Chapter

Importance of Air Quality Networks in Controlling Exposure to Air Pollution

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Abstract

An air quality monitoring network (AQMN) is a basic piece of environmental management due to that it satisfies the major role in monitoring of environment emissions, in special relevance to target air pollutants. An adequate installation would lead to support high efficiency of the network. Therefore, AQMN pre-layout should be considered as an essential factor in regarding with the location of fixed measurement stations within AQMN, as the minimum number of sampling points. Nevertheless, once AQMN has been already installed, and given that the spatial air pollutants pattern can vary along time, an assessment of the AQMN design would be addressed in order to identify the presence of potential redundant fixed monitoring stations. This approach would let to improve the AQMN performance, reduce maintenance costs of the network and consolidate the investment on those more efficient fixed stations. The chapter includes aspects relative to air pollutants measured by networks, their representativeness, limitations, importance, and the future needs. It ponders the need of re-assessment of the AQMN layout for assuring (i) a right evaluation of the human being exposure to atmospheric pollutants and controlling the environmental emissions into the atmosphere and (ii) an adequate performance of the network along time.

Keywords: environmental emissions, air quality, fixed monitoring stations, design and performance

1. Introduction

While technological advances have generated an improvement in the human being's life quality, they have also contributed to the emergence of associated issues, such as exponential industrial grown and increase of transportation networks, due to a fast growing population and its centralization into urban centers, mainly. As a consequence, the rise of the pollutant emissions toward the environmental compartments has been framed as a Public Health concern. Therefore, the impact of environmental emissions on the climate and the environment is an ultimate subject, both to local, regional as global level. Particularly, an increase of environmental well-being would bring in greater the quality of life, due to the exchange internal-external between the human being and the environment.

Environmental emissions play a key role in the release of pollutants on air, water and soil matrix, which is relevant because drives a decline of biodiversity [1]. In this sense, deforestation, water pollution, acid rain or endangered animals are factors linked to likely environmental repercussions [2, 3]. In the health framework, numerous epidemiological studies associate the presence of pollutants in the environment and harmful effects on human being health [4, 5].

Taking into account the interaction between human being and environmental, the human well-being is a factor tied to the presence of clean air, otherwise, the emergence of harmful effects could drive to devastating implications on human health. According to the 68th World Health Assembly (see [6]), each year, a total of 4.3 and 3.7 million deaths result from exposure to indoor and outdoor pollutants, respectively.

Among different environmental compartments, this chapter will focus on atmospheric matrix, given that atmospheric pollution is considered the major environmental risk to human health worldwide. Atmospheric pollution result from the release of a damaging chemical or material into the atmosphere and it encompasses a wide variety of pollutants, either organic or inorganic compounds. Once air pollutants are released into the atmosphere, those ones can be exhibited both gaseous phase as solid and liquid particles suspended in the air (particulate material, PM) [7].

The occurrence of pollutants in the atmosphere depends on emissions sources. Although the atmospheric pollution is considered as a global character issue, the highest levels of air pollutants have been monitored in the developing countries, as a consequence of the industrial growth. A more detailed analysis would pointed to large cities [8, 9], where environmental emissions to atmospheric level could come from several types of sources of pollution, such as industrial developments implying combustion processes, vehicular emissions and domestic-heating [10].

Environmental emissions have a direct effect on the outdoor ambient pollution, as well as on indoor air quality, given that outdoor emission sources are responsible for the presence of air pollutants at indoor environments [11], due to the gases and particles infiltration.

Based on previously mentioned, atmospheric pollution monitoring is of a fundamental importance in Public Health [12] in order to (i) control the human being exposure to air pollutants [13] and (ii) support the decision making on environmental management, in particular air quality management [14]. So, for example, an adequate management of major dominant emission sources in urban environments, as it can be to limit the road transport and more restricted industrial emissions, would result in lower levels of pollution into the atmosphere.

European Union develops Air Quality Directives [15] for setting air quality objectives in order to reduce potential harmful effects of air pollutants on human health and environment, establishing limit and target values for criteria of air pollutants. Air quality assessment is a responsibility of each Member States within their territory. These ones have the obligation for maintaining an air quality good, or improve it, and they should assume action in order to comply with the limit values and critical levels and, where possible, to reach the target values and long-term objectives. For that, Member States establish air quality monitoring networks (AQMN) in their territories for verifying compliance with those air quality objectives.

Therefore, AQMN performs an essential function within Public Health framework, monitoring environment emissions and controlling exposure in order to take care of human being health.

2. Criteria of air pollutants measured at AQMN

Criteria of air pollutants are those atmospheric pollutants generally monitored by AQMNs. They usually measure the next legislated criteria of air pollutants (see **Table 1**): sulfur dioxide, nitrogen oxides (monoxide and dioxide nitrogen), benzene, carbon monoxide. Ozone and atmospheric particles (PM_{10} particles, with an aerodynamic diameter of 10 μm or less, and $PM_{2.5}$, aerodynamic diameters ≤2.5 μm) [16, 17].

The measurements recorded by AQMNs must be able to provide traceability, in order to compare air quality data among all Member States, for which those measures must be monitored using common measurement methods. For that, Member States apply normalized reference measurement methods (see **Table 2**).

The previously mentioned methods are cataloged as automatic method, nevertheless, the AQMNs dispose manual methods for determining the chemical composition of atmospheric particles (PM_{10} and $PM_{2.5}$), mainly for heavy metals and polycyclic aromatic hydrocarbons. While the samples are collected by manual equipment installed at AQMN, their composition is analyzed in the laboratory.

Pollutant	Quantitative value	Concept	Averaging period
Sulfur dioxide (gas)	350 μg/m^3 125 μg/m^3	Limit value Limit value	1 hour 1 day
Nitrogen dioxide (gas)	200 μg/m^3 40 μg/m^3	Limit value Limit value	1 hour A calendar year
Benzene (gas)	5 μg/m^3	Limit value	A calendar year
Carbon monoxide (gas)	10 mg/m^3	Limit value	Maximum daily 8-hour mean
Ozone (gas)	120 μg/m^3	Target value (January 1, 2010)	Maximum daily 8-hour mean
PM_{10} (particles)	50 μg/m^3 40 μg/m^3	Limit value Limit value	1 day A calendar year
$PM_{2.5}$ (particles)	25 μg/m^3 20 μg/m^3	Target value (January 1, 2020) Limit value	A calendar year A calendar year

Table 1.
Limit and target value for the protection of human health [15].

Pollutant	European standard	Measurement method
Sulfur dioxide	EN 14212:2012 [18]	Ultraviolet fluorescence
Monoxide and nitrogen dioxide	EN 14211:2012 [19]	Chemiluminescence
Benzene	EN 14662:2005 [20]	Automated pumped sampling with in situ gas chromatography
Carbon monoxide	EN 14626:2012 [21]	Non-dispersive infrared spectroscopy
Ozone	EN 14625:2005 [22]	Ultraviolet photometry
PM_{10} and $PM_{2.5}$	EN 12341:2015 [23]	Gravimetric method

Table 2.
Reference measurement methods for measuring criteria of air pollutants.

The occurrence of criteria of air pollutants into the atmosphere measured at fixed stations within AQMN is dependent on several factors, such as meteorological features and sources of pollution.

3. Types of air pollutant emission sources

The comprehension of emission sources and knowledge on pollution levels reached in the air matrix could be useful tool for understanding the spatial and temporal distribution of air pollutants, which would provide an overview picture about human exposure to environmental emissions coming from different sources of contamination.

In function of their origin, it is necessary to distinct between anthropogenic and natural sources. Broadly, the first ones are sources that release mixtures of pollutants come from transport, power generation, industrial activity, biomass burning, and domestic heating, mainly in urban environments [24–26] while volcanic eruptions, plant emission and oceans are tied to natural sources. Nevertheless, in terms of released pollutant, the sources can be defined as primary and secondary. Primary emission sources result from the direct emissions from an air pollution source, while secondary emission sources result from the formation of a pollutant in the atmosphere from the chemical reaction between theirs precursors, which are emitted from air pollution primaries sources, and the meteorological variables. Finally, once pollutants are released, either from primary or secondary sources, the pollutants can be deposited on the Earth's terrestrial or aquatic surfaces, followed by re-emission to the atmosphere; in this case the sources are named as re-emission sources [27].

While the identification of emissions sources is a fundamental factor in order to carry out the distribution of the fixed monitoring stations within an AQMN, other elements also perform a primordial role, such as population density, peculiar features of target territory, amplitude of geographic area to be controlled as further meteorological variables.

4. Air quality monitoring network

4.1 Concept

AQMN is an essential element within environmental management, in special emphasis to air quality management. It is consisted of fixed monitoring stations for measuring air pollutants (see **Figure 1**). Although the total number of stations depends on several factors, according to Section 3, these ones should be attributed conveniently in the domain of interest for providing suitable air pollutant information and estimating the exposure of the ambient pollution on human being of righter way. So, one of the keys in the AQMN layout is the distribution of monitoring stations as well as the determination of a sufficient and confident number of sampling points for carrying out the air quality measurements. These features are associated with the network management, which should focus on reducing the fixed stations within the AQMN to a reliable and non-redundant number. So, the network would not duplicate information on air pollution.

Given that the assessment of air quality in Member States is approached by means of the data generated by AQMN, those ones divide their territories at zones and agglomerations in order to reach that objective. Generally, air quality must be assessed in all zones and agglomerations by means of one or more fixed stations.

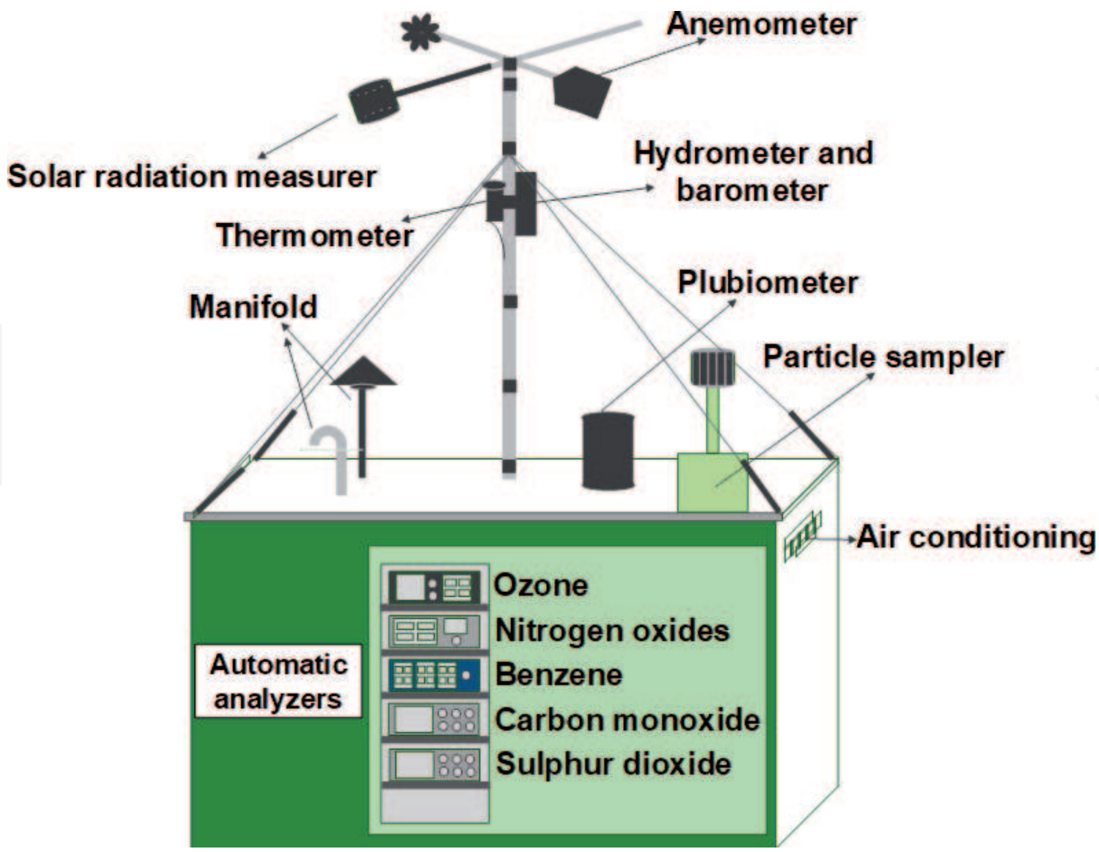

Figure 1.
Basic setup of a fixed monitoring station.

The number of zones can vary in function of geographical location, distribution of emission sources and meteorology, although the final number of those ones must provide an adequate representation of the territory heterogeneity.

Current European legislation [15] lays down criteria for siting fixed stations within an AQMN, pointing a wide number of considerations regards at macroscale siting of sampling points in order to protect the human health, vegetation and natural ecosystems. Similarly, in terms of microscale, the legislation set criteria relative to air flow no-restriction around the inlet of sampling point, its height regards to ground level (between 1.5 and 4 m) and distance regards to the edge of major junctions (at least 25 m) and the kerbside (no more than 10 m).

Regarding to minimum number of fixed monitoring stations, the European legislation set criteria in those zones and agglomerations where fixed measurement is the sole source of information for evaluating compliance with limit values for the protection of human health and alert thresholds. This criterion is based on zone inhabitant number and measured pollutants.

Fixed stations included into AQMN can be sorted in function of several typologies. So, in terms of area where is located it can be named:

- Urban stations: Those ones located at zones with presence of buildings of continued way.
- Suburban stations: Those ones located at zones with presence of buildings of continued way but separated by no-buildings areas, such as lakes, forests and agricultural land.
- Rural stations: Those ones located at zones not included within the previous two categories.

In terms of major dominant emission source:

- Traffic stations: Those ones which contamination levels are mainly appointed to emission sources coming from vehicles.

- Industrial stations: Those ones which contamination levels are majorly dependent on industrial activities.

- Background stations: Those ones which contamination levels cannot be directly attributed to any dominant emission source.

4.2 Representativeness of fixed monitoring stations within AQMN

Regardless the function exhibited by fixed measurement stations included into an AQMN, as the assessment of air quality, cross-border pollution, spatial-temporal trends or exposure studies, the representativeness of each station should be considered as a primordial reflection. The efficiency degree of the fixed stations into AQMN can be assessed in terms of:

4.2.1 Representation degree of any station within its zone or agglomeration

Given that one target zone can be represented by one or more fixed stations, it is relevant to know the spatial representativeness of each station in order to evaluate whether air quality monitored by those ones can or not be extrapolated to all zone. In this sense, in order to provide an overview regards to atmospheric pollution within zone, the passive methodology simultaneously samples a large number of sampling points, which supplies opportune information on spatial pollution in the researched zone [28]. This approach lets to compare air quality data measured by AQMN vs. those ones monitored by passive methods, thereby confirming or not the station representativeness within target zone.

4.2.2 Whole contribution of any station regarding environmental pollution data recorded by AQMN

Spatial representativeness of the information provided by AQMN is dependent on type of station, in terms of spatial scale, and the pollutant.

Broadly, representativeness of a fixed station can be defined as the variability of the target pollutant concentrations around sampling point, while others authors enlarged the definition to the radius of a circular area where the concentration can vary up to ±20%, as maximum value [29].

The AQMN performance does not depend on number of fixed measurement stations, given that the presence of redundant stations could result in existence of non-efficient fixed stations. This means that potential emission sources close to those stations could have a strong probability of similitude. For this reason, the representativeness of each station within an AQMN should be properly studied.

Although a final agreement regarding on procedure for assessing the efficiency of fixed stations have not been reached, this subject have been widely studied in the scientific literature. Recent studies have reported on approaches in order to test the AQMN performance. They are based on the use of several combined chemometric techniques for reached the aforementioned objective. Some authors have used the analysis of correlation for revealing the existence of redundant fixed stations, although this method does not identify efficient stations. For that, they apply the principal component analysis technique, which appoints a new set of linearly uncorrelated stations [29]. Other studies have expanded the number of chemometric techniques, combining correlation analysis, principal component analysis, assignment method, clustering analysis and correspondence analysis [30].

A significate consideration would drive to know the contribution degree of each source of pollution in regarding with air pollutants levels reached into the atmosphere. Some authors have solved this subject using a combination of techniques, combined principal component analysis and multiple linear regression.

Nevertheless, the practical application of the mentioned approaches were not tested along a period did not include in the development of these approaches. Similarly, they did not assess spatial information percentage that is lost when redesigning the AQMN due to the removal redundant fixed measurement stations.

Therefore, while different approaches have been developed to estimate the area of spatial representativeness of monitoring stations, a unique robust methodology to assess the representativeness of in-situ measurements has not yet been agreed.

Spatial representativeness is required for distinct actions:

- Station classification and network design [31],
- Air quality and exposure assessment, for example, to estimate the air quality standards exceedance areas and to quantify the population exposure to the air pollution [32],
- Model validation and data assimilation [33].

A lack of information in regarding with the AQMN performance, based on the representativeness of their fixed stations, would support their potential limitations.

4.3 Potential limitations of AQMN

4.3.1 Relative to the design

Given that air quality in any zone, either local, regional or global, is dependent on a wide number of factors such emission sources (transport network and industries) and meteorological features, the assessment of atmospheric pollution is a hard assignment, and due to these factors it is specific for each zone. Therefore, it is possible that the spatial information on environmental pollution reported by AQMNs is not representative of the target zone.

This limitation could influence on AQMN efficiency, if its function is framed within activity of informing population of levels which they are exposed to. This fact is relevant because numerous epidemiological studies use air quality data recorded by AQMNs, in order to associate air pollutant levels with damaging effects or hospital admissions. Nevertheless, the pollution data measured by AQMNs along study time is not equivalent to the daily concentrations which the human being is exposed to. So, the reached conclusions could exhibit a limited scope.

4.3.2 Relative to current European legislation

While European Legislation clearly establish criteria, on the one hand, for siting potential fixed measurement stations and, on the other hand, setting minimum number of those ones, criteria for identifying the more representative fixed sampling points within AQMN is not considered. This fact is fundamental in order to optimize the AQMN performance.

4.3.3 Relative to the development of specific procedure for evaluating the representativeness of fixed stations

FARIMODE study [34] reported on collected information coming from questionnaire to get technical information concerning the methodologies used to estimate the representativeness of air quality monitoring stations. The questionnaire was answered by 22 workgroups from 14 different countries providing information on 25 methodologies.

Major methodological limitations were appointed to input data availability (9 answers), expert or local knowledge (1), modeling domain (1), modeling uncertainties (6), input data uncertainties (10), temporal-spatial resolution (7), directive metrics (1), computational resources (4), pollutants (2), definition of parameters of methodology (3), coverage of station network (1) and no limitation (2). Within this study, a relevant conclusion was the possibility for examining if the similarities or discrepancies between the representativeness estimates are more or less significant according to the concentration levels measured by target station.

4.4 Importance of AQMNs

Consequently to previously mentioned, an AQMN play a paramount lead in the evaluation of the air quality [35], in order to:

- Inform to the population in regarding with pollution levels which they are exposed to [30],
- Know spatial-temporal pattern of air pollutants (see **Figure 1**),
- Identify predominant emission sources [36],
- Support the development of monitoring strategies [37] and.
- Assist to authorities in decisions making.

Besides, in the case of Member States, those ones must report to European Commission on recorded pollution data, which lets to evaluate the cross-border pollution and model the spatial-temporal air pollution pattern, among others applications.

AQMN links important subjects framed into Public Health, such as sources of pollution, environmental emissions, outdoor air pollutant levels and human health. Therefore, AQMN proves a helpful implement for estimating risk associated with human being exposure to air pollutant levels occurred into the atmosphere.

4.5 Management of AQMNs

Within the European Union, Member States are liable for controlling and assuring data quality of fixed monitoring stations. Each one establishes the necessary number and the location of fixed measurement stations included in their AQMNs, in order to ensure an adequate air quality assessment in its territory and comply with air quality standards. Similarly, each Member State is responsible for managing their AQMNs, according to requirements set in current European Legislation, meaning, the used measurement methods should be those ones included in air quality standards (they have been mentioned in **Table 2**). Similarly, they should guarantee a proper maintenance of those measure devices employed for monitoring atmospheric pollutants in the outdoor ambient air. For that, the air quality standards [18–23] set several basic qualifications regards to the measure devices and their management:

- Components of sampling system: (i) Sampling line: standards indicate the frequency of clear or, if necessary, its change, (ii) Particle filters: standards indicate where should site and (iii) Sampling pump: standards set the sampling flux required for working properly.

- Equipment requirements. They depend on target atmospheric pollutant. The components of the devices used for measuring atmospheric pollutants are described in the Air Quality Standards. The next devices can be differenced:

Continuous devices: The air pollutant levels are continuously measured using automatic analyzers.

Integrated devices: Levels of the target air pollutants are measured by manual or automated methods and the data is registered hourly or daily.

Static devices: Levels of the target air pollutants are estimated by using qualitative measurement devices from weekly or monthly exposure.

- Maintenance operations: The Air Quality Standards determine those necessary actions in order to test if an equipment is working within specifications marked by the manufacturer. For that aim, technical aspects such as verification of zero, the higher concentration level and lack of fit, among other should be checked. All these tests should provide satisfactory results, complying with the criteria set in the air quality standards.

- Equipment calibration: Standards exhibit the frequency of calibration for each criteria of air pollutant, as well as recommended concentration/s, acceptation criteria, methodology, etc.

- Quality control and quality assurance: The execution of this subject assures that the uncertainty or dispersion associated with the measured values by AQMNs fall down criteria set by current European Legislation. For that, the compliance of the previous requirements should be reached.

More detailed information about this section can be found in air quality standards, which have been published by CEN/TC 624 Work Programme and can be acquired through European Committee for Standardization (https://www.cen.eu/Pages/default.aspx, accessed March 6, 2020).

4.6 Data measured by AQMNs

Given that the AQMNs management is a responsibility for the Member States, those ones should ensure valid air quality data. The data registered during maintenance, check and calibration processes should be not included within the air quality dataset, as well as the faulty data. The air quality standards establish requirements relative to the way for expressing the air quality data (number of decimals) and data capture (temporal coverage).

At the State level, Member States transfer air quality data to Europe Union. Those data can be compared given that, on the one hand, their measure was monitored using reference methods and, on the other hand, they complied with those QC/QA criteria set by air quality standards. As an example, the European

Monitoring and Evaluation Programme (EMEP) is the co-operative program for assessing long range transmission of atmospheric pollutants over Europe. Member States have an air quality network in order to monitor background levels of air pollutants. Information relative to this subject can be found in https://www.emep.int/ (accessed March 6, 2020), where emission data, measurement data and modeling results for air pollutants are available through an open's database. Similarly, air quality data monitored by Member States is reported by European Environment Agency (https://www.eea.europa.eu/data-and-maps/explore-interactive-maps/up-to-date-air-quality-data, accessed March 9, 2020) by means of interactive maps and reports. Other website providing real-time air pollution data by interactive maps in Europe and other countries over the world can be visited at https://aqicn.org/map/europe/ (accessed March 9, 2020).

4.7 Potential suggestions for improving the AQMN management

Given that the AQMNs have a large historical series of ambient air data for target air pollutants [38] (sulfur dioxide, nitrogen monoxide and dioxide, benzene, carbon monoxide, ozone and atmospheric particles), a count of the number of times that the measurements exceeded the limit and target value established by the European Legislation would help to identify those air pollutants who should be monitored.

As a consequence, the measurement of those air pollutants which do not exceeded the limit values could be reduced in terms of number of fixed monitoring stations, which would give to reinvest those economic resources towards the monitor of other pollutants, e.g. benzene, given that the measurements of this last pollutant are very limited within AQMNs and, according to European Legislation, its measure is mandatory.

Based on the role of AQMNs within environmental emission control, and given that their spatial monitoring coverture is limited [39], nowadays, new wireless low cost sensors are available in order to assess pollution levels in ambient [40] and indoor air [41], by simultaneous monitoring in an elevated number of sampling points,

5. Possible future trends

At European level, although the application of measurement methods for monitoring air pollutants in AQMNs is normalized by Air Quality Standards, providing traceability to air pollution data among Member States, a harmonized technique for estimating the representativeness of fixed monitoring stations have not been defined.

In the future, the major requirement in regards to AQMN design should point towards the development of a particular methodology for evaluating representativeness of fixed monitoring sampling points within a network.

On the one hand, this methodology should offer evaluation criteria which would assure an adequate estimation of the representativeness and, on the other hand, they should be common and similar to all Member States.

The implementation of this reflection would result in a significant benefit for population, given that an optimization regards to location of fixed stations, and by extension on AQMN performance, it would aid to control the human exposure to atmospheric pollution in a more precise way, supporting a more realistic estimate of human health risk.

6. Conclusions

The binomial between environmental emissions and human exposure leads to Public Health concerns. In particular, emissions towards ambient air are considered the higher environmental risk. In order to control those issues, AQMNs play a paramount role for controlling air pollution in order to evaluate the compliance with those air quality objectives set by Air Quality European Standards and assist to authorities in decisions making. They consist of fixed monitoring stations and measure several criteria of air pollutants. Although each fixed station should be representative of an around area, the spatial coverture of AQMNs is very limited, due to the restricted number of sampling points as a consequence of the large investment need for setting up an AQMN. Current European legislation lays down criteria for supporting location and minimum number of the fixed measurement stations within AQMN. There are numerous websites exhibiting air quality data (at local, regional and global level), by means of reports, interactive maps or time-real data.

In order to support the AQMN management, a study regards to number of times that air pollutant measures have exceeded the criteria of air quality set in European Legislation should be addressed, for identifying the pollutants which should be measured.

A relevant subject of an AQMN would point to its layout. Although, the legislation does not set methods for evaluating representativeness of the fixed measurement points or requirements for refereeing representativeness degree, this one should be tested over the time, given that new emission air pollutant sources can be emerged, which would directly affect to the AQMN performance.

Therefore, the deployment of a harmonized methodological framework is required, which allows to establish a comprehensive and comparative evaluation of the AQMN efficacy, by evaluating the representativeness of fixed monitoring stations.

This methodology should be assisted by scientists, AQMN's managers and technicians and experts of air quality and it should lay down the concrete type of method to use, either passive methodology, modeling, series of historical data, a combination of them or other methods.

The development of this harmonized methodological would help to the reporting of spatial representativeness by the Member States to Commission European by means of a common approach.

Conflict of interest

The author declares no conflict of interest. This work does not have commercial purposes, only scientific ones.

Other declarations

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