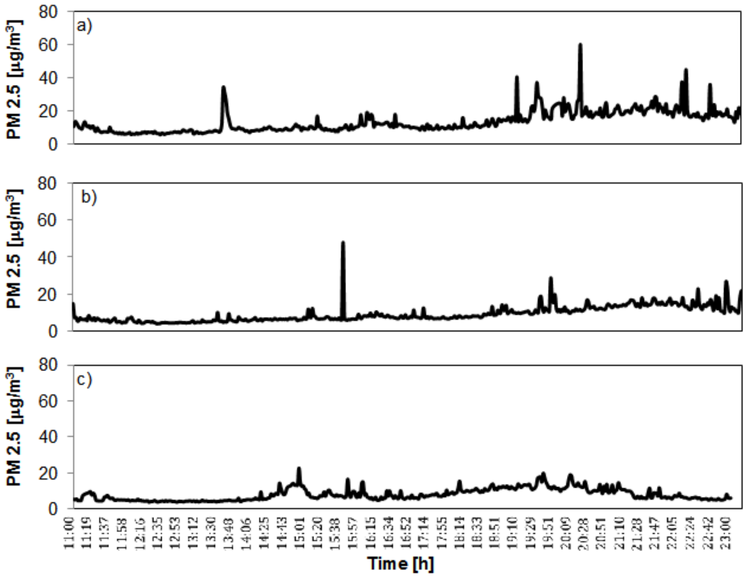

Figure 4: PM 2.5 concentration profile in Portanova (a), Duomo (b) and Teatro Verdi (c) recorded on Sunday 17th of December.

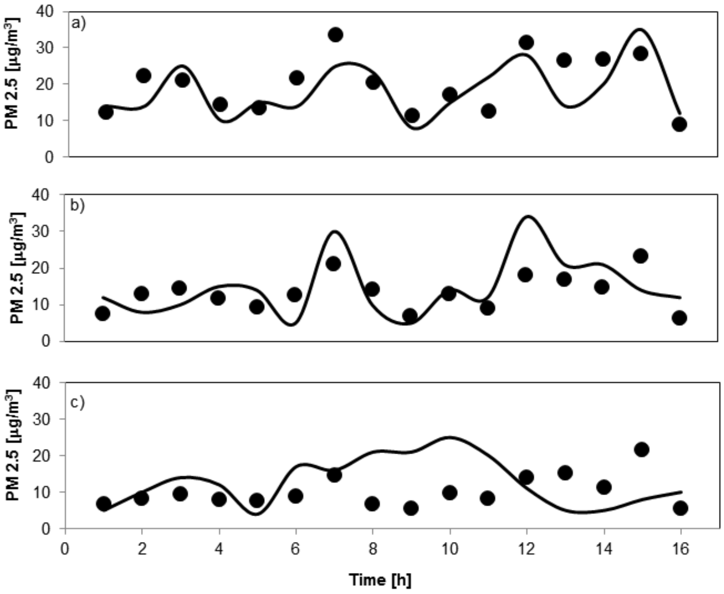

Figure 5: Comparison of experimental and modelled results of PM 2.5 concentrations in Portanova (a), Duomo (b) and Teatro Verdi (c) monitoring stations.

Finally the daily average of PM 2.5 concentration levels measured in the three station points is compared with OSPM predicted values (Figure 5). The model is able to predict concentration trends of PM 2.5 especially in the case of first two monitoring points Portanova (Figure 5 a) and Duomo (Figure 5 b). In the last point, Teatro Verdi monitoring station (Figure 5 c) there is not a correspondence between the model and the experimental data only in some days probably due to different urban conformation compared to other locations. In fact Teatro Verdi is closer to the sea and to a park, which probably helps to remove a part of the PM 2.5 in atmosphere.

4. Conclusion

In this work an analysis of the data obtained after the installation of monitoring networks in Salerno city was carried out. In detail, after an improvement of laser scattering technique, a methodology was put forward to employ OSPM for prediction of PM 2.5 levels. The successful application of the methodology was confirmed by comparison with measurements.

Furthermore a statistic model was used to evaluate the PM 2.5 concentration in the monitored area. In particular, the average concentration is higher in weekends, as expected, due to an increase in anthropic activities. The point of greatest concentration is almost always the Portanova monitoring station. Applying the dispersion model to the experimental data, we can see how the model is able to predict the trend based on the hypotheses carried out mainly in the case of Duomo and Portanova monitoring stations but less in the case of Teatro Verdi station. The reason is probably due to different urban conformation compared to other locations.

References

Cariou S., Fanlo J.L., Stitou Y., Buty D., Saman, D., Akiki R., 2016, Application of ODEMS (odorant dispersion and emissions monitoring system) to measure odorous emissions from composting plant, Chem. Eng. Trans., 54, 241–246.

Ciarlo G., Bonica E., Bosio B., Bonavita N., 2017, Assessment and testing of sensor validation algorithms for environmental monitoring applications, Chem. Eng. Trans., 57, 331–336.

EEA, 2009, EMEP/CORINAIR Atmospheric Emissions Inventory Guidebook, Chapter on Exhaust Emissions from Road Transport, Version June 2009, Methodology for COPERT 4. Technical Report, European Environmental Agency, p. 128.

Frejafon E., Kasparian J., Rambaldi P., Vezin B., Boutou V., Yu J., Ulbricht M., Weibauer D., Ottobrini B., de Saeger E., Kramer B., Leisner T., Rairoux P., Woste L., Wolf J.P., 1998, Laser applications for atmospheric pollution monitorin., The European Physical Journal D, 4, 231-238.

Giuliano A., Gioiella F., Sofia D., Lotrecchiano N., 2018, A novel methodology and technology to promote the social acceptance of biomass power plants avoiding Nimby Sindrome., Chem. Eng. Trans., 67.

Jerrett M., Arain A., Kanaroglou P., Beckerman B., Potoglou D., Sahsuvaroglu T., Morrison J., Giovis C., 2005, A review and evaluation of intraurban air pollution exposure models, Journal of Exposure Analysis and Environmental Epidemiology, 15, 185-204.

Lauret P., Perrin M., Heymes F., Aprin L., Slangen P., Pey A., Steinkrauss M., 2016, Atmospheric powder dispersion in an urban area, Chem. Eng. Trans., 48, 91–96.

Salehi Kahrizsangi H., Sofia D., Barletta D., Poletto M., 2015, Dust generation in vibrated cohesive powders. Chem. Eng. Trans. 43, 769–774.

Silver J.D., Ketzel M., Brandt J., 2013, Dynamic parameter estimation for a street canyon air quality model. Environ. Model. Softw. 47, 235–252.

Sofia D., Giuliano A., Barletta D., 2013, Techno-Economic Assessment of Co-gasification of Coal-Petcoke and Biomass in IGCC Power Plants, Chem. Eng. Trans. 32, 1231–1236.

Wei H., Qin Z., 2010, Using the OSPM Model on pollutant dispersion in an urban street canyon, Advances in atmospheric sciences, 27, 621-628.