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.

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)

<table>
<thead>
<tr>
<th>Pollutants</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ozone (O(_3))</td>
<td>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].</td>
</tr>
<tr>
<td>Particulate Matter (PM)</td>
<td>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].</td>
</tr>
<tr>
<td>Carbon monoxide (CO)</td>
<td>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…</td>
</tr>
</tbody>
</table>
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 (SO₂):** 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 (O₃):** The reaction of this method produces excited formaldehyde, which emits photons visibly. In turn, the chemiluminescence intensity will be proportional to the ozone concentration. O₃ 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\textsubscript{2} 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\textsubscript{2}.

- 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\textsubscript{2} [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 pollutants concentrations are usually measured in units of micrograms per cubic meter (μg/m\textsuperscript{3}) or milligrams per cubic meter (mg/m\textsuperscript{3}). 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 SO\textsubscript{2} 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

<table>
<thead>
<tr>
<th>Reference</th>
<th>Target gas</th>
<th>Detection range</th>
</tr>
</thead>
<tbody>
<tr>
<td>MICS5525</td>
<td>CO</td>
<td>1-1000 ppm</td>
</tr>
<tr>
<td>MICS2710</td>
<td>NO₂</td>
<td>0.5-5ppm</td>
</tr>
<tr>
<td>TGS2600</td>
<td>CO, CH₄</td>
<td>500–10.000 ppm</td>
</tr>
<tr>
<td>MQ135</td>
<td>CO₂, NH₄, NOₓ</td>
<td>10-200 ppm</td>
</tr>
<tr>
<td>TIDA-00378</td>
<td>PM₂.₅/PM₁₀</td>
<td>12-35 pcs/cm³</td>
</tr>
<tr>
<td>TLAS Sensor Neo</td>
<td>NO₂</td>
<td>Min Range NO₂: 0-50 ppm, Max range NO₂: 0-1000 ppm</td>
</tr>
</tbody>
</table>

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 O₃, CO, and NOₓ 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 NOₓ 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/m²).

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

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Scale</th>
<th>Height (m)</th>
<th>Average Time</th>
<th>Measurement Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO₂</td>
<td>Medium, local, urban, regional</td>
<td>3 to 15</td>
<td>Annual</td>
<td>Ultraviolet Fluorescence.</td>
</tr>
<tr>
<td>CO</td>
<td>Micro scale, medium, local</td>
<td>3/4/0.5</td>
<td>8 hours**</td>
<td>NDIR. (Nondispersive infrared)</td>
</tr>
<tr>
<td>O₃</td>
<td>Medium, local, urban, regional</td>
<td>3 to 15</td>
<td>8 h**</td>
<td>UV photometric.</td>
</tr>
</tbody>
</table>

* 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.
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-automated 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 NO2, SO2, 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 dioxide, 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.

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
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.

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