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The Evolution of Air Quality Monitoring: Measurement Techniques and Instruments

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Abstract: Air quality monitoring has been developing after serious contamination events affected the environment and human health. This research aims to collect existing information about air quality monitoring, its history, and global context over the years, as well as technologies and methods of measuring different existing air pollutants. As a methodology, we used a systematic literature review to find the main typologies of atmospheric pollutants, measuring methods, pollutants used from the 20th century to the present, technologies used, and meteorological variables. Likewise, we described the established times and locations and the initiatives of air quality measurement globally through the years and, as a result, proposed an alternative monitoring system. In conclusion, precision depends on the type of pollutant monitoring used or on the treatment of the data.

Keywords: air quality control, environmental health, human health, pollution.

空氣質量監測的演變：測量技術和儀器

摘要：在嚴重污染事件影響環境和人類健康後，空氣質量監測一直在發展。本研究旨在收集有關空氣質量監測的現有信息、其歷史和多年來的全球背景，以及測量不同現有空氣污染物的技術和方法。作為一種方法，我們使用系統的文獻綜述來查找大氣污染物的主要類型、測量方法、從 20 世紀至今使用的污染物、使用的技術和氣象變量。同樣，我們描述了多年來全球空氣質量測量的既定時間和地點以及舉措，並因此提出了替代監測系統。總之，精度取決於所使用的污染物監測類型或數據處理方式。

关键词：空氣質量控制、環境健康、人類健康、污染。

1. Introduction

Air quality monitoring strategies have principally been developed in response to environmental disasters affecting human health and the environment. With increasing frequency, first-world countries present high levels of air pollution due to the industrial activities that characterize the economy of the regions, in conjunction with social and cultural variables that are particular to the relationship between human beings and ecosystems [1]. The implementation of public policies and their incorporation into the regulations that establish air pollution controls is the basis for air quality monitoring. In addition, the development of monitoring techniques is reflected in the implementation of technologies and in the growing consciousness concerning the need for the improvement of the quality of the air to which human beings are exposed, which is one of the main factors that determine the quality of life of a population.

This research aims to collect existing information about air quality monitoring, its history and global context over the years, as well as technologies and methods of measuring different existing air pollutants. The realization of this article is motivated by the search for more accurate and advanced measurement methods that have been given along with technological advances that minimize human intervention in the processes of obtaining data, allowing a higher quality in them, making them more affordable, and highlighting the relevance of air quality for the health of populations in general and for the environment.

The article contains a description of the main typologies of atmospheric pollutants, the methods of measuring the pollutants used from the 20th century to the present, followed by the technologies used, the meteorological variables that influence the monitoring processes, the established times and locations, and the initiatives of air quality measurement in a global context through the years. Finally, this work proposed an alternative monitoring system.

The initiatives of the countries to control the air quality and make more precise monitoring of atmospheric pollutants led to the reduction of the levels present in the cities and the improvement of the quality of life of the people. Technological advances and developments in air quality monitoring allow more accurate and actual data to be obtained on the pollutants to which populations are exposed, also creating greater awareness among people about the implications of these variables on human health.

This study's novelty lies in its multifaceted approach to air quality monitoring, as it aims to provide a comprehensive overview of the history and global context of air quality monitoring. By exploring the historical development of monitoring techniques and technologies, this study offers valuable insights into the progression of air quality monitoring over time.

Second, this research highlights the importance of technological advances in air quality monitoring and their impact on obtaining more accurate and real-time data on pollutants. By identifying the latest advancements in measurement methods, this study contributes to the ongoing efforts to improve the precision and efficiency of air quality monitoring.

Furthermore, the article considers the relationship between air quality and human health, emphasizing the implications of atmospheric pollutants on the well-being of populations and raising awareness among individuals and communities about the importance of monitoring and addressing air pollution.

Finally, this research proposes an alternative monitoring system, presenting innovative approaches to air quality measurement. The study contributes to the ongoing discussions and efforts to refine monitoring practices and enhance the effectiveness of pollution control measures.

This work is as follows: section 2 presents the methodology used in this work, section 3 - the results, section 4 - the discussion, and section 5 - the conclusion.

2. Research Method

This study used a systematic literature review methodology to collect information on air quality monitoring. A comprehensive search used various online databases, including Google Scholar, Scopus, and OpenAQ. The inclusion criteria for the articles were that they were published in English and Spanish and provided information on the history, global context, technologies, and methods of measuring different air pollutants. The exclusion criteria were non–peer–reviewed articles and not relevant to the research topic. The search considered articles from 1980 to 2020 to ensure including the most recent and up-to-date articles.

To ensure a comprehensive search for relevant scientific articles related to air pollution and air quality monitoring, a set of carefully chosen keywords, including "air pollution," "pollution health effects," "air quality monitoring," "particulate matter," and "urban air quality management strategy" were used. The selected period provided a comprehensive understanding of how air quality monitoring has evolved over the past four decades, including developing new measurement technologies and initiatives.

The collected information described the typologies of atmospheric pollutants and measuring methods used from the 20th century to the present, the technologies used, meteorological variables, and the established times and locations of air quality measurement initiatives in a global context. Based on these findings, we proposed an alternative monitoring system.

The text below outlines the steps involved in the research process:

2.1. Identification of Research Objectives

This study aimed to collect information about air quality monitoring, including its history, global context, technologies, and methods of measuring different air pollutants. The objective was to provide a comprehensive understanding of the subject and propose an alternative monitoring system based on the findings.

2.2. Selection of Databases and Search Strategy

Various online databases, including Google Scholar, Scopus, and OpenAQ, were selected for the literature search. A systematic search strategy was developed, incorporating carefully chosen keywords related to air pollution, air quality monitoring, and relevant topics.

These keywords captured a broad range of scientific articles.

2.3. Application of Inclusion and Exclusion Criteria

The retrieved articles were screened based on specific inclusion and exclusion criteria. Inclusion criteria required articles published in English or Spanish that provide information relevant to the research objectives. Non-peer–reviewed articles and those not directly related to the topic were excluded from the study.

2.4. Literature Screening and Data Extraction

The screened articles were further assessed for relevance and quality. Pertinent information, such as the historical context, technologies, methods, and initiatives related to air quality monitoring, was extracted from the selected articles for further analysis.

2.5. Synthesis and Analysis of Collected Data

The extracted information was synthesized and analyzed to identify patterns, trends, and key insights related to air quality monitoring that involved categorizing and organizing the data to draw meaningful conclusions.

2.6. Proposal of an Alternative Monitoring System

Based on the findings and analysis, an alternative monitoring system was proposed, incorporating innovative approaches to air quality measurement and addressing potential gaps or limitations identified in existing methods.

2.7. Discussion and Interpretation of Results

The results were discussed in the context of the existing literature and relevant scientific knowledge. Interpretations provided a deeper understanding of the implications and significance of the findings.

3. Results

The results are as follows: the defined types of pollutants, the most used measurement methods and technologies, the meteorological variables taken into account, the necessary monitoring equipment, and finally, air quality measurement initiatives in a global context.

3.1. Types of Pollutants

Pollutants are substances found in the atmosphere in a concentration more than usual or are natural. The first kinds of atmospheric pollutants were those typified by large concentrations of sulfur compounds, such as SO_2, sulfates, and particles resulting from the combustion of carbon and other fuels containing sulfur. The cities with this type of pollution are those with cold climates where energy generation and domestic heating occur because of the unregulated burning of carbon. The second type of pollution appeared as using petrol became more common as a fuel for engines. Although pollution caused by cars was acknowledged in 1915, it was not until 1945 that more severe incidents arose because of the increase in cars worldwide [2]. This type of pollution is called smog or photochemical smog generated when solar radiation causes a diverse series of reactions in an atmosphere full of organic gases and nitrogen oxides NO_x. The main components of smog are nitric oxide (NO) and hydrocarbons, which are easily turned into ozone (O_3), organic nitrogen, and photochemical aerosols, which are harmful to human health [3]. At present, EPA recognized six primary atmospheric pollutants due to their relevance to adverse effects on human health and the environment. Table 1 presents six primary pollutants.

Table 1 The types of pollutants (Developed by the authors)

Pollutants	Description
Ozone (O_3)	Ozone is not a pollutant that is emitted directly into the air, but rather it is generated due to chemical reactions between nitrogen oxides and volatile organic compounds (VOC) in the presence of sunlight. It is a powerful oxidizing agent generated from dioxygen by its exposure to ultraviolet light, and it reacts with other pollutants like nitrogen oxides and sulfur. Exposure to tropospheric ozone can cause several health issues, mainly in children, elderly people, and people with asthma and lung problems. In addition, it has damaging effects on vegetation and ecosystems [4].
Particulate Matter (PM)	Particulate matter is a mixture of extremely small particles and droplets in the air. They can be of different shapes and sizes and can include hundreds of different chemicals. The particles contain microscopic solids or liquid droplets that are so small that they can be inhaled and cause serious health problems. Particles of less than 10 micrometers in diameter are the ones that cause more problems, given that they can penetrate deeply into the lungs, and some can even enter the bloodstream. Fine particles or $PM_{2.5}$ are the primary causes of reduced visibility [5].
Carbon monoxide (CO)	CO is a colorless and odorless gas that can harm health if inhaled in large quantities mainly produced in combustion processes. Some of the primary sources of carbon monoxide are cars and the burning of fossil fuels, by-products of the combustion of organic compounds such as hydrocarbons. Breathing air with high concentrations of CO reduces the amount of oxygen in the bloodstream to vital organs such as the heart and brain. At very high levels, which are possible indoors or in enclosed environments, CO may cause dizziness, confusion, loss of consciousness, and even death. It is unlikely enough that very high levels of CO can be in the open natural air. Nevertheless, when levels are high, people who suffer from certain heart diseases and Parkinson’s

	disease should take care [6].
Lead (Pb)	Lead is a natural element found in small quantities in the Earth's crust. Even though it has some beneficial uses, it can be toxic for human beings and animals, damaging their health. Most of our exposure comes from human activities, including using fossil fuels, the widespread use of leaded petrol in the past, some industrial installations, and using lead-based paint in houses [7].
Sulfur dioxide (SO_2)	Sulfur dioxide can be created in high quantities from carbon and mineral oil combustion processes. Short-term exposure to SO_2 can damage the human respiratory system and cause difficulty when breathing. Children, elderly people, and those who suffer from asthma are particularly sensitive to the effects of this pollutant. Generally, sulfur dioxide emissions that lead to high concentrations of SO_2 in the air also contribute to forming other sulfur oxides. SO_x can react with other compounds in the atmosphere to form small particles that can penetrate sensitive areas of the lungs and cause other health issues [8].
Nitrogen dioxide (NO_2)	Nitrogen dioxide belongs to a group of highly reactive gases known as NO_x. Other nitrogen oxides include nitrous and nitric acids used as an indicator for the largest group of nitrogen oxides. NO_2 is mainly produced by burning fuels and from car, truck, bus, and power plant emissions. Breathing air containing a high concentration of NO_2 may irritate the respiratory tracts of the human respiratory system. This exposure over short periods may aggravate respiratory diseases, particularly asthma. Prolonged exposure to high concentrations of NO_2 may contribute to the development of asthma, apart from potentially augmenting a person's susceptibility to respiratory infections, cancer, and even leukemia [9].

The six pollutants summarized above cause health effects, varying their risk levels according to the characteristics of the exposure, the intensity of the pollutant present in the air, and the period that the population is exposed.

3.2. Measurement Methods

The measurement methods used to monitor air quality have undergone various changes over time; some of the methods used in the 20th century no longer apply due to their lack of accuracy and difficulty in obtaining precise data. Some methods used in the 21st century are no longer manual but automatic ones, which provide better quality data and minimize human intervention in the processes.

3.2.1. Methods Used in the 20th Century

Concerning the first measuring methods, it is possible to find some processes that are now obsolete due to their lack of practicality and low percentage of accuracy, most of them being manual [10]. Some of these methods apply to the measurements of different gases such as sulfur dioxide, tropospheric ozone, and particulate matter.

- *Pararosaniline, the wet process (SO_2):* This type of measurement, also called the West-Gaeke method, serves as a field and laboratory method. Its precise application is passing air through a solution of sodium tetrachloromercurate over 24 hours. This reactive absorbs the sulfur dioxide forming a complex of dichlorosulfitemercurate (HgSO3Cl2-2), which reacts with pararosaniline and formaldehyde. Measurement of the sample absorbance used visible spectrophotometry [11]. According to the Institute of Hydrology, Meteorology, and Environmental Studies, in 2010, the application of this method was reported as a measurement of the concentration of sulfur dioxide in the environment, using sample-taking periods of 30 min to 24 h [12]. Other general manual methods for measuring sulfur dioxide in the air apply iodometry, turbidimetry, or colorimetry.
- *Reaction with ethylene + chemiluminescence (O_3):* The reaction of this method produces excited formaldehyde, which emits photons visibly. In turn, the chemiluminescence intensity will be proportional to the ozone concentration. O_3 can also be measured by absorption in the visible I3 spectrum since iodine is soluble in solution after a prior reaction with iodide. However, the last method detects the sum of the oxidants capable of oxidizing the iodide. For this reason, it is better to call it a method to determine total oxidants, although, in general, the most important oxidant is ozone [13].
- *Atmospheric sedimentable dust:* The measurement of this parameter uses a small sheet left in the open air for an average of 30 days, with the upper part coated with oil or vaseline. To obtain the atmospheric sedimentable dust, the sheet will be weighed after exposure time to compare the weight to the sheet before the exposition. The result of this measurement is in atmospheric sedimentable dust weight units. More automatized and specialized equipment, which can discern the size of the particles in micrometers, replaced this method [14].

3.2.2. Methods Used in the 21st Century

Among the methodologies currently used for measuring atmospheric pollutants, automatic methods are the most common, as shown below. These methods include a great variety of chemical processes to determine the concentration of pollutant gases and particulate matter. Some of these methods are beta attenuation, tapered element, oscillating microbalance, chemiluminescence, and UV absorption.

- *Beta attenuation:* This is a mass method for measuring particles usually used in detectors of particulate matter, total suspended particles, particulate matter less than 10 m (PM10), and particulate matter less than 2.5 m (PM2.5) collected from ambient air with a ribbon. The rate at which the flow of beta radiation is attenuated or reduced by a solid matter depends on its mass [15].

- *Tapered element oscillating microbalance:* The measurement system has a filter at the end of a hollow glass conical tube. The latter vibrates at its natural frequency as the air sample passes through the filter, and the matter is deposited there. The vibration frequency decreases as the mass of particulate matter increases [16].
- *UV fluorescence:* This method applies to determine the concentration of sulfur oxides. SO_x absorbs the UV light and becomes excited at one wavelength. Then they decay to a lower energy state, emitting UV light at different wavelengths. The intensity of fluorescence is proportional to the concentration of SO_x.
- *Chemiluminescence:* This method applies to determine the concentration of a substance for the measurement of nitrogen oxides and consists of provoking a reaction between nitrogen monoxide and ozone to form nitrogen dioxide. Because of this chemical reaction, the molecules enter an excited state and emit detectable rays, such as ultraviolet, visible, or infrared radiation. The intensity of the light emitted is proportional to the concentration of NO_x [17].
- *UV absorption:* This is a general method used to measure concentrations of ozone. The airflow divides into two equal flows, one of which goes through a section that contains molybdenum oxides as a catalyzer that traps the ozone of the sample to direct later it to a measurement cell. The other flow goes directly to another measurement cell. The irradiation of the samples takes place in the cells. The absorbance signals of both cells are internally translated into electric signals by the analyzer, and the difference between these signals is proportional and equivalent to the concentration of ozone present in the air sample entered [18].
- *Gas filter correlation (GFC):* The incidence of infrared radiation passes through a rotating gas-filled filter wheel before entering the sample chamber. The wavelengths absorbed by CO are removed from the radiation, creating a reference beam not affected by CO in the sample measured. When the IR energy passes through the middle of the wheel that contains nitrogen, the specific CO wavelengths are not removed from the radiation, and the measurement beam is attenuated by the CO in the sample. The rotation of the gas filter wheel generates a beam that alternates between the reference and measurement phases. A liquid state sensor detects the infrared energy that passes through the filter, and the sample chamber turns it into a concentration value [18]. It is necessary to consider that polluting concentrations are usually measured in units of micrograms per cubic meter ($\mu g/m^3$) or milligrams per cubic meter (mg/m3). The measurement methods shown above are currently used by gas sensors at air quality stations, which provide information on pollution at various times of the day.

3.3. Technologies Used

The technologies used for monitoring air quality can be classified depending on the number of human interactions needed into passive or manual monitoring, automatic monitoring, and semi-automatic monitoring.

3.3.1. Manual Monitoring

The air quality monitoring systems that are manual and comprise sampling equipment are as follows.

- *High-volume air sampler:* A high-volume air sampler applies to measure continuous or intermittent concentrations of PM2.5, PM10, and PST for low concentrations related to enclosed environments or outdoor monitoring, as well as for industrial monitoring with high content of aerosols. In general, the basic system of the sampler consists of an open-air anodized aluminum shelter with a gabled roof, including an on/off timer, a device that controls the flow and the pressure, and a motor that controls the recirculation fan, so the particles are trapped in the filter by gravimetry. The fiber filters are weighed before and after taking the sample; they are then sent to the lab to determine the total suspended particulate matter. The efficiency of a high-volume particulate sampler usually depends on variables such as the orientation of the wind and its speed, the diameter of the particles, and its operational state [18], [19], [20].
- *Three and five gas samplers:* Also known as wet chemical methods or wet scrubbers, these ambient air pollutant samplers absorb pollutant gases through solutions (three to five) contained in a series of bubblers analyzed in the laboratory. They can test for combining nitrogen dioxides, sulfuric acid, ammonia, sulfur dioxide, and aliphatic aldehydes. The vacuum pump draws ambient air through a conical rain shield and the inlet tube. The inlet manifold divides the air stream into equal volumes that flow through the tubes or hoses to the bubbles [21]. U.S. EPA demonstrated that the measurement of concentrations made with this instrument is adversely affected by high ambient air temperatures, especially affecting SO2 measurements, given its instability. However, new technologies developed by Newstar Environmental add a thermoelectric system to ensure more precision when measuring sulfur dioxide [22].

3.3.2. Automatic Monitoring

Automatic equipment for air quality monitoring analogously transmits information and directs it to a computer to analyze the data obtained in real-time without direct human intervention. Among them, there are automatic samplers, which, in turn, operate by using sensors to collect data.

- *Compact sampling equipment:* Equipment developed by Thermo Fisher Scientific [23] and Ecotech [24] uses automatic measurement methods for each analyzed pollutant, such as UV fluorescence and chemiluminescence. These can work continuously or intermittently to show their results on digital screens and to send data to a remote receiver. Such equipment can analyze multiple gases, including meters of atmospheric variables such as relative humidity and temperature. Among the different types of automatic monitoring are also wireless mobile sampling devices capable of obtaining data with representative temporal and spatial quality. In addition, portable devices collect personalized information regarding the type of pollution to which an individual is exposed, including polluting gases and particles, and as a complement to the existing air quality monitoring networks, so the localization of pollution events can be determined with more precision, thus promoting the modeling of maps with information that is constantly being updated [25-28]. Some technological advances have focused on collecting data and developing applications for mobile devices (smartphones), which in real-time display the data collected from any source of emission, outdoor or indoor, improving individual and collective decision-making, as well as the capacity to achieve better environmental health [29], [30].
- *Sensors:* Sensors, the functional basis of automatic monitoring samplers, show a low-cost alternative characterized by its versatility concerning collecting data on environmental quality, allowing for broader scale monitoring with fewer energy demands and greater resolution, as shown in Table 2 [31]. These compact technologies apply to provide wireless signals (WiFi, Bluetooth, among others) to computer and smartphone software, among others, responsible for the conditioning of the signal and the digital conversion to obtain the data directly in real-time, and thus create monitoring networks [32], [33], [34].

Table 2 Comparison between sensors that exist in the market for the monitoring of atmospheric pollutants

Reference	**Target gas**	**Detection range**
MICS5525	CO	1-1000 ppm
MICS2710	NO_2	0.5-5ppm
TGS2600	CO, CH_4	500–10.000 ppm
MQ135	CO_2, NH_4, NO_x	10-200 ppm
TIDA-00378	$PM_{2,5}$/PM_{10}	12-35 pcs/cm3
TLAS Sensor Neo Monitors Lasergas™ Q NO_2	NO_2	Min Range NO_2: 0-50 ppm. Max range NO_2: 0-1000 ppm

Note: Sensors developed by different companies worldwide are compared according to the target gas to be measured and their respective detection range.

3.3.3. Semi-Automatic Monitoring

Semi-automatic monitoring devices involve a combination of manual and automatic equipment. Among them are remote control devices combining automatization and human intervention, usually making the process simpler and more reliable. Unmanned aerial vehicles (UAV) have recently been equipped with different automatic sensors to obtain information about the in-situ air quality as well as atmospheric variables, making it possible to collect data that would be inaccessible with other devices, given that they can cover remote areas and places that are difficult to access. They transport easily, are compact, and have minimal infrastructure requirements. In addition, they allow for improved precision in analyzing the distribution of pollutants and validating this information as they describe their in-flight trajectory and behavior and allow for the measurement of pollutants in three-dimensional space. Through mathematical models, a cube of pollution is obtained, providing a clearer view of the influence of pollutants in determined areas [35], [36], [37], [38].

In general, the UAVs need minimal human interaction, given that they can be programmed for automatic take-off and landing, transmitting the information from the sensors during flights and even recording it on internal memory for later review in the case of interrupting the signal through unmanned aerial systems [39], [40].

Different types of UAVs can have diverse types of sensors, such as rotary-wing aircraft, among which can be found helicopters and multi-rotors, as well as airships, convertiplanes, or hybrids. They can also be classified by the type of engine, given that they can be electric, use turbines, or even petrol or other fuel engines. The capacity of the UAVs depends on their size; also, depending on their cost, they can have limitations on energy, speed, and resistance, as well as being adapted for short flights, depending on their propulsion system. However, they can be better adapted to collect information in specific areas, allowing for a greater collection of data and a more precise location of the sources of pollution [41]. Fig. 1 shows the classification of the technologies used for air quality monitoring.

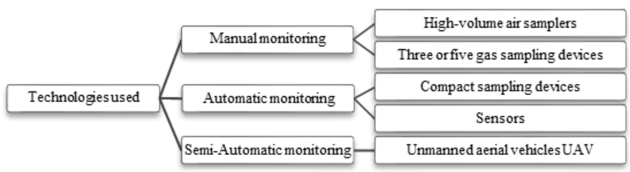

Fig. 1 Classification of technologies used for air quality monitoring (Developed by the authors)

3.4. Meteorological Variables

Meteorological models apply to simulate the transportation and behavior of the pollutants in the atmosphere [42]. Depending on the meteorological characteristics of the sampling location or locations, it is relevant to make a selection of the necessary parameters that have a direct or indirect influence on the spreading of pollutants in the air, their chemical reactions and concentration levels, and their effects on human health. Until now, several studies have been carried out where the maximum and minimum concentrations of polluting gases like O_3, CO, and NO_x relate to variables such as the seasons. In this way, a positive relation has been identified between tropospheric ozone and temperature, as well as a difference in the levels of said gas depending on the direction and speed of the wind, the latter being one of the meteorological variables most strongly associated with polluting gases [43-46].

On the other hand, meteorological processes include diverse atmospheric processes that interact with emissions and air quality in general, such as vertical and horizontal transportation, turbulent mixing, convection, the generation of NO_x induced by light, and the wet and dry deposition on the surface. In addition, the production of aerosols or particles and certain chemical reactions are directly influenced by the relative humidity, solar energy, temperature, and the presence of liquid water [47].

The meteorological variables that are related to air pollution and the different pollutants are the following: the direction of the wind (°), its speed (km/h), the temperature (Kelvin, K), the relative humidity (%), the precipitation pattern (mm) and solar radiation (w/m^2).

3.5. Equipment Location Requirements and Monitoring Time

To measure the air quality, the monitoring device must be at least 10 times its height away from the obstacles and avoid trees and buildings with a perimeter of approximately 10 m. Table 3 shows particular height measurements for air pollutants, considering the scale [48]. To discount the effect of local sources, a perimeter of more than 20 m is necessary from industrial, domestic, or traffic sources. Two main strategies of air pollutant analysis exist regarding measurement time: the measurement of concentrations of long exposure and short exposure.

Table 3 Height measurement and monitoring time for atmospheric pollutants of interest

Pollutant	Scale	Height (m)	Average Time	Measurement Method
SO_2	Medium, local, urban, regional	3 to 15	Annual*	Ultraviolet Fluorescence.
CO	Micro scale, medium, local	3 +/- 0.5	8 hours**	NDIR. (Nondispersive infrared)
O_3	Medium, local, urban, regional	3 to 15	8 h**	UV photometric. Chemiluminescence
NO_2	Medium, local, urban	3 to 15	Annual*	Chemiluminescence
PM_{10}/ $PM_{2.5}$	Micro scale Medium, local, urban, regional	2 to 7 2 to 15	Annual *	Beta Attenuation.

***** *Annual:* 104 measurements per year in a particular site for 24 hours, twice a week at regular intervals
** *8 hours:* Weekly measurements in a particular site for 1 hour at regular intervals

Measurement of concentrations media over long periods corresponds to approximately 24-hour periods over consistent intervals, usually to obtain data on annual concentrations. It applies to measure concentrations where human beings stay for long periods.

Measurement of instantaneous or short-term exposure concentrations provides precise readings with short measurement times. An 8-hour measurement commonly applies, which implies exposure to the population during the work day, or instantaneous measurements (1 hour) to determine concentrations and exposure over a short period or at a determined event. On the other hand, concerning the types of monitoring or study designs to determine the concentration and exposure of the population, these can be direct and indirect. The direct type applies when the exposure profile of a population sample applies to identify that of a whole population. The indirect method develops simulated exposure profiles by combining information on the amount of time that people dedicate to certain activities with the concentration associated with those activities. There are temporal distributions associated with the measured pollutant according to its respective measurement method, as indicated in Table 3 [49].

3.5.1. Measurement Implementation Protocol According to the Monitoring Scale

According to U.S. EPA, six scales of spatial representativeness used to locate the monitoring systems in a site exist; each one fulfills specific monitoring objectives, as seen in Table 4 [48]. The air quality monitoring scale must be representative of and appropriate for this. Some parameters have to be considered, such as the spatial representativeness scale related to each pollutant for the physical localization of the place and the monitoring stations.

Table 4 Air quality monitoring scales [48]

Category	Definition
Micro- Scale	< 100 m
Medium Scale	100 –500 m
Local Scale	500–4000 m
Urban Scale	4000–50000 m (50 km)
Regional Scale	It defines a rural area or a homogeneous geography.
National or Global Scale	Characteristics of a nation or the world in general.

According to the objective of the monitoring, it is necessary to determine the appropriate spatial scales. The measurements of high concentrations use a micro, medium, local, and urban scale. Measurements of the effects on the population take place at a local and urban scale, and the impact of sources is developed on a micro, medium, and local scale [48].

3.6. Initiatives of Air Quality Measurements on a Global Context

Air pollutant monitoring processes originate from the perception of air quality as a resource directly related to human health. However, the first efforts to improve it only really took place after severe environmental impacts caused by socio-economic activities developed in different regions. These impacts became visible to the populations due to the deterioration of their quality of life, in addition to being the cause of diseases in the people exposed. As a result of the importance of air quality as an environmental parameter, as from before the 19th century, there have been many attempts to create public policies that regulate the activities that generate air pollutants, introducing concentration limits and also creating production alternatives that minimize environmental impact. Due to technological developments and the improvement in the precision of the data obtained, many changes have taken place concerning the measurement methods of pollutants present in the atmosphere, focusing especially on the practicality of the means of data quantification and collection.

3.6.1. Europe

The concerns to carry out air quality monitoring associated with its effect on health and visibility or the deterioration of the landscape took place in Europe due to an event called The Great Smog of London or The Great Smog of 1952. The combination of climatic variables, such as the poor wind circulation with the pollution generated by the use and burning of coal led to a dense layer of smog in the city, which took five days to dissipate. Due to this situation, the government of the United Kingdom introduced the Clean Air Act in 1956 to reduce the emissions of pollutants produced by domestic sources, forbidding the production of black smoke from chimneys and establishing smog control areas [50]. This was followed by the Clean Air Act of 1968, which established concepts like the height of chimneys to reduce the impacts associated with the levels of exposure to SO2 or sulfur dioxide and to reduce these pollutants as much as possible, which are products of combustion. After that, the first act of pollution control was issued, the Control of Air Pollution Act in 1974 [51], followed by the National Air Quality Strategy in 1997. Following these national policies, it was sought to implement new regulation levels and control strategies to mitigate the impact generated by air pollutants, associating them with human health issues and the deterioration of the environment. These acts have been periodically updated and have given rise to new national public policies focused on the constant improvement of the quality of the air.

In the United Kingdom, the local authorities monitor the levels of air pollution, including pollutants like PM10, PM2.5, tropospheric O3, SO2, and NOx, using automatic monitoring networks which report information in 1-hour intervals. In addition, they use non-automatized monitoring stations, where the data is collected manually on a daily, weekly, and monthly basis [52]. However, the information in real-time is not generally public knowledge, instead, people are informed about the quality of the urban air through a daily index, where the levels of pollution are classified on a scale from 1 to 10, from very low to very high [53].

3.6.2. North America

In the United States, the first federal law regarding air pollution was enacted in 1955 under the Air Pollution Control Act [54]. However, over the years, several jurisdictions attempted to pass regulations related to air quality, but they failed in their implementation [55]. In 1958, the Public Health Service held the first National Conference on Air Pollution in Washington. The Clean Air Act [56], declared by the government of the United States as a federal law in 1970, regulated the emissions coming from stationary and mobile sources. With this, the EPA established the National Ambient Air Quality Standards, commonly known as NAAQS. By 1974, emission standards for 50 cities and counties and regulations for 29 substances appeared. Since the first Clean Air Act, more amendments have been made to it under the direction of the EPA in the years after its first publication. The latest amendment was in 1990 when NAAQS set six principal pollutants considered toxic for human health and the environment. In addition, two types of standards were recognized. Primary standards protect public health, including the protection of the health of sensitive populations with asthma, children, and the elderly. The secondary standards protect the well-being, including against reduced visibility and harm to animals, crops, vegetation, and buildings/constructions [57].

The EPA has a Menu of Control Measures (MCM), most recently updated in 2012, which provides state, local and tribal agencies with information on existing emission reduction measures and relevant information concerning the efficiency and cost-effectiveness of the measures. State, local and tribal agencies can use this information to develop emissions reduction strategies, plans, and programs to assure that they attain and maintain the National Ambient Air Quality Standards [58].

The United States has networks integrated by the EPA that established and expanded the monitoring of ultrafine particulate matter or small particles of less than 2.5 microns, increasing the number of local and state air monitoring stations. In the last decade, these programs called the National Chemical Speciation Network (CSN) & Interagency Monitoring of Protected Visual Environments (IMPROVE), have been established, which obtain information about the spatial and temporal chemical composition of ultrafine particles [59].

On the other hand, satellite remote sensing is used with more frequency to control the quality of the air in localized sources in Canada and some states in the north of the United States. For this reason, an Ozone Monitoring Instrument (OMI) has been used to develop new monitoring methods for other polluting gases, such as SO2 [60], [61].

3.6.3. Asia

Most of the people who inhabit Asian cities are exposed to high levels of air pollution both indoors and outdoors, which are harmful to health, contributing to 2.1 million premature deaths on this continent every year [62]. The deteriorated quality of the air in Asian cities is the result of rapid economic expansion, population growth, the increase of industries, and the number of circulating vehicles. To counteract this growing impact, the Air (Prevention & Control of Pollution) Act was created by the government of India in 1981 [63], establishing controls and requiring permits for industries and other activities that generate pollution. In 1986, the Environment (Protection) Act was created by which the central government of India takes the necessary measures to protect and improve the environment, and also to prevent, control, and reduce air pollution, through the restriction of certain activities that have adverse impacts on the environment [64]. In addition, special acts were created for the control of the pollution produced by motor vehicles, such as the Motor Vehicles Act [65] and the Central Motor Vehicles Rules [66], in 1988 and 1989, respectively. Moreover, cities like Mumbai, in India, joined the Metropolitan Environmental Improvement Program (MEIP) [67], which is a pilot program developed in the year 1989 that sought to find innovative solutions to environmental problems in cities of the Asian continent.

As a result of the issues related to air quality that occur in cities, the Urban Air Quality Management Strategy in Asia (URBAIR) was developed and launched in Mumbai in 1992 [68]. In the evaluation of air quality described in this report, the concentrations of air pollutants are shown, obtaining an estimation of the population exposure and quantifying the contribution of different sources to the emission of pollution.

In 2001, Clean Air Asia was established as the air quality-monitoring network by the Development Bank of Asia, the World Bank, and the United States Agency for International Development to implement policies and actions to reduce air pollution and greenhouse gas emissions from activities such as transport, energy production, and other sectors [69].

At present, Asian countries like China have experienced serious and persistent levels of air pollution. Despite improving in the last few years, pollution due to ultrafine particles in winter has worsened. Furthermore, the high levels of O3 and other pollutants measured by the air quality monitoring stations found in the country represent a threat to public health [70].

3.6.4. Africa

Energy generation in South Africa is mainly dependent on the burning of coal, which results in the emission of different atmospheric pollutants like particulate matter, sulfur dioxide, nitrogen oxides, and mercury.

The impact on air quality caused by the pollutants resulting from the generation of energy is felt greatly in the province of Mpumalanga, where most of the coal reserves are located [71]. Historically has been very little recognition of the importance of developing air quality controls on the African continent, given that many African countries refuse to bear the costs of monitoring system implementation and the maintenance of an air quality monitoring system [72]. Furthermore, there is limited data regarding air pollution in major cities like Nairobi – Kenya, where the open-air burning of biomass generates pollution. According to estimates, motor vehicles cause 90% of urban pollution, additionally to domestic cooking and industrial activities [73].

The meteorology study of the air polluting episodes in South Africa used estimations from the OMI and AIRS satellites and climatic models produced in situ since 2004. Said satellites estimate the concentrations of tropospheric NO_2, SO_2, CO, and particulate matter. This information is mostly provided by the AIRS satellite [74].

3.6.5. Latin America

Polluted air is a relevant health hazard in developing countries. According to a report published by the Clean Air Institute (CAI) in 2013 more than 100 million people in Latin America breathe polluted air [75].

In 1980 REDPANAIRE ceased activities and joined the Global Programme of Air Quality Monitoring, initiated in 1976 by the World Health Organization and the United Nations Programme for the Environment, UNPE, as part of the Global Environmental Monitoring System (GEMS) [76]. In the 1990s, the WHO guaranteed the Air Monitoring Information System (AMIS) globally, where the GEMS was integrated [77].

The evolution of air quality monitoring in Latin America used the reports presented in the meeting of health and environment agents of the Pan American Health Organization (PAHO), in conjunction with the WHO and the collaborators from the Air Quality Monitoring in the Americas, celebrated in Mexico F.D. in 1996; in addition to the reports prepared by the agents of the PAHO and the WHO in early 1998 [78].

Most of the data available on developing countries was about PST concentrations, a measure that includes large particles. During the last decade, the information about air pollution in Latin American countries has remained behind that of the United States and Europe, given that only eight countries have established national air quality standards for PM2.5 [79]. Additionally, countries like Argentina show critical levels of NOx and particulate matter in the atmosphere, especially in the largest and most populated cities with few air quality monitoring stations on their territory [80].

Proposals for monitoring air quality and making use of unmanned aerial vehicles have been little documented in Latin America. However, it is worth mentioning that there are projects like “QAirA”, carried out in Peru, where a drone was adapted with sensors to measure the quality of the air and provides data in real-time about air pollutants, such as carbon oxide, ozone, nitrogen dioxide, sulfur dioxide, and hydrogen sulfide, among other atmospheric variables such as temperature and atmospheric pressure [81]. Moreover, in Colombia, there is a proposal to measure air quality in real-time using an aerial drone with the capacity to measure concentrations of CO2, propane, butane, humidity, temperature, and smoke [82].

4. Discussion

This research has found that first-world countries have a closer relationship with air pollution control, regulating this issue with public policies and bringing the population, in general, closer to the information regardless of this topic making atmospheric contamination a public health issue. These countries have greater advances in developing technology for air quality monitoring, while in third-world countries, there is less information accessible about air quality monitoring systems and the treatment of the data obtained from this source. This information leads to the need to develop more types of systems and technologies for the recollection of air pollutants concentration data, highlighting the importance of making that information accessible to the general population.

To provide data regarding air pollution as a global environmental issue, it seeks to create an alternative for air quality monitoring using UAVs, driven remotely, also known as a drone. It would be adapted with air pollutant measuring sensors for its respective remote use, aiming to collect data about the concentrations within a certain period and, thus, relate them with the periods in which the populations are exposed to said pollutants in particular areas or trajectories.

This method includes three phases. In the first, the location for the measurements and the characterization of the working area are determined; in the second, the pollutants to be tested are decided upon, as well as the corresponding sensors for data collection; and in the third, the implementation takes place in the infrastructure for sample taking and data analysis described in the following five modules:

(1) Drone adapted with gas sensors for measuring atmospheric pollutants and particulate matter.

(2) Remote control operated manually to handle the drone during its flight.

(3) Wireless communication protocol established between sensors and the data processing software.

(4) Software for processing signals emitted by the drone during data collection.

(5) Generation and delivery of reports based on the data analyzed.

Fig. 2 shows a general schematic of the implementation of the architecture.

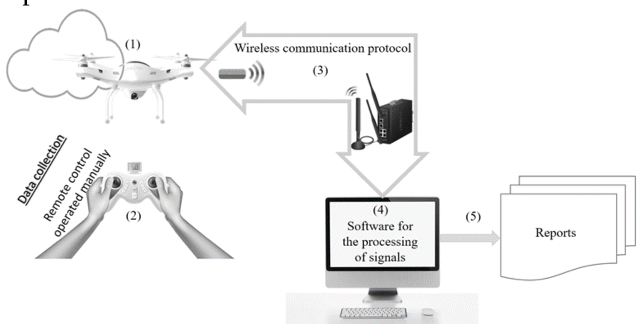

Fig. 2 Proposed air quality monitoring system (Developed by the authors)

The drone will be capable of covering and taking measurements in remote areas, including difficult-to-access areas, to learn information about different locations as regards their existing degree of pollution and the primary sources of emission of the particles and pollutants which cause adverse effects to the health of the communities exposed to them.

The aim of developing the technological platform described is the later publication and diffusion of the data regarding concentrations of atmospheric pollutants and determining air quality in the set study areas. Thus, this data will serve as the basis for future studies regarding the risks of exposure. It will also be sought to create a geographical model that is periodically updated, and which is portable, and available to the population in general, making use of the geographical information systems and current technologies to highlight the most and least contaminated traversable areas.

5. Conclusion

Implementing public policies that seek to continuously reduce the environmental impact principally caused by anthropogenic activities is vital in the control of air pollution. This will lead to the improvement of the quality of life in countries, along with their development and progress.

Some third-world countries, such as countries in Africa, have very little information regarding air quality and its monitoring, so they lack proposals for pollution control and reduction when compared to developed countries where the initiatives for the monitoring of environmental variables have been implemented and updated over time.

The different techniques employed for the measurement of air quality are chosen based on the analysis of the variables through chemical methodologies. Therefore, their improvement is the result of the implementation of ever newer technologies which allow for greater precision and also for the automatization of monitoring, as well as a greater knowledge of the atmospheric variables and a more immediate collection of data. Their precision mainly depends on the type of pollutant monitoring used or on the treatment of the data.

The global population can be affected positively by the regulation of atmospheric pollution and the constant technological advances related to air quality monitoring, given the direct relationship between life quality and environmental health. Newer air quality monitoring methods bring people closer and, in a faster way, to the information about the pollutants they are being exposed to daily.

Overall, the academic contribution of this work lies in its comprehensive review of air quality monitoring, the proposal of an alternative monitoring system, and the exploration of the implications for human health. These contributions bring innovation to the existing literature by providing fresh insights, proposing alternative approaches, and fostering a deeper understanding of the importance of air quality for human well-being and environmental protection. The study expands the knowledge base on air quality monitoring by synthesizing and analyzing the available information, providing a valuable resource that offers a comprehensive understanding of the subject matter.

Additionally, the proposed alternative monitoring system presents innovative ideas and methodologies, addressing potential limitations and paving the way for future developments in the field. By emphasizing the link between air quality and human health, the study raises awareness among individuals and communities, underscoring the significance of monitoring and addressing air pollution. These academic contributions collectively contribute to the ongoing efforts to improve air quality and protect human well-being.

6. Limitations of the Study

This scientific paper acknowledges several limitations that should be considered when interpreting the findings. First, the inclusion criteria for the literature review focused on articles published in English and Spanish, which introduces the potential for language bias. Relevant studies published in other languages may have been excluded, limiting the comprehensiveness and generalizability of the findings. Future studies should aim to include a wider range of languages to ensure a more representative sample of the available research.

Secondly, the time frame for the literature search was confined to articles published from 1980 to 2020. While this period provides a substantial understanding of the evolution of air quality monitoring, it may not capture the most recent advancements or initiatives in the field. The rapid pace of technological developments in recent years necessitates ongoing monitoring of the literature to stay up-to-date with the latest research and advancements in air quality monitoring.

Additionally, publication bias is a potential limitation inherent in any literature review. The reliance on published studies may introduce a bias towards positive or significant findings while excluding unpublished studies or those published in less accessible sources. Future studies should aim to mitigate this limitation by incorporating additional sources of information and including unpublished or grey literature to provide a more comprehensive analysis.

References

[1] MANNUCCI P.M., and FRANCHINI M. Health effects of ambient air pollution in developing countries. International *Journal of Environmental Research and Public Health*, 2017, 14(9), 1-8. https://doi.org/10.3390/ijerph14091048

[2] SEINFELD J. 1986 Atmospheric Chemistry and Physics of Air Pollution. *Geochimica et Cosmochimica Acta*, 512. https://doi.org/10.1063/1.882420

[3] CROUSE D.L., PETERS P.A., HYSTAD P., BROOK J.R., VAN DONKELAAR A., MARTIN R.V., VILLENEUVE P.J., JERRETT M., GOLDBERG M.S., ARDEN POPE C., BRAUER M., BROOK R.D., ROBICHAUD A., MENARD R., and BURNETT R.T. Ambient PM2.5, O3, and NO2 exposures and associations with mortality over 16 years of follow-up in the canadian census health and environment cohort. *Environmental Health Perspectives*, 2015, 123(11): 1180-1186. https://doi.org/10.1289/ehp.1409276

[4] LAZRAK N., ZAHIR J., and MOUSANNIF H. Air Quality Monitoring Using Deterministic and Statistical Methods. In: FARHAOUI Y., and MOUSSAID L. (eds.) Big Data and Smart Digital Environment. *Studies in Big Data*, 53. Springer, Cham, 2019. https://doi.org/10.1007/978-3-

030-12048-1_39
[5] KHANIABADI Y.O., GOUDARZI G., DARYANOOSH S.M., BORGINI A., TITTARELLI A., and DE MARCO A. Exposure to PM10, NO2, and O3 and impacts on human health. *Environmental Science and Pollution Research*, 2017, 24(3): 2781-2789. https://doi.org/10.1007/s11356-016-8038-6
[6] LEE, H., MYUNG, W., KIM, D.K., KIM, S.E., KIM, C.T., and KIM H. Short-term air pollution exposure aggravates Parkinson's disease in a population-based cohort. *Scientific Reports*, 2017, 7: 44741. https://doi.org/10.1038/srep44741
[7] U.S. ENVIRONMENTAL PROTECTION AGENCY. *The lead-safe certified guide to renovate right*. 2010. https://www.epa.gov/sites/production/files/2020-09/documents/renovaterightbrochurebwlandscapesept2011.pdf
[8] U.S. ENVIRONMENTAL PROTECTION AGENCY. *Overview of the human health and environmental effects of power generation: focus on sulfur dioxide, nitrogen oxides, and mercury*. Clear Skies Initiative, 2002. https://archive.epa.gov/clearskies/web/pdf/overview.pdf
[9] DEHGHANI M., KESHTGAR L., REZA M., and DERAKHSHAN Z. The effects of air pollutants on the mortality rate of lung cancer and leukemia. *Molecular Medicine Reports*, 2017, 3390-3397. https://doi.org/10.3892/mmr.2017.6387
[10] SBARATO D., and SBARATIO V. *Air pollution*. 2009.
[11] Warner P.O. *Analysis of air pollutants*. Auditorium, Madrid, 1981.
[12] IDEAM. *Reference method for the determination of sulfur dioxide (SO_2) in the atmosphere (para-rosaniline method)*. 2010: 1-22. http://www.ideam.gov.co/documents/51310/527464/3.+DIOXIDO_DE_AZUFRE_V04_VB.pdf/66cf1c9b-e25f-43b8-a634-156fd41cef0f
[13] OSPINA A., and GARRIDO M. Ozone measurement techniques: Traditional versus chamber absorption methods with ultraviolet. *Management and Environment*, 2013, 16(2) 95-104.
[14] MARCOS R., CABRERA M., LAOS H., MAMANI D., and VALDERRAMA A. Comparative study for the determination of the atmospheric dust sedimentable employing the methodologies of passive pipe and of plate's receptor as in the University Campus of San Marcos. *Scientific Journal of the Center for Development and Research in Thermofluids*, 2008, 1(3): 49-58.
[15] SHIN S.E., JUNG C.H. AND KIM Y.P. Analysis of the Measurement Difference for the PM10 Concentrations between Beta-ray Absorption and Gravimetric Methods at Gosan. *Aerosol and Air Quality Research*, 2011, 11: 846-853. https://doi.org/10.4209/aaqr.2011.04.0041
[16] FU L., NUNIFU T., and LEUNG B. A two-step approach for relating tapered element oscillating microbalance and dichotomous air sampler PM2.5 measurements. *Journal of the Air and Waste Management Association*, 2014, 64(10): 1195-1203. https://doi.org/10.1080/10962247.2014.934484
[17] JIMENEZ A.M., and NAVAS M.J. *Chemiluminescence methods (present and future). Fats* and Oils, 2002, 53: 64-75. https://doi.org/10.3989/gya.2002.v53.i1.290
[18] MINISTRY OF ENVIRONMENT, HOUSING AND TERRITORIAL DEVELOPMENT. *Air Quality Surveillance Systems Operation Manual. Protocol 1.* 2010. https://www.minambiente.gov.co/wp-content/uploads/2021/06/Protocolo_Calidad_del_Aire_-_Manual_Operacion.pdf
[18] ALASKA POWER AUTHORITY. *Hi-Volume air monitoring program: initial monitoring and quality assurance report. Federal Energy Regulatory Commission Project No. 7114*. 1984. https://www.arlis.org/docs/vol1/Susitna/16/APA1695.pdf
[19] HEIM M., MULLINS B., UMHAUER H., and KASPER G. Performance evaluation of three optical particle counters with an efficient "multimodal" calibration method. *Journal of Aerosol Science*, 2008, 39(12): 1019-1031. https://doi.org/10.1016/j.jaerosci.2008.07.006
[20] KRUG J., DART A., WITHERSPOON C., GILBERRY J., MALLOY Q., KAUSHIK S., VANDERPOOL R., KRUG J., DART A., WITHERSPOON C., and GILBERRY J. Revisiting the size selective performance of EPA's high-volume total suspended particulate matter sampler. *Aerosol Science and Technology*, 2017, 51(7): 868-878. https://doi.org/10.1080/02786826.2017.1316358
[21] U.S. ENVIRONMENTAL PROTECTION AGENCY. *Air Pollution Control Technology Fact Sheet - Spray-Chamber and Spray-Tower Wet Scrubber*. 2003 https://www3.epa.gov/ttnchie1/mkb/documents/fcataly.pdf
[22] NEWSTAR ENVIRONMENTAL. *RAC 3 - Gas Sampler*. 2022. http://www.newstarenvironmental.com/rac-3-gas-sampler.html
[23] THERMO FISHER SCIENTIFIC. *Model 5014i Beta Continuous Particulate Monitor*. 2022. https://www.thermofisher.com/order/catalog/product/5014I#/5014I
[24] ECOTECH - ENVIRONMENT MONITORING SOLUTIONS. *Serinus 50. Sulfur Dioxide Analyser - User Manual Version 3.3*. 2022. https://www.ecotech.com/wp-content/uploads/2022/03/M010029-Serinus-50-SO2-User-Manual-3.3.pdf
[25] ANAGNOSTOPOULOS C., HADJIEFTHYMIADES S., and KOLOMVATSOS K. Accurate, dynamic, and distributed localization of phenomena for mobile sensor networks. *ACM Transactions on Sensor Networks*, 2016, 12(2). https://doi.org/10.1145/2882966
[26] ARVIND D.K., MANN J., BATES A., and KOTSEV K. The AirSpeck family of static and mobile wireless air quality monitors. In: *Proceedings* of 19th Euromicro Conference on Digital System Design, 2016: 207-214. https://doi.org/10.1109/DSD.2016.110
[27] KAUR S., NIEUWENHUIJSEN M., and COLVILE R. Personal exposure of street canyon intersection users to PM2.5, ultrafine particle counts and carbon monoxide in Central London, UK. *Atmospheric Environment*, 2005, 39(20): 3629-3641. https://doi.org/10.1016/j.atmosenv.2005.02.046
[28] MCKERCHER, G.R., SALMOND, J.A., and VANOS, J.K. Characteristics and applications of small, portable gaseous air pollution monitors. *Environmental Pollution*, 2017, 223: 102-110. https://doi.org/10.1016/j.envpol.2016.12.045
[29] CHOI S., KIM D.J., CHOI Y.Y., PARK K., KIM S.W., WOO S.H., and KIM J.J. A multisensor mobile interface for industrial environment and healthcare monitoring. *IEEE Transactions on Industrial Electronics*, 2017, 64(3): 2344-2352. https://doi.org/10.1109/TIE.2016.2626239
[30] GOZZI F., DELLA VENTURA G., and MARCELLI A. Mobile monitoring of particulate matter: State of art and

perspectives. *Atmospheric Pollution Research*, 2016, 7(2): 228-234. https://doi.org/10.1016/j.apr.2015.09.007
[31] LOH M., SARIGIANNIS D., GOTTI A., KARAKITSIOS S., PRONK A., KUIJPERS E., ANNESI-MAESANO I., BAIZ N., MADUREIRA J., FERNANDES E.O., JERRETT M., and CHERRIE J.W. How sensors might help define the external exposome. *International Journal of Environmental Research and Public Health*, 2017, 14(4). https://doi.org/10.3390/ijerph14040434
[32] BARAKEH Z., BREUIL P., REDON N., PIJOLAT C., LOCOGE N., and VIRICELLE J.P. Development of a normalized multi-sensors system for low cost on-line atmospheric pollution detection. *Sensors and Actuators, B: Chemical*, 2017, 241: 1235-1243. https://doi.org/10.1016/j.snb.2016.10.006
[33] DUTTA J., GAZI F., ROY S., and CHOWDHURY C. AirSense: Opportunistic crowd-sensing based air quality monitoring system for smart city. In: *2016 IEEE Sensors, 30 October 2016 – 03 November 2016, Orlando, USA*. 2017: 5-7. https://doi.org/10.1109/ICSENS.2016.7808730
[34] KHUNSONGKIET P., and BOONCHIENG E. Converting air quality monitoring low cost sensor data to digital value via mobile interface. In: *2016 9th Biomedical Engineering International Conference (BMEiCON), 07-09 December 2016, Laung Prabang, Laos*. 2016, https://doi.org/10.1109/BMEiCON.2016.7859628
[35] HAAS P.Y., BALISTRERI C., PONTELANDOLFO P., TRISCONE G., PEKOZ H., and PIGNATIELLO A. Development of an unmanned aerial vehicle UAV for air quality measurement in urban areas. In: *32nd AIAA Applied Aerodynamics Conference*, 2014: 1-9. https://doi.org/10.2514/6.2014-2272
[36] TOSCANO P., GIOLI B., DUGHERI S., SALVINI A., MATESE A., BONACCHI A., ZALDEI A., CUPELLI V., and MIGLIETTA F. Locating industrial VOC sources with aircraft observations. *Environmental Pollution*, 2011, 159(5): 1174-1182. https://doi.org/10.1016/j.envpol.2011.02.013
[37] WATAI T., MACHIDA T., ISHIZAKI N., INOUE G., WATAI T., MACHIDA T., ISHIZAKI N., and INOUE G. A lightweight observation system for atmospheric carbon dioxide concentration using a small unmanned aerial vehicle. *Journal of Atmospheric and Oceanic Technology*, 2006, 23(5): 700-710. https://doi.org/10.1175/JTECH1866.1
[38] ZHOU X., AURELL J., MITCHELL W., TABOR D., and GULLETT B. A small, lightweight multipollutant sensor system for ground-mobile and aerial emission sampling from open area sources. *Atmospheric Environment*, 2017, 154, 31-41. https://doi.org/10.1016/j.atmosenv.2017.01.029
[39] MINGIREANU F., GRIGORESCU S., CEPISCA C., STEFAN C., MOCANU I., and GEORGESCU L.P. Methods of Spatial Modeling for Evaluation of Air Quality based on UAV. *Recent Advances in Energy and Environmental Management*, 2013: 25-28. http://www.wseas.us/e-library/conferences/2013/Rhodes/ENVIR/ENVIR-02.pdf
[40] VILLA T.F., SALIMI F., MORTON K., MORAWSKA L., and GONZALEZ F. Development and validation of a UAV based system for air pollution measurements. *Sensors (Switzerland)*, 2016, 16(12). https://doi.org/10.3390/s16122202
[41] VILLA T., GONZALEZ F., MILJIEVIC B., RISTOVSKI Z., and MORAWSKA L. An Overview of Small Unmanned Aerial Vehicles for Air Quality Measurements: Present Applications and Future Prospectives. *Sensors*, 2016, 16(7): 1072. https://doi.org/10.3390/s16071072
[42] GILLIAM R.C., HOGREFE C., and RAO S.T. New methods for evaluating meteorological models used in air quality applications. *Atmospheric Environment*, 2006, 40(26): 5073-5086. https://doi.org/10.1016/j.atmosenv.2006.01.023
[43] AZNARTE J.L. Probabilistic forecasting for extreme NO2 pollution episodes. *Environmental Pollution*, 2017, 229: 321-328. https://doi.org/10.1016/j.envpol.2017.05.079
[44] BANTA R.M., SENFF C.J., ALVAREZ R.J., LANGFORD A.O., PARRISH D.D., TRAINER M.K., DARBY L.S., HARDESTY, R.M., LAMBETH B., NEUMAN, J.A., ANGEVINE W.M., NIELSEN-GAMMON J., SANDBERG S.P., and WHITE A.B. Dependence of daily peak O3 concentrations near Houston, Texas on environmental factors: Wind speed, temperature, and boundary-layer depth. *Atmospheric Environment*, 2011, 45(1): 162-173. https://doi.org/10.1016/j.atmosenv.2010.09.030
[45] KATSOULIS B.D. The relationship between synoptic, mesoscale and microscale meteorological parameters during poor air quality events in Athens, Greece. *Science of the Total Environment*, 1996, 181(1): 13-24. https://doi.org/10.1016/0048-9697(95)04953-3
[46] TONG L., ZHANG H., YU J., HE M., XU N., ZHANG J., QIAN F., FENG J., and XIAO H. Characteristics of surface ozone and nitrogen oxides at urban, suburban and rural sites in Ningbo, China. *Atmospheric Research*, 2017, 187: 57-68. https://doi.org/10.1016/j.atmosres.2016.12.006
[47] SEAMAN N.L. Meteorological modeling for air-quality assessments. *Atmospheric Environment*, 2000, 34(12-14): 2231-2259. https://doi.org/10.1016/S1352-2310(99)00466-5
[48] GENERAL DIRECTORATE OF ENVIRONMENTAL HEALTH. 2005 Air Quality Monitoring Protocol and Data Management. *Digesa*, 1, 71. http://www.digesa.minsa.gob.pe/norma_consulta/Protocolo-de-Calidad-del-Aire.pdf
[49] CENTRAL POLLUTION CONTROL BOARD, and MINISTRY OF ENVIRONMENT and FORESTS. *Guidelines for the Measurement of Ambient Air Pollutants*. 2009.
http://mahenvis.nic.in/Pdf/Report/report_epm_NAAQMS.pdf
[50] PARLIAMENT OF THE UNITED KINGDOM. *Clean Air Act*. 1956. https://www.legislation.gov.uk/ukpga/1956/52/pdfs/ukpga_19560052_en.pdf
[51] RSPH. Control of Pollution Act 1974. The *Journal of the Royal Society for the Promotion of Health*, 1974, 97(2): 1-144. https://doi.org/10.1177/146642407709700203
[52] HUCK J.J., WHYATT J.D., COULTON P., DAVISON B., and GRADINAR A. Combining physiological, environmental and locational sensors for citizen-oriented health applications. *Environmental Monitoring and Assessment*, 2017, 189(3). https://doi.org/10.1007/s10661-017-5817-6
[53] DEFRA. *Air Quality Statistics in the UK. DEFRA National Statistics Release: Air Quality Statistics in the UK 1987 to 2016*. 2017.
[54] UNITED STATES CONGRESS. *Air Pollution Control Act 787*. 1955.
[55] STERN A.C. History of Air Pollution Legislation in the United States. *Journal of the Air Pollution Control*

Association, 1982, 32(1): 44-61. https://doi.org/10.1080/00022470.1982.10465369

[56] U.S. ENVIRONMENTAL PROTECTION AGENCY. *Clean Air Act Text*. U.S. Government Printing Office, 1970. https://www.epa.gov/clean-air-act-overview/clean-air-act-text

[57] U.S. ENVIRONMENTAL PROTECTION AGENCY. *National Ambient Air Quality Standards (NAAQS)*. Office of Air Quality Planning and Standards, 4, 2014 http://www.epa.gov/air/criteria.html

[58] U.S. ENVIRONMENTAL PROTECTION AGENCY. *Menu of Control Measures*, 2012: 1194-1196. https://19january2017snapshot.epa.gov/sites/production/files/2016-02/documents/menuofcontrolmeasures.pdf

[59] SOLOMON P.A., CRUMPLER D., FLANAGAN J.B., JAYANTY R.K.M., RICKMAN E.E., and MCDADE C.E. U.S. National PM2.5 chemical speciation monitoring networks-CSN and IMPROVE: Description of networks. *Journal of the Air and Waste Management Association*, 2014, 64(12): 1410-1438. https://doi.org/10.1080/10962247.2014.956904

[60] FIOLETOV V.E., MCLINDEN C.A., KROTKOV N., and LI C. Lifetimes and emissions of SO_2 from point sources estimated from OMI. *Geophysical Research Letters*, 2015, 42(6): 1969-1976. https://doi.org/10.1002/2015GL063148

[61] MCLINDEN C.A., FIOLETOV V., BOERSMA K.F., KHAROL S. K., KROTKOV, N., LAMSAL, L., MAKAR, P.A., MARTIN, R.V., VEEFKIND J.P., and YANG K. Improved satellite retrievals of NO_2 and SO_2 over the Canadian Oil Sands and comparisons with surface measurements. *Atmospheric Chemistry and Physics*, 2014, 14(7): 3637-3656. https://doi.org/10.5194/acp-14-3637-2014

[62] ASIA DEVELOPMENT BANK. *Improving air quality monitoring in Asia*. 2014. http://learning-cleanairasia.org/lms/library/ga1/02-Improving-Air-Quality-Monitoring-in-Asia.pdf

[63] GOVERNMENT OF INDIA. *The Air Prevention and Control of Pollution Act*. 1981: 1-45. http://legislative.gov.in/sites/default/files/A1981-14.pdf

[64] GOVERNMENT OF INDIA. *The Environment Protection Act*. Ministry of Environment and Forests, Department of Environment Forests and Wildlife. 1986. https://www.iitr.ac.in/wfw/web_ua_water_for_welfare/environment/eprotect_act_1986.pdf

[65] GOVERNMENT OF INDIA. *The Motor Vehicles Act*. 1988. http://legislative.gov.in/sites/default/files/A1988-59.pdf

[66] GOVERMENT OF INDIA. *The Central Motor Vehicles Rules*. 1989. http://chdtransport.gov.in/Forms/CMVR_1989.pdf

[67] WORLD BANK and UNDP. *The Metropolitan Environmental Improvement Program (MEIP) in A*sia. 1989. http://documents1.worldbank.org/curated/en/289871468772748976/pdf/multi-page.pdf.

[68] METROPOLITAN ENVIRONMENTAL IMPROVEMENT PROGRAM. *Urban air quality management strategy in Asia: Kathmandu Valley report*. 1996. http://search.ebscohost.com/login.aspx?direct=trueanddb=ecnandAN=0470203andsite=ehost-live.

[69] CLIMATE INITIATIVES PLATFORM. *Clean Air Asia*. 2001. https://climateinitiativesplatform.org/index.php/Clean_Air_Asia

[70] SONG C., WU L., and XIE Y. Air pollution in China: Status and spatiotemporal variations. *Environmental Pollution*, 2017, 227: 334-347. https://doi.org/10.1016/j.envpol.2017.04.075

[71] U.S. ENVIRONMENTAL PROTECTION AGENCY. Air Quality. In: *Environmental Outlook*, 2011: 182-207. http://www.epa.ie/air/quality/

[72] ECONOMIC AND SOCIAL COMMISSION FOR WESTERN ASIA and LEAGUE OF ARAB STATES. *Air quality and atmospheric pollution in the Arab region*. United Nations National Environment Programme, Regional Office for West Asia. 2006: 1-40.

[73] KINNEY P.L., GICHURU M.G., VOLAVKA-CLOSE N., NGO N., PETER, K., LAW A., GACHANJA A., GAITA S.M., CHILLRUD S.N., and SCLAR E. Traffic impacts on PM2.5 air quality in Nairobi, Kenya. *Environmental Science and Policy*, 2012, 14(4): 369-378. https://doi.org/10.1016/j.envsci.2011.02.005

[74] JURY M.R. Statistics and meteorology of air pollution episodes over the South African highveld based on satellite-model datasets. *Journal of Applied Meteorology and Climatology*, 2017, 56(6): 1583-1594. https://doi.org/10.1175/JAMC-D-16-0354.1

[75] BIFFI C.A., and TUISSI A. State of the art on additive manufacturing techniques for metals. *Italian Metallurgy*, 2017, 109(1): 5-10. https://doi.org/10.1017/CBO9781107415324.004

[76] GEMS and WHO. *The Quality of the Environment: A Health-Based Global Assessment*. 1988. https://apps.who.int/iris/handle/10665/62009

[77] WHO. *A Healthy Cities Programme for Urban Air Quality Management*. 1997: 1-43. https://docplayer.net/64004193-A-healthy-cities-programme-for-urban-air-quality-management.html

[78] KORC M. Air quality monitoring in Latin America. In: *Air Pollution Control Program*. 1999. https://www.paho.org/es/file/50078/download?token=84h55RCq

[79] FAJERSZTAJN L., SALDIVA P., PEREIRA L.A.A., LEITE V.F., and BUEHLER A.M. Short-term effects of fine particulate matter pollution on daily health events in Latin America: a systematic review and meta-analysis. *International Journal of Public Health*, 2017, 62: 729-738. https://doi.org/10.1007/s00038-017-0960-y

[80] GARCIA F., CURCI G., and LANFRI M. First Implementation of the WRF-CHIMERE-EDGAR Modelling System Over Argentina. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 2016, 9(12): 5304-5314. https://doi.org/10.1109/JSTARS.2016.2588502

[81] ABARCA M., SAITO C., and CUÉLLAR F. *QAIRamap*. 2015. http://www.qairadrones.com/index.php?r=site/nosotros

[82] LOAIZA J.P., GIRALDO E., and AGUIRRE E. *Device measures air quality in real time*. National University of Colombia, 2016. http://agenciadenoticias.unal.edu.co/detalle/article/dispositivo-mide-calidad-del-aire-en-tiempo-real.html

参考文:

[1] MANNUCCI P.M. 和 FRANCHINI M. 發展中國家環境空氣污染對健康的影響。國際環境研究與公共衛生雜

誌，2017，14(9)，1-8。https://doi.org/10.3390/ijerph14091048
[2] SEINFELD J. 1986 大氣化學和空氣污染物理學。地球化學與宇宙化學學報，512。https://doi.org/10.1063/1.882420
[3] CROUSE D.L.、PETERS P.A.、HYSTAD P.、BROOK J.R.、VAN DONKELAAR A.、MARTIN R.V.、VILLENEUVE P.J.、JERRETT M.、GOLDBERG M.S.、ARDEN POPE C.、BRAUER M.、BROOK R.D.、ROBICHAUD A.、MENARD R.和 BURNETT R.T. 環境下午 2.5、氧气 和二氧化氮 暴露以及與加拿大人口普查健康和環境隊列 16 年隨訪期間死亡率的關聯。環境健康展望，2015, 123(11): 1180-1186. https://doi.org/10.1289/ehp.1409276
[4] LAZRAK N.、ZAHIR J. 和 MOUSANNIF H. 使用確定性和統計方法進行空氣質量監測。載於：FARHAOUI Y. 和 MOUSSAID L.（編）大數據和智能數字環境。大數據研究，53。斯普林格，湛，2019。https://doi.org/10.1007/978-3-030-12048-1_39
[5] KHANIABADI Y.O.、GOUDARZI G.、DARYANOOSH S.M.、BORGINI A.、TITTARELLI A. 和 DE MARCO A. 接觸顆粒物 10、二氧化氮和氧气以及對人類健康的影響。環境科學與污染研究，2017, 24(3): 2781-2789. https://doi.org/10.1007/s11356-016-8038-6
[6] LEE, H., MYUNG, W., KIM, D.K., KIM, S.E., KIM, C.T. 和 KIM H. 短期空氣污染暴露加重了基於人群的帕金森病。科學報告，2017 年，7：44741。https://doi.org/10.1038/srep44741
[7] 美國環境保護署。經鉛安全認證的翻新指南。2010. https://www.epa.gov/sites/production/files/2020-09/documents/renovaterightbrochurebwlandscapesept2011.pdf
[8] 美國環境保護署。發電對人類健康和環境的影響概述：關註二氧化硫、氮氧化物和汞。 晴空計劃，2002 年。https://archive.epa.gov/clearskies/web/pdf/overview.pdf
[9] DEHGHANI M., KESHTGAR L., REZA M. 和 DERAKHSHAN Z. 空氣污染物對肺癌和白血病死亡率的影響。分子醫學報告，2017，3390-3397。https://doi.org/10.3892/mmr.2017.6387
[10] SBARATO D. 和 SBARATIO V. 空氣污染。2009.
[11] 華納郵政信箱 空氣污染物分析。禮堂，馬德里，1981 年。
[12] IDEAM。大氣中二氧化硫 （測定參考方法 （對玫瑰苯胺法）。2010：1-22。http://www.ideam.gov.co/documents/51310/527464/3.+DIOXIDO_DE_AZUFRE_V04_VB.pdf/66cf1c9b-e25f-43b8-a634-156fd41cef0f
[13] OSPINA A. 和 GARRIDO M. 臭氧測量技術：傳統與紫外線室吸收法。管理與環境, 2013, 16(2) 95-104.
[14] MARCOS R., CABRERA M., LAOS H., MAMANI D. 和 VALDERRAMA A. 聖大學校園採用被動管和板接收器方法測定大氣塵埃可沉降性的比較研究 馬科斯。熱流體發展與研究中心科學雜誌, 2008, 1(3): 49-58.
[15] SHIN S.E., JUNG C.H. 和 KIM Y.P. 高山的顆粒物 10 濃度在 β 射線吸收法和重量法之間的測量差異分析。氣溶膠與空氣質量研究，2011 年，11：846-853。https://doi.org/10.4209/aaqr.2011.04.0041
[16] FU L.、NUNIFU T. 和 LEUNG B. 將錐形元件振盪微天平和二分空氣採樣器下午 2.5 測量相關聯的兩步法。空氣與廢物管理協會雜誌，2014 年，64(10)：1195-1203。https://doi.org/10.1080/10962247.2014.934484
[17] JIMENEZ A.M. 和 NAVAS M.J. 化學發光方法（現在和未來）。油脂，2002，53：64-75。https://doi.org/10.3989/gya.2002.v53.i1.290
[18] 環境、住房和領土發展部。空氣質量監測系統操作手冊。協議 1. 2010. https://www.minambiente.gov.co/wp-content/uploads/2021/06/Protocolo_Calidad_del_Aire_-_Manual_Operacion.pdf
[18] 阿拉斯加電力局。大容量空氣監測程序： 初始監測和質量保證報告。聯邦能源管理委員會項目編號 7114。1984。https://www.arlis.org/docs/vol1/Susitna/16/APA1695.pdf
[19] HEIM M., MULLINS B., UMHAUER H. 和 KASPER G. 三種光學粒子計數器的性能評估，採用高效的“多模式”校準方法。氣溶膠學報，2008, 39(12): 1019-1031. https://doi.org/10.1016/j.jaerosci.2008.07.006
[20] KRUG J.、DART A.、WITHERSPOON C.、GILBERRY J.、MALLOY Q.、KAUSHIK S.、VANDERPOOL R.、KRUG J.、DART A.、WITHERSPOON C. 和 GILBERRY J. 重新審視尺寸環保局大容量總懸浮顆粒物採樣器的選擇性性能。氣溶膠科學與技術，2017, 51(7): 868-878. https://doi.org/10.1080/02786826.2017.1316358
[21] 美國環境保護署。空氣污染控制技術情況說明書-噴霧室和噴霧塔濕式洗滌器。2003 https://www3.epa.gov/ttnchie1/mkb/documents/fcataly.pdf
[22] 新星環境。RAC 3 - 氣體採樣器。2022. http://www.newstarenvironmental.com/rac-3-gas-sampler.html
[23] 賽默飛世爾科學。型號 5014 我測試版 連續顆粒物監測儀。2022. https://www.thermofisher.com/order/catalog/product/5014I#/5014I
[24] 環境監測解決方案。塞里努斯 50。二氧化硫分析儀 - 用戶手冊版本 3.3。2022. https://www.ecotech.com/wp-content/uploads/2022/03/M010029-Serinus-50-SO2-User-Manual-3.3.pdf
[25] ANAGNOSTOPOULOS C., HADJIEFTHYMIADES S. 和 KOLOMVATSOS K. 移動傳感器網絡現象的準確、動態和分佈式定位。傳感器網絡上的 ACM 交易，2016 年，12(2)。 https://doi.org/10.1145/2882966
[26] ARVIND D.K.、MANN J.、BATES A. 和 KOTSEV K. AirSpeck 系列靜態和移動無線空氣質量監測儀。在：第 19 屆歐洲微電子數字系統設計會議論文集，2016 年：207-214。https://doi.org/10.1109/DSD.2016.110
[27] KAUR S., NIEUWENHUIJSEN M. 和 COLVILE R. 英國倫敦市中心街道峽谷交叉口用戶對下午 2.5、超細顆粒物計數和一氧化碳的個人暴露。大氣環境，2005, 39(20): 3629-3641. https://doi.org/10.1016/j.atmosenv.2005.02.046
[28] MCKERCHER, G.R., SALMOND, J.A. 和 VANOS, J.K. 小型便攜式氣態空氣污染監測儀的特點和應用。環境污染，2017, 223: 102-110. https://doi.org/10.1016/j.envpol.2016.12.045
[29] CHOI S., KIM D.J., CHOI Y.Y., PARK K., KIM S.W., WOO S.H. 和 KIM J.J. 用於工業環境和醫療保健監測的多傳感器移動接口。電氣和電子工程師協會工業電子彙刊，2017 年，64(3)：2344-2352。

https://doi.org/10.1109/TIE.2016.2626239
[30] GOZZI F.、DELLA VENTURA G. 和 MARCELLI A. 移動監測顆粒物：技術現狀和觀點。大氣污染研究, 2016, 7(2): 228-234. https://doi.org/10.1016/j.apr.2015.09.007
[31] LOH M.、SARIGIANNIS D.、GOTTI A.、KARAKITSIOS S.、PRONK A.、KUIJPERS E.、ANNESI-MAESANO I.、BAIZ N.、MADUREIRA J.、FERNANDES E.O.、JERRETT M. 和 CHERRIE J.W. 傳感器如何幫助定義外部暴露組。國際環境研究與公共衛生雜誌, 2017, 14(4)。https://doi.org/10.3390/ijerph14040434
[32] BARAKEH Z., BREUIL P., REDON N., PIJOLAT C., LOCOGE N. 和 VIRICELLE J.P. 開髮用於低成本在線大氣污染檢測的標準化多傳感器系統。傳感器和執行器, B：化學, 2017 年, 241：1235-1243。https://doi.org/10.1016/j.snb.2016.10.006
[33] DUTTA J., GAZI F., ROY S. 和 CHOWDHURY C. 空氣感：基於人群感知的智慧城市空氣質量監測系統。在：2016 電氣和電子工程師協會傳感器, 2016 年 10 月 30 日至 2016 年 11 月 3 日，美國奧蘭多。2017：5-7。https://doi.org/10.1109/ICSENS.2016.7808730
[34] KHUNSONGKIET P. 和 BOONCHIENG E. 通過移動界面將空氣質量監測低成本傳感器數據轉換為數字值。時間：2016 年第 9 屆生物醫學工程國際會議，2016 年 12 月 7 日至 9 日，老撾朗布拉邦。2016 年，https://doi.org/10.1109/BMEiCON.2016.7859628
[35] HAAS P.Y.、BALISTRERI C.、PONTELANDOLFO P.、TRISCONE G.、PEKOZ H. 和 PIGNATIELLO A. 開髮用於城市地區空氣質量測量的無人機。在：第 32 屆美国航空航天局應用空氣動力學會議，2014 年：1-9。https://doi.org/10.2514/6.2014-2272
[36] TOSCANO P.、GIOLI B.、DUGHERI S.、SALVINI A.、MATESE A.、BONACCHI A.、ZALDEI A.、CUPELLI V. 和 MIGLIETTA F. 通過飛機觀測定位工業揮發性有機化合物來源。環境污染, 2011, 159(5): 1174-1182. https://doi.org/10.1016/j.envpol.2011.02.013
[37] WATAI T., MACHIDA T., ISHIZAKI N., INOUE G., WATAI T., MACHIDA T., ISHIZAKI N. 和 INOUE G. 使用小型無人機的輕型大氣二氧化碳濃度觀測系統. 大氣與海洋技術學報, 2006, 23(5): 700-710. https://doi.org/10.1175/JTECH1866.1
[38] ZHOU X., AURELL J., MITCHELL W., TABOR D. 和 GULLETT B. 一種小型、輕型多污染物傳感器系統，用於從開放區域來源進行地面移動和空中排放採樣。大氣環境, 2017, 154, 31-41. https://doi.org/10.1016/j.atmosenv.2017.01.029
[39] MINGIREANU F.、GRIGORESCU S.、CEPISCA C.、STEFAN C.、MOCANU I. 和 GEORGESCU L.P. 基於無人機的空氣質量評估空間建模方法。能源與環境管理的最新進展，2013：25-28。http://www.wseas.us/e-library/conferences/2013/Rhodes/ENVIR/ENVIR-02.pdf
[40] VILLA T.F.、SALIMI F.、MORTON K.、MORAWSKA L. 和 GONZALEZ F. 基於無人機的空氣污染測量系統的開發和驗證。 傳感器（瑞士），2016 年, 16(12)。 https://doi.org/10.3390/s16122202
[41] VILLA T.、GONZALEZ F.、MILJIEVIC B.、RISTOVSKI Z. 和 MORAWSKA L. 用於空氣質量測量的小型無人機概述：當前應用和未來前景。傳感器，2016 年，16(7)：1072。https://doi.org/10.3390/s16071072
[42] GILLIAM R.C., HOGREFE C. 和 RAO S.T. 評估空氣質量應用中使用的氣象模型的新方法。大氣環境, 2006, 40(26): 5073-5086. https://doi.org/10.1016/j.atmosenv.2006.01.023
[43] AZNARTE J.L. 極端二氧化氮污染事件的概率預測。環境污染, 2017, 229: 321-328. https://doi.org/10.1016/j.envpol.2017.05.079
[44] BANTA R.M., SENFF C.J., ALVAREZ R.J., LANGFORD A.O., PARRISH D.D., TRAINER M.K., DARBY L.S., HARDESTY, R.M., LAMBETH B., NEUMAN, J.A., ANGEVINE W.M., NIELSEN-GAMMON J., SANDBERG S.P. 和 WHITE A.B. 德克薩斯州休斯敦附近每日氧气 濃度峰值對環境因素的依賴性：風速、溫度和邊界層深度。大氣環境，2011, 45(1): 162-173. https://doi.org/10.1016/j.atmosenv.2010.09.030
[45] KATSOULIS B.D. 希臘雅典惡劣空氣質量事件期間天氣、中尺度和微尺度氣象參數之間的關係。整體環境科學，1996, 181(1): 13-24. https://doi.org/10.1016/0048-9697(95)04953-3
[46] TONG L., ZHANG H., YU J., HE M., XU N., ZHANG J., QIAN F., FENG J. 和 XIAO H. 城市、郊區地表臭氧和氮氧化物的特徵 和中國寧波的農村網站。大氣研究, 2017, 187: 57-68. https://doi.org/10.1016/j.atmosres.2016.12.006
[47] SEAMAN N.L. 用於空氣質量評估的氣象建模。大氣環境, 2000, 34(12-14): 2231-2259. https://doi.org/10.1016/S1352-2310(99)00466-5
[48] 環境衛生總局。2005 年空氣質量監測協議和數據管理。迪格薩, 1, 71. http://www.digesa.minsa.gob.pe/norma_consulta/Protocolo-de-Calidad-del-Aire.pdf
[49] 中央污染控制委員會和環境與森林部。環境空氣污染物測量指南。2009. http://mahenvis.nic.in/Pdf/Report/report_epm_NAAQMS.pdf
[50] 英國議會。清潔空氣法。1956. https://www.legislation.gov.uk/ukpga/1956/52/pdfs/ukpga_19560052_en.pdf
[51] 英國皇家健康促進會。1974 年污染控制法。皇家促進健康學會雜誌，1974 年，97(2)：1-144。https://doi.org/10.1177/146642407709700203
[52] HUCK J.J.、WHYATT J.D.、COULTON P.、DAVISON B. 和 GRADINAR A. 將生理、環境和位置傳感器結合起來用於面向市民的健康應用。環境監測與評價, 2017, 189(3). https://doi.org/10.1007/s10661-017-5817-6
[53] 英國環境食品和農村事務部) 的空氣質量統計。英國環境食品和農村事務部國家統計數據發布：1987 年至 2016 年英國的空氣質量統計數據。2017 年。
[54] 美國國會。空氣污染控制法 787. 1955。
[55] STERN A.C. 美國空氣污染立法的歷史。大氣污染防治協會會刊, 1982, 32(1): 44-61. https://doi.org/10.1080/00022470.1982.10465369
[56] 美國環境保護署。清潔空氣法文本。美國政府印刷局，1970 年。https://www.epa.gov/clean-air-act-overview/clean-air-act-text
[57] 美國環境保護署。國家環境空氣質量標準。空氣質量規劃和標準辦公室，4，2014

http://www.epa.gov/air/criteria.html
[58] 美國環境保護署。控制措施菜單，2012：1194-1196。https://19january2017snapshot.epa.gov/sites/production/files/2016-02/documents/menuofcontrolmeasures.pdf
[59] SOLOMON P.A.、CRUMPLER D.、FLANAGAN J.B.、JAYANTY R.K.M.、RICKMAN E.E. 和 MCDADE C.E. 美國國家下午 2.5 化學形態監測網絡-南航和提升：網絡描述。空氣與廢物管理協會雜誌，2014 年，64(12)：1410-1438。https://doi.org/10.1080/10962247.2014.956904
[60] FIOLETOV V.E., MCLINDEN C.A., KROTKOV N. 和 LI C. 奧米估算的點源 SO_2 的壽命和排放。地球物理研究快報，2015, 42(6): 1969-1976. https://doi.org/10.1002/2015GL063148
[61] MCLINDEN C.A.、FIOLETOV V.、BOERSMA K.F.、KHAROL S.K.、KROTKOV, N.、LAMSAL, L.、MAKAR, P.A.、MARTIN, R.V.、VEEFKIND J.P. 和 YANG K. 改進了二氧化氮 和二氧化硫的衛星反演 加拿大油砂和與地表測量的比較。大氣化學與物理，2014, 14(7): 3637-3656. https://doi.org/10.5194/acp-14-3637-2014
[62] 亞洲開發銀行。改善亞洲的空氣質量監測。2014. http://learning-cleanairasia.org/lms/library/ga1/02-Improving-Air-Quality-Monitoring-in-Asia.pdf
[63] 印度政府。《空氣污染防治法》。1981 年：1-45。http://legislative.gov.in/sites/default/files/A1981-14.pdf
[64] 印度政府。環境保護法。環境和森林部，環境森林和野生動物司。1986. https://www.iitr.ac.in/wfw/web_ua_water_for_welfare/environment/eprotect_act_1986.pdf
[65] 印度政府。機動車法。1988. http://legislative.gov.in/sites/default/files/A1988-59.pdf
[66] 印度政府。中央機動車輛規則。1989. http://chdtransport.gov.in/Forms/CMVR_1989.pdf
[67] 世界銀行和開發計劃署。亞洲大都市環境改善計劃。1989. http://documents1.worldbank.org/curated/en/289871468772748976/pdf/multi-page.pdf。
[68] 大都市環境改善計劃。亞洲城市空氣質量管理戰略：加德滿都谷地報告。1996. http://search.ebscohost.com/login.aspx?direct=trueanddb=ecnandAN=0470203andsite=ehost-live。
[69] 氣候倡議平台。清潔空氣亞洲。2001. https://climateinitiativesplatform.org/index.php/Clean_Air_Asia
[70] SONG C.、WU L. 和 XIE Y. 中國的空氣污染：狀況和時空變化。環境污染，2017, 227: 334-347. https://doi.org/10.1016/j.envpol.2017.04.075
[71] 美國環境保護署。空氣質量。在：環境展望，2011 年：182-207。http://www.epa.ie/air/quality/
[72] 西亞和阿拉伯國家聯盟經濟社會委員會。阿拉伯地區的空氣質量和大氣污染。聯合國國家環境規劃署西亞區域辦事處。2006 年：1-40。
[73] KINNEY P.L.、GICHURU M.G.、VOLAVKA-CLOSE N.、NGO N.、PETER, K.、LAW A.、GACHANJA A.、GAITA S.M.、CHILLRUD S.N. 和 SCLAR E. 交通對下午 2.5 空氣質量的影響 在肯尼亞內羅畢。環境科學與政策，2012, 14(4): 369-378. https://doi.org/10.1016/j.envsci.2011.02.005
[74] JURY M.R. 基於衛星模型數據集的南非高地空氣污染事件的統計和氣象學。應用氣象與氣候學報，2017, 56(6): 1583-1594. https://doi.org/10.1175/JAMC-D-16-0354.1
[75] BIFFI C.A. 和 TUISSI A. 金屬增材製造技術的最新進展。意大利冶金，2017, 109(1): 5-10. https://doi.org/10.1017/CBO9781107415324.004
[76] 全球環境監測系統和世界衛生組織。環境質量：基於健康的全球評估。1988. https://apps.who.int/iris/handle/10665/62009
[77] 世衛組織。城市空氣質量管理的健康城市計劃。1997 年：1-43。https://docplayer.net/64004193-A-healthy-cities-programme-for-urban-air-quality-management.html
[78] KORC M. 拉丁美洲的空氣質量監測。在：空氣污染控制計劃。1999. https://www.paho.org/es/file/50078/download?token=84h55RCq
[79] FAJERSZTAJN L.、SALDIVA P.、PEREIRA L.A.A.、LEITE V.F. 和 BUEHLER A.M. 細顆粒物污染對拉丁美洲日常健康事件的短期影響：系統回顧和薈萃分析。國際公共衛生雜誌，2017 年，62：729-738。https://doi.org/10.1007/s00038-017-0960-y
[80] GARCIA F.、CURCI G. 和 LANFRI M. 在阿根廷首次實施 WRF-奇米尔-埃德加建模系統。電氣和電子工程師協會應用地球觀測和遙感選題雜誌, 2016, 9(12): 5304-5314. https://doi.org/10.1109/JSTARS.2016.2588502
[81] ABARCA M.、SAITO C. 和 CUÉLLAR F. 质量保证协会地图。2015. http://www.qairadrones.com/index.php?r=site/nosotros
[82] LOAIZA J.P.、GIRALDO E. 和 AGUIRRE E. 設備實時測量空氣質量。哥倫比亞國立大學，2016 年。http://agenciadenoticias.unal.edu.co/detalle/article/dispositivo-mide-calidad-del-aire-en-tiempo-real.html