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Air quality monitoring and control in complex environments by advanced and integrated system

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Abstract Large civil engineering projects, such as the construction and expansion of Ports are strategic actions for the social and economic development of territories. Air gaseous emissions are among the most important environmental pressures linked to all stages of these projects. Prolonged exposure to air pollutants can cause respiratory disease, nausea, reduced resistance to infections and increased fatigue in humans. Advanced real time monitoring systems are thus needed in order to control the emissions and avoid potential negative impacts. The research presents and discusses the identification and application of an advanced and integrated multi-criteria environmental system for the air quality continuous monitoring in sensitive area. The experimental activities are carried out with reference to a real case study of the Port of Salerno (SA). Conventional and emergent air contaminants are measurred by fixed monitoring stations and mobile laboratories. All data are collected and transmitted in real time on a specifically designed spatial information system (SIT). The results of four years of analysis and monitoring are presented. The proposed system highlights the importance of developing and implementing integrated multi-criteria monitoring plan in order to be effective and guarantees environmental protection and data transparency.

Keywords: air pollution; continuous monitoring; particulate matter; port area.

1. Introduction

Environmental air pollution is responsible of more than 4.2 million premature deaths each year. (Zarra et al., 2010; Cordova et al., 2021; Edwards et al., 2022). Furthermore the 80% of the planet's urban population lives in cities that don't meet their standards in terms of air quality (Naddeo et al., 2013; Kousis et al., 2021; World Health Organization, 2021). Prolonged exposure to high concentrations of air pollutants can cause a variety of adverse health effects such as respiratory disease, emphysema, bronchitis and asthma, wheezing, chest pain, headache, nausea (Zarra et al., 2012; Stanek & Brown, 2019; World Health Organization, 2021). Thus, air quality issues are extremely important for both human health and the environment (Zarra et al., 2009; Mueller et al., 2011). Seaports play a key strategic role in the development of world economies, but at the same time they are among the most important sources of anthropogenic atmospheric emissions (Yang et al., 2022; Bachvarova et al., 2018). The different sources, direct or indirect, are represented by transport ships, cargo trucks, cranes, cargo handling equipment (Mocerino et al., 2020). While the main air pollutants emitted are particulate matter (PM), nitrogen oxides (NO_x), sulfur dioxide (SO_2), carbon monoxide (CO), as well as other harmful emerging pollutants such as vanadium (V), nickel (Ni) and polycyclic aromatic hydrocarbons (PAH) (Merico et al., 2021). Ports that, also in relation to the changed needs and the necessity of increasing trade and new transport methods, are continuously subject to modernization and expansion works, thus adding to ordinary air emissions also those additional ones due to the works. Port areas, moreover, which are often located in direct contact with residential areas, making the problem of atmospheric emissions even more important to address. It is therefore clear the need to control the atmospheric emissions of port areas, or to monitor air quality in relation to the considerable number of existing sources, in order to avoid significative negative impacts on the exposed population and related ecosystems. Monitoring that is also essential to support decision-making processes, to choose between different interventions to be adopted, both for expansion and mitigation. Air quality monitoring in complex areas that is still a challenge for the modern community, in relation to the lack of standardized or univocally defined and universally recognized systems and procedures (Zheng et al., 2016). As well as at the current state of research, there are only a few air quality data available for port areas, thus making it difficult to identify the best plan protection actions or intervention strategies.

The research presents and discusses the development and application of an advanced and integrated air quality monitoring system (*aiAQMS*) applied to a complex area, with the aim of helping to overcome the existing lack of information and the highlighted critical issues. The experimental activities are carried out with reference to a real case study of the Port of Salerno (SA), during the port enhancement works. The port expansion works, the architecture of the advanced monitoring system and main air quality data of a 4 years monitoring activities, are highlithed and discussed.

2. Port of Salerno: site area and enhancement works

The port of Salerno (Campania Region, Italy) is located in one of the oldest areas of the city of Salerno and has very ancient origins dating back to Roman times. The port is in direct contact with a densely populated residential and tourist area of the city of Salerno, as well as being close to valuable environmental landscapes and directly connected to the famous Amalfi Coast: an area of great natural beauty and rich in sites of community importance, declared UNESCO World Heritage.
The current structure of the port comprises four piers: Manfredi, Levante, Ponente and Trapezio. While with regard to the functional set-up, the port of Salerno offers different services and types of traffics, such as passengers and goods. In order to meet the new needs defined by the evolution of maritime transport and linked mainly to the development of container ships of ever-increasing size, the port has been subject to important modernization and expansion works. The works, which began in 2020 and were completed in 24 months, were subject to the Environmental Impact Assessment procedure. Three macro-interventions were planned: the enlargement of the port entrance, the extension of the Molo Manfredi and the deepening of the seabed. The port mouth widening intervention was aimed at allowing longer ships to enter the port basin. To this end, the resection of the sub-billow pier was planned to bring the size of the mouth to about 310 meters, and, to ensure greater protection of the basin from the foreseeable increase in wave motion within it, the extension of the breakwater pier for about 200 meters was planned. The deepening of the seabed, instead, was aimed at allowing vessels with a draft equal to or greater than 14 meters to enter the port basin. The total maximum volume dredged, including overdredging, was about 3.2 milion m^3.

3. Advanced and Integrated Air Quality Monitoring System (*aiAQMS*)

The objective of the proposed advanced and integrated air quality monitoring system (*aiAQMS*) is the continuous characterization and control of the air quality. In the presented research, the *aiAQMS* is tailored for the monitoring of the air quality in the area of the porto of Salerno, during the enhancement works. Specifically, the System is realized in order to implement an air quality monitoring plan in the three design phases, identified in accordance with the Environmental Impact Assessment procedure: ante-operam (AO), during construction (IO) and post-operam (PO).
Figure 1 identifies the number and location of sampling and monitoring points identified for air quality control (ATM0i) and the types of monitoring stations installed.
The monitoring points were identified on the basis of the environmental impact study elaborated from the port authority, taking into account the specificities of the territorial and environmental context, so as to allow the characterization of air quality in the peri-port area concerned and to represent the potential impacts on the atmospheric component attributable to construction site operations and the movement of road and sea vehicles.

Figure 1. Identification and location of the monitoring points and typologies of monitoring stations.

In total, 6 air quality monitoring and control points have been identified.
3 monitoring points (ATM01-03) have been located within the port area, to monitor air quality at the emissions, in direct contact with the sources. Fixed air quality monitoring stations have been installed for these points. While 3 monitoring points (ATM04-06) have been located outside the port area, in direct contact with sensitive areas and receptors, to control the quality of the air at the immissions. These points were monitored through the use of a special Mobile Monitoring Laboratory called seedAIR.
Table 1 shows, for the three phases of the project, the frequencies, durations and number of monitoring campaigns implemented.

Table 1. Monitorng campaigns

Phase	Phase duration	Campaign		Total number of campaigns
		Frequency	Duration	
AO	4 months	2 months		2
IO	24 months	half-yearly	30 days	4
PO	24 months	half-yearly		4

In total, 10 campaigns were planned, lasting 30 consecutive days, for each of the monitoring points (ATM01-06), for a total of almost five years of monitoring.
Figure 2 shows the list of monitored pollutants, for each of the monitoring stations, with the relative acquisition criteria and reference regulatory limits.

PARAMETER	ACQUISITION CRITERIA	MEDIATION PERIOD	CONCENTRATION
PM_{10}	24 hours	24 hours	**50 µg/m³**
	24 hours	Annual	**40 µg/m³**
CO	Average hourly value	24-hour hug hog the 8-hour moving average	**10 mg/m³**
NO_2	1 hour	1 hour	**200 µg/m³**
		1 hour (measured over 3 consecutive hours)	**400 µg/m³**
		Annual	**40 µg/m³**
NO_x	1 hour	Annual	**30 µg/m³**
SO_2	1 hour	1 hour	**350 µg/m³**
		1 hour (measured over 3 consecutive hours)	**500 µg/m³**
		Daily average	**125 µg/m³**
		Annual	**20 µg/m³**
Benzene (C_6H_6)	24 hours	Annual	**5 µg/m³**
Ozono (O_3)	1 hour	1 hour	**180 µg/m³**
		24-hour high of the 8-hour moving average	**120 µg/m³**
Arsenic	24 hours	Annual	**6,0 ng/m³**
Cadmium			**5,0 ng/m³**
Nickel			**20,0 ng/m³**
Benzo(a)pyrene	24 hours	Annual	**1,0 ng/m³**

Figure 2. List of the monitored air pollutants

The monitored air pollutants are determined with the analytical methods in accordance to the current regulations. As highlighted in table 2, the investigated air pollutants include carbon monoxide, sulfur dioxides, nitrogen oxides, benzene, ozone, PM10 particulate matter, as well as emerging pollutants such as arseinc, cadmium and nickel.

In order to allows the continuous visualization of the measured data, allowing immediately intervention in case in case of exceeding the limits, a specific spatial information system (*SIS*) has been elaborated. The SIS can be consulted remotely (www.mapsa.it), and reports not only the raw data collected, but also some immediate graphic elaborations, in order to promptly visualize the results.

4. Results and Discussions

Figures 2, 3 and 4 show respectively, the mean of the daily mean concentrations of PM10, calculated with reference to the daily mean values measured in the entire monitoring period, referred to the three project phases (AO, IO and PO), at all monitoring stations , and the principal average wind direction detected during the same phases at monitoring station ATM02.

The results show that the mean of the average daily concentrations of PM_{10} increased slightly from about 15 µg/m³ to 29 µg/m³ at stations ATM01, ATM02, ATM03, ATM04 in the transition from the AO phase to the IO phase, to a maximum value of about 35 µg/m³ in ATM01 in PO phase. In addition, a slight decrease was observed at station ATM06 to a daily average concentration value of 13 µg/m³ in the PO phase. However, the recorded increases bring the concentration of PM_{10} contaminant to values well below the normative limit of 50 µg/m³.

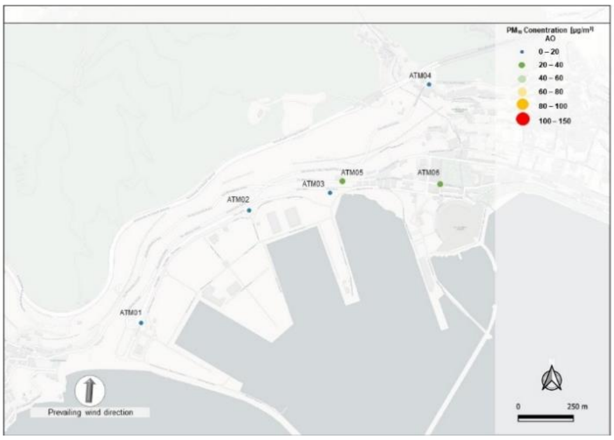

Figure 2. PM_{10} average daily concentration values measured in the AO phase for all monitored points.

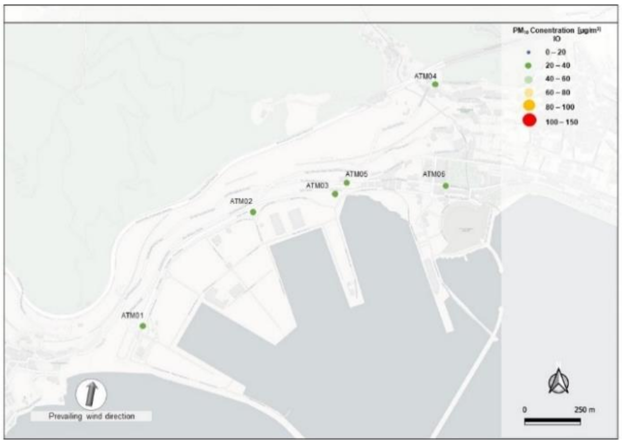

Figure 3. PM_{10} average daily concentration values measured in the IO phase for all monitored points.

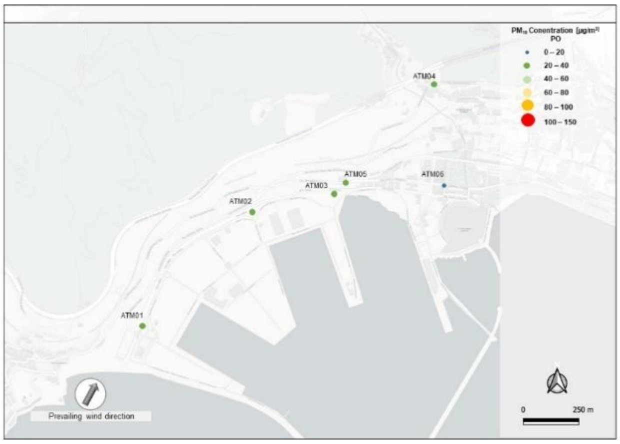

Figure 4. PM_{10} average daily concentration values measured in the PO phase for all monitored points.

Considering these points as representative of the emissive source, the analysis allows the evaluation of the mechanisms of horizontal dispersion of pollutants on receptors with respect to the source under consideration. Results acquired during the monitoring campaigns show how the concentration values measured at the receptors taken as reference, are for all the pollutants analyzed, in line and, in some cases, even above the concentration values measured at the points located within the port area. The analysis shows how port activities and induced traffic determine an incidence of limited significance in terms of air quality at the referenced receptors during the investigated monitoring period.

5. Conclusions

The research presents and discusses the development and application of an advanced and integrated air quality monitoring system (*aiAQMS*) for the air quality control in a complex port area. The experimental activities are carried out with reference to three phases of the implemented civil work (AO, IO and PO). Results show how an increase in daily average concentration values of PM10 in the different phases. However, these growing values are all well below the normative limit. The results obtained highlight the importance to build a tailored advanced and integrated air quality monitoring system in order to avoid negative effects on the human health and the environment and identify immediate mitigation actions in case of exceeding of the limits. Implementation of air quality measurement system are needed to ensure environmental protection and provide transparency of the data acquired.

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