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An Advanced Odour Monitoring Approach based on Citizens Science: a Real Application in Southern Italy

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Odours emissions sources are always closer to residential areas since their increasing expansion towards industrial contexts. The need of an effective solution to characterize the real odour annoyance perceived by the exposed population is thus of fundamental importance to avoid complaints and increase the quality of life in the areas surrounding industrial centres. The characterization of the odour emissions can be implemented with analytical, sensorial and senso-instrumental techniques. However, in order to have a complete and effective characterization, the implementation of integrated approaches is rising as preferred method since the need to take into account simultaneously emissive, sociological and morphological aspects.
The present study aims to report the development and application of a novel integrated method for the proactive characterization of odour annoyance in urban areas. The system has been implemented with a tailor-made design with regards to a sensitive municipality in which are located significant odour emissions plants. The proposed approach integrates analytical, sensorial and senso-instrumental techniques. The main feature is related to the validation of odour annoyance data collected from citizens with the data collected from Instrumental Odour Monitoring Systems (IOMSs), Air Quality and meteorological stations. Data from citizens are collected by a novel mobile APP. All the collected data are continuously elaborated for the creation and validation of interactive maps able to proactively identify possible undesirable conditions before the occurrence of odour annoyance events. The results of the real application of the proposed method demonstrated the importance of applying the citizen science approach to increasing the social engagement and of validating sensorial data with meteorological data by applying near-real-time dispersion models.

1. Introduction

Odour emissions from industrial and environmental protection plants are often the cause of olfactory nuisance capable of generating annoyance in citizens residing in their vicinity (Estrada et al., 2012; Zarra et al., 2021).
The emission of odours is intrinsically connected to the functionality of some types of plants, such as those for the treatment and disposal of waste, the treatment of wastewater, for livestock activities, food industries, chemical industries (Giuliani et al., 2012). The deriving annoyance is often continuous and, therefore, this phenomenon can interfere with the state of well-being of people, generating complaints and triggering conflicts that can also have repercussions on the economic, commercial and tourist activities, as well as significantly affecting the value of the soil (Oliva et al., 2021). Although the presence of unpleasant odours is generally not associated with a real risk to health, due to the presence of odorous compounds present at low concentration values, exposure to unpleasant odours is nevertheless associated with the triggering of a general state of disease, with frequent presence of symptoms such as headache, nausea, irritability (Blanco-Rodríguez et al., 2018). The perception of olfactory discomfort also triggers a perception of unhealthy air and health risk in the exposed population (Zarra et al., 2012). The hypothetical risk associated with them has marked characteristics of subjectivity, as it is influenced by physical factors, socio-economic conditions and psychological aspects (Lehtinen et al., 2012).

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It is therefore essential to monitor these emissions and minimize them within certain thresholds through control and mitigation actions. However, to date, the quantitative and qualitative characterization of odorous compounds is still of complex execution, both due to the intrinsic subjectivity of the olfactory perception and the effect of the influence of the meteorological conditions on the phenomena of odorous dispersion and on the perceived annoyance levels. To identify useful solutions to contain the olfactory disturbance, it is essential to measure in real time the effective disturbance perceived by the exposed population (Zarra et al., 2021). To this end, research activities are focussed on identifying advanced solutions. Furthermore, with a view to increasing the confidence of the population in the objective characterization of odours and related impacts, the implementation of aspects of communication and active involvement in decision-making and control models are suggested (Zarra et al., 2010; Levontin et al., 2022).The retrieval of odour characterization data through the active involvement of the population directly impacted from the odour nuisance is part of a virtuous approach know as Citizen Science, in which participation becomes an opportunity for institutions, businesses and citizens to identify the best strategy for managing the problem, sharing the decision-making processes in solving the critical issues reported (Alharbi and Soh, 2019; Zarra et al., 2021).In this context, the research presents an advanced monitoring system that applies the active involvement of the population in order to characterize the odour nuisance events and thus allow the identification of immediate and appropriate solutions.

2. Integrated monitoring system

2.1 Orographic and meteorological characterization of the interested area

The identification of the criteria for the location of the odour monitoring instrumentation was carried out with reference to a preliminary characterization of the site in terms of odour sources and microclimatic conditions. With reference to the first point, the area under investigation highlights the presence of a wastewater treatment plant and a waste treatment plant, identified as the main potential odour sources and located in a neighborhood very close to the residential area. While the meteorological characterization was performed using the CALMET model and the meteorological data referring to the year 2020.

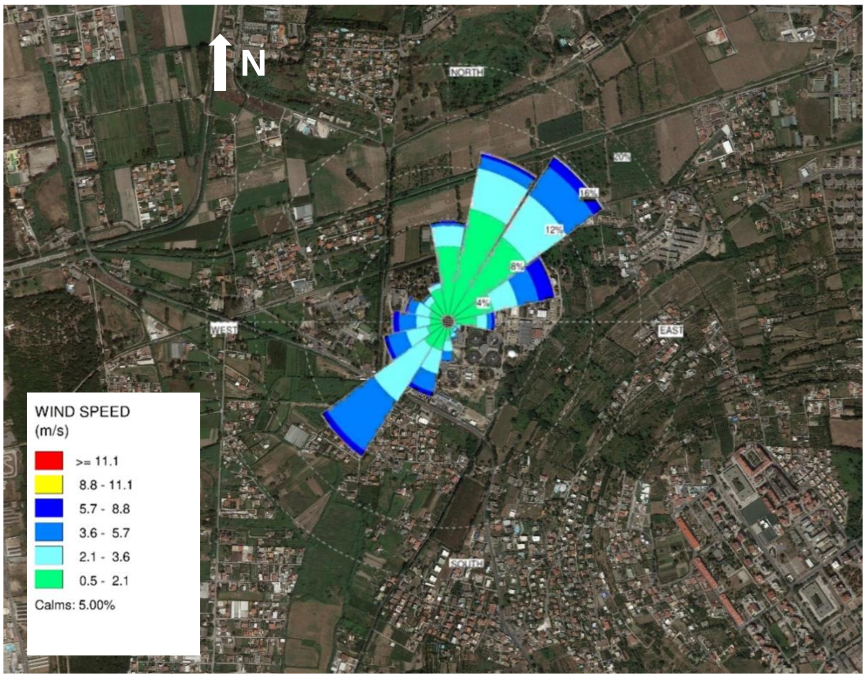

Figure 1 - Wind-rose in the area under investigation

A modeling spatial Domain of 4 x 4 km was used, with a horizontal resolution of 200 x 200 m and vertical resolution 0-20-50-100-200-500-1000-2000-4000 m above sea level (asl).
The orography is mainly flat, with altitudes up to 140 meters asl. There are no significant orographic barriers between the neighborhood and the investigated plants. According to the data of the meteorological analyzes, the wind blows mainly from the NNE (Figure 1) and this direction causes the dispersion of odor emissions from the sources identified to the residential area.

2.2 Design of the integrated monitoring system

The integrated monitoring system consists of 2 IOMS (Instrumental Odour Monitoring System) devices (MSEM32® by Sensigent, Baldwin Park, CA, USA), an air quality monitoring station for SO_2/H_2S and BTX analysis equipped with a weather station and an Android/iOS APP for collecting citizens reports of olfactory nuisance. The first IOMS (IOMS1) was located at the southeastern fence of the wastewater treatment plant, along the direction of prevailing winds coming from the plant to the nearest urban receptors. While the second IOMS (IOMS 2) was installed within the cabin of the air quality monitoring station, in the courtyard of a school close to the plant (Figure 2).

Figure 2 – Location of the integrated monitoring devices in the investigated area and the considered odour sources (WWTP (A) and waste treatment plant (B)).

The air quality monitoring station is comprised of two instruments, an SO_2 analyzer with converter for H_2S APSA-370 SO_2/H_2S (TRS) and a GC for the measurement of BTX compounds (Benzene - Toluene - Xylenes) model Synspec GC 955 series 600. The monitoring station is also equipped with a weather station for the collection of the main meteorological data (temperature, pressure, humidity, wind speed and direction, solar radiation and rain gauge). The IOMS has an array of 32 sensors (S3, S4, S5 Environmental Sensors, i.e., pressure, humidity, and temperature, S7, S8, S9, S10 Electrochemical Sensors, S11-12-13-14 Metal Oxide Sensors, S18 Photoionization Detector, S21-22-23-24 Nanocomposite-based Sensors, S42-43-44-45-46-47-48-49 Metal Oxide Sensors, S50-51-52-53-54-55 Nanocomposite-based Sensors, S56- 57 Metal Oxide Sensors).
While the app developed to involve the population, called Olysis, allows the selection, for communication purposes, of the odour intensity (weak, discernible or very strong), its duration (less than 5 minutes, more than an hour, more than 6 hours) and the type of odour perceived (waste, sewer, plastic, traffic, burnt, manure, chemical or other). All the data collected by the instruments, together with their communicated by the population, are saved in a cloud storage to be subsequently analyzed in order to be able to cross-reference and validate them with the meteorological and climatic data of the wind direction, downwind with respect to the location of the source in order to characterize the odour nuisance events.

2.3 Training of the IOMSs

In order to train the IOMS, according to the investigated odour sources, six odour classes were identified: Class 1 (wastewater arrival), Class 2 (primary treatments), Class 3 (primary sedimentation), Class 4 (sludge conditioning), Class 5 (waste treatment plant) and Class 0, defined as "ambient air", which was not influenced by the above emission sources. The training phase was carried out in the field, as it is important that the gaseous samples were fed in different environmental conditions, mainly related to the humidity and temperature parameters. To ensure that the baseline before sample feeding represented the ambient air conditions of odorless air, air was drawn by the instrument after filtering to remove odorous compounds but preserve the temperature and humidity of the ambient air. Moreover, a sufficient amount of time elapsed before the following feeding so that the sensors returned to the baseline values. Specifically, the measurement cycle consisted of 1 min of odorless ambient air, 4 min sample draw-in by IOMS (acquisition phase), and 3 min for baseline recovery; for each sample, the measurement cycle was repeated two times. For each collected sample, the odour concentration according to EN13725 was also determined. Table 1 highlights the range of the odour concentrations detected for the investigated classes in the overall monitored period.

Table 1: Collected dataset, used for the IOMS training.

Class	Odour Concentrations Range [ou/m^3]
Class 1	156-322
Class 2	256-302
Class 3	112-1218
Class 4	159-1798
Class 5	173-346

Machine learning algorithms described in the study of Cangialosi et al., 2021, were applied to create the odour monitoring models in terms of classification and quantification.

2.4 Validation of the IOMSs

To validate the training phase, the “leave one out” Cross-validation method (LOOCV) was employed: after splitting the dataset into a training set and a testing set, using all but one observation as part of the training set, the selected model is used to predict the response value of the one observation left out of the model and calculate the mean squared error (MSE). This process is then repeated n time, where *n* is the total number of observations in the dataset. The global MSE is calculated as the average of all the test MSE’s. The overall MSE value was 0.95, indicating that the training was successful.

3. Results

3.1 Citizens report

From 9 April 2022 to 9 July 2022 the validated reports from the population were n.690. 92% of the reports are located in the area at south of the WWTP and come from the houses immediately adjacent to the plant.
While with reference to the odour classes reported, as many as 71% were of the sewer type (Figure 3).

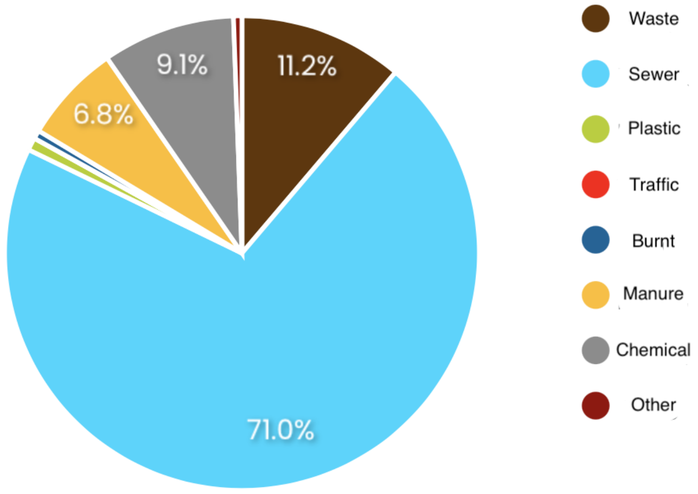

Figure 3 - Odour classes percentage distribution perceived by the population.

3.2 On-site monitoring data

Figure 4 shows an example of the signals detected by the IOMS and the H_2S monitoring analyzer located in the school, for a period of 5 days in the month of June. Results highlight very high values both in terms of H_2S concentration and predicted odour unit, considering that odour threshold for H_2S ranges from 1 to 8 ppb (Laraia et al., 2003; Chou, 2003).

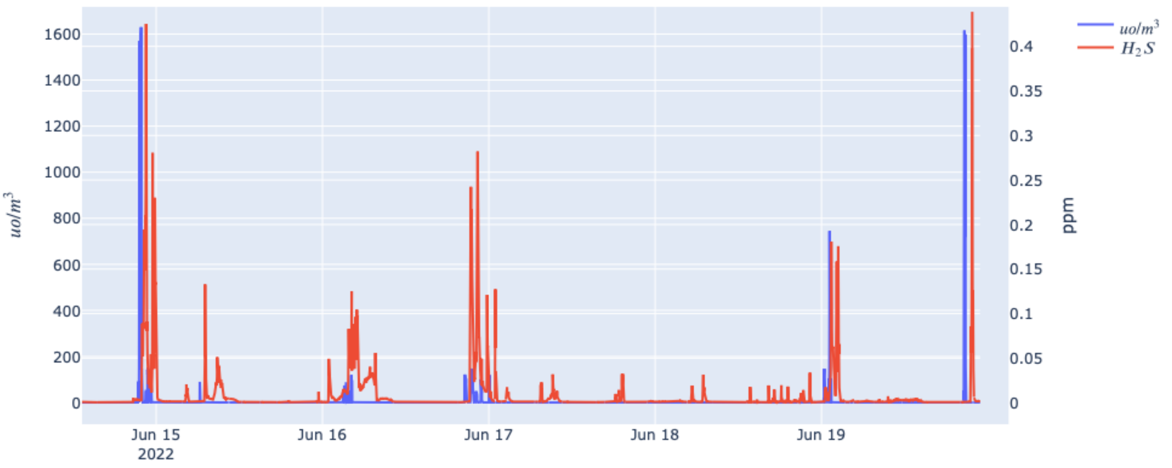

Figure 4 - Values of OU/ m^3 and H_2S recorded in the period 14 June - 19 June

Furthermore, by analyzing the odour classes distribution detected by the IOMS, during the events at concentrations higher than 100 ou/m^3, the 70% were recognized as Class 4 (sludge conditioning). While, by analyze the distribution of the classes in two different ranges of odor concentrations, R1 = 100-500 ou/m^3 and R2 > 500 ou/m^3, results shown in R1, Class 4 as predominant (61%), whereas 32% of odour events were recognized as Class 5 (waste treatment plant): at intermediate concentrations, both the WWTP and the waste treatment plant were recognized as source of odour emissions, with different contributions.
In higher range of odour concentrations, more likely to be more responsible for receptors nuisance, IOMS recognized 92% of the events as related to Class 4 and a marginal contribution (5%) of Class 1 (wastewater arrival), thus suggesting that all of the classes associated with high concentration values refer to the sources within the WWTP, in particular with the most critical ones, according to the earliest literature studies on the subject (Gostelow et al., 2001).

4. Conclusions

An advanced integrated odour monitoring approach has been proposed and is currently working in an urban area located in the southern Italy, where a big WWTP and a waste treatment plant are located.
The system designed allows the acquisition, management, processing and integrated evaluation of data acquired via Citizens Science APP and with analytical and sense-instrumental instruments.
The preliminary results showed a great involvement of the exposed population in the use of the designed APP. The odour event reported by the citizens were mainly classified as sewage type.
Similarly, analyzing the results from the IOMS installed in the school, the prevalent odour classes recognized are related to the WWTP and mainly to the sludge condition phase.
In addition, according to the preliminary results, a good correlation between the predicted odour concentration measured by the IOMS and the H2S concentration, measured by the monitoring station, is highlighted. As consequence, hydrogen sulfide may be considered among the tracing gas of the odour sources in the area.
The activity is still ongoing and further data are still needed to validate the full implementation of the integrated monitoring system. However, the citizen science approach already proves to be a useful platform for actively involving the exposed population in the characterization of the odour events and in supporting the identification the causes of the odour annoyance. The integration nature of the proposed systems aims at promote the active engagement of the population in the decision-making processes, the validation of the signals from the Mobile APP and the implementation of a proactive approach able to active early-warning procedure to avoid odour annoyance events.

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