









## Drone-based Multi sensor System for Air Quality Monitoring





### Sistema multi sensor para el monitoreo de la calidad del aire utilizando un dron

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#### Abstract

Air pollution represents a global environmental and health challenge. This study addresses the issue of air quality in the central area of Huatusco, Veracruz, through the implementation of a monitoring system based on low-cost sensors and the SparkFun platform. Strategic sampling points were selected based on population density and pollutant emission sources, using data from INEGI. The study focused on measuring criterion pollutants by conducting vertical soundings to obtain a detailed profile of their atmospheric concentration.

#### Resumen

La contaminación atmosférica representa un desafío ambiental y de salud a nivel global. En este trabajo, se aborda la problemática de la calidad del aire en la zona centro de Huatusco, Veracruz, mediante la implementación de un sistema de monitoreo con sensores de bajo costo y la plataforma SPARKFUN. Se seleccionaron puntos de muestreo estratégicos, considerando la densidad poblacional y las fuentes de emisión de contaminantes, a partir de información proporcionada por el INEGI. El estudio se enfocó en la medición de contaminantes criterio, realizando sondeos verticales para obtener un perfil detallado de su concentración en la atmósfera.

Drone-based Multisensor System for Air Quality Monitoring		
Objetivos	Methodology	Contribution
Develop a multi-sensor intelligent system for remote air quality monitoring using a Drone.	<ol style="list-style-type: none"> <li>1) Determine the pollutants to be included in the study scope.</li> <li>2) Identify the suitable microcontroller/sensors for the project's needs.</li> <li>3) Acquire air quality measurements in designated areas.</li> </ol>	It will enable us to more effectively identify pollution sources, assess the effectiveness of mitigation measures, and make informed decisions to improve air quality and protect public health.

Sistema multi sensor para el monitoreo de la calidad del aire utilizando un dron		
Objetivos	Metodología	Contribución
Desarrollar un sistema inteligente multi sensor destinado al monitoreo remoto de la calidad del aire, empleando un dron.	<ol style="list-style-type: none"> <li>1) Determinar los contaminantes a incluir en el alcance del estudio.</li> <li>2) Identificar el microcontrolador/sensor es adecuados para las necesidades del proyecto.</li> <li>3) Adquirir mediciones de calidad del aire en las áreas designadas.</li> </ol>	Nos permitirá identificar de manera más efectiva las fuentes de contaminación, evaluar la eficacia de las medidas de mitigación y tomar decisiones informadas para mejorar la calidad del aire y proteger la salud pública.

**Drone monitoring, air quality, low-cost sensors.**


**Monitoreo con Drones, calidad del aire, sensores de bajo costo.**

**Area:** Development of strategic leading-edge technologies and open innovation for social transformation

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Peer review under the responsibility of the Scientific Committee  in the contribution to the scientific, technological and innovation Peer Review Process through the training of Human Resources for continuity in the Critical Analysis of International Research.



## Introduction

Air pollution poses a serious threat to global health, causing millions of premature deaths and a substantial loss of healthy life years annually. Its health impact is comparable to that of other well-known risk factors, such as unhealthy diets and tobacco use. Indeed, atmospheric pollution has been identified as the leading environmental risk to human health globally [17].

In Mexico, the Secretariat of Environment and Natural Resources [SEMARNAT], through the National Institute of Ecology and Climate Change [INECC], established the National Air Monitoring Program [PNMA]. Furthermore, SEMARNAT issued an Official Mexican Standard [Norma Oficial Mexicana, NOM] that stipulates the minimum requirements for the establishment and operation of systems for air quality monitoring and atmospheric pollutant sampling [14].

Previous research includes a field experiment where air quality was measured using a drone [DR-TAPM] equipped with sensors for carbon monoxide [CO], ozone [O<sub>3</sub>], nitrogen dioxide [NO<sub>2</sub>], particulate matter [PM<sub>2.5</sub> and PM<sub>10</sub>], and sulfur dioxide [SO<sub>2</sub>].

The measurements were conducted in a controlled open-burn scenario simulating typical pollution in agricultural areas. The experimental design involved varying the drone's altitude [5 and 10 meters] and distance from the emission source [1 to 20 meters] to capture the spatial variability of pollutants [8].

Another precedent in the country involved testing a UAV-based system across different sites in Mexico, selected based on their pollution levels and geographical features. The UAV collected data at various altitudes [10, 30, 50, and 100 meters] for periods ranging from 16 to 26 minutes, storing the data on a micro SD card and transmitting it in real-time via LoRaWAN and ThingSpeak networks [5].

On a regional level, studies in the cities of Xalapa and Veracruz have applied drones and sonars for vertical atmospheric sounding. These works describe the equipment, procedures, and analysis of vertical profiles for temperature, relative humidity, and wind.

Data were analyzed using graphical and statistical methods, compared to reference data, and the limitations of the techniques were evaluated [1].

The application of Unmanned Aerial Vehicles [UAVs] is rapidly expanding beyond established fields into specialized urban and environmental management tasks. Recent research highlights the versatility of these platforms in addressing complex challenges within Latin American contexts. For instance, studies in Mexico have explored the use of data-driven technologies like IoT and drone-based sensors to optimize resource management in critical sectors such as agriculture [13].

In Colombia, the viability of drones for urban logistics has been analyzed, identifying the key regulatory and social barriers to successful implementation [11]. Furthermore, the methodological frontier is being pushed by combining UAVs with advanced artificial intelligence. High-resolution projects have successfully used deep learning models to detect specific objects like floating plastic debris or to estimate agricultural yields, proving the superiority of this approach over satellite-based methods for detailed tasks [7].

Other developments have focused on creating autonomous drone systems for security and surveillance applications, such as tracking individuals in outdoor environments [2]. This growing body of work demonstrates a clear trend: the integration of customized sensor technology on drone platforms is a powerful and adaptable solution for a wide range of monitoring and operational challenges.

This paper presents the development of a low-cost air quality monitoring system for the central area of Huatusco, Veracruz. The study is structured as follows: first, the methodology is detailed, including the identification of the criterion pollutants of interest, the selection and acquisition of specific sensors, and the choice of an unmanned aerial vehicle [UAV] as the measurement platform. Subsequently, the numerical results from monitoring these pollutants at strategic sampling points are presented.

Finally, the implications of these findings are discussed, and conclusions are drawn regarding the feasibility of the implemented system.

Methodology

1.1 Identification of Pollutants of Interest

Numerous studies have been conducted in diverse settings, including schools [16], urban environments such as parks [3] and city centers [15], suburban and rural areas [18], and locations known for high pollutant concentrations, such as landfills [12], wastewater treatment plants [4], and coal-fired power plants [6]. The primary variables of interest in these investigations included particulate matter, ozone, carbon dioxide, and atmospheric variables. In Mexico, the National Air Quality Information System [SINAICA] identifies six criterion pollutants for measuring air quality: particulate matter [PM10 and PM2.5], Ozone [O3], Sulfur Dioxide [SO2], Nitrogen Dioxide [NO2], Carbon Monoxide [CO], and Lead [Pb]. Based on the objectives of this project, this study focuses on particulate matter PM10 and PM2.5, and the pollutant gases O3, SO2, NO2, and CO.

Furthermore, meteorological variables specifically pressure, temperature, and humidity were also included, as they can significantly influence the distribution and characterization of these pollutants.

Table 1 details the key characteristics of each target pollutant as defined by the official standard NOM-172-SEMARNAT-2019. This includes the permissible limit values concentrations that do not pose a health risk their corresponding measurement unit, and the specific guidelines within the standard that establish these limits.

1.2 Sensor Selection and Acquisition

Box 1

Table 1

Specifications for Criteria Pollutants

Pollutant	Average concentration	Limit value	NOM
PM10	24 hrs	70 µg/m3	NOM-025-SSA1-2021
PM 2.5	24 hrs	41 µg/m3	NOM-025-SSA1-2021
O3	1 hrs	0.09 PPM	NOM-020-SSA1-2022
NO2	1 hrs	0.106 PPM	NOM-023-SSA1-2023
CO	8 hrs	9 PPM	NOM-021-SSA1-2024
SO2	24 hrs	0.11 PPM	NOM-022-SSA1-2025

Source: [sinaica.inecc.gob.mx/scica/#](http://sinaica.inecc.gob.mx/scica/#)

A review of the literature identified sensors with operational principles similar to those employed in this study. Among the examples found, some sensors [e.g., SPS30, SEN0470] are factory-calibrated, whereas for others [e.g., MQ131, MICS 6814], calibration procedures are specified in their respective datasheets. The selection of all sensors was guided by the pollutant specifications detailed in Table 1.

The sensors selected for this study are presented in Table 2.

Box 2

Table 2

Selected Sensors for the Study and Their Characteristics.

Sensor Name	Parameter	Resolution
SPS30	PM 2.5 y PM 10	1 µg/m <sup>3</sup> , 2,5 µg/m <sup>3</sup> , 4 µg/m <sup>3</sup> y 10 µg/m <sup>3</sup> .
SEN0470	SO2	0.1 PPM
MICS 6814	CO	1 PPM
	NO2	0.1 PPM
MQ131	O3	10 PPB

The microcontroller used to process the signals from each sensor is the SparkFun IoT RedBoard development board. The components that constitute the multi sensor module are shown in Figure 1.

Box 3

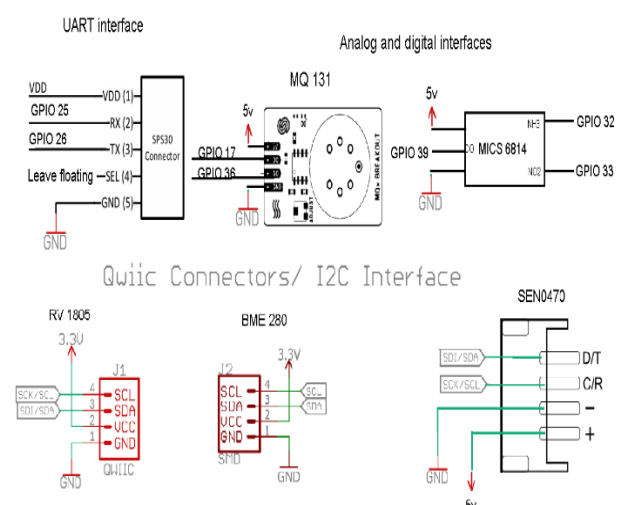


Figure 1

Design of the multi-sensor module for retrieving criteria pollutant parameters.

### 1.3 Drone Selection and Acquisition

The selection of a suitable drone platform for this project was based on fundamental technical criteria: sufficient payload capacity to accommodate the developed multi sensor system, adequate flight autonomy for the planned sampling missions, structural robustness, reliable control and navigation systems, and modularity to facilitate integration and future adaptations [10]. Based on these criteria, the Holybro X650 development kit was selected. The most significant features of the drone are summarized in Table 3.

#### Box 4

**Table 3**

Notable Features of the X650 Kit.

Feature	Description/Specification
Frame Material	High-quality carbon fiber, articulated arms with aluminum connectors, and reinforced landing gear.
Payload	Up to 3.1 KG [with 10,000 mAh battery].
Sistema de control y navegación	Controladora de vuelo PIXHAWK 6X, GPS M10, telemetría radio SIK Plug & Play
Advantage	Simplifies the integration of custom payloads, streamlines setup and maintenance.

Source: [holystone.com/collections/x650-kits/products/x650-development-kit?variant=43004805447869](https://holystone.com/collections/x650-kits/products/x650-development-kit?variant=43004805447869)

The methodological framework adopted in this study, which integrates a custom-built sensor module with a low-cost UAV platform for remote monitoring, aligns with a proven architectural approach for specialized urban applications. A similar configuration, employing an ESP32-based sensor module with Wi-Fi data transmission mounted on a drone, was successfully implemented for the detection of inactive aerial cabling in an urban setting [9].

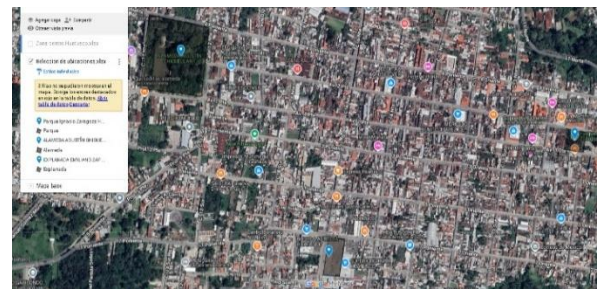
This precedent validates the technical feasibility of our chosen components for infrastructure inspection. Furthermore, the core principle of using drone-mounted systems to detect and quantify specific environmental targets is well-established.

For example, the work in [7] effectively used a YOLO-based AI model to identify and classify different types of physical objects [plastic debris] from UAV imagery, demonstrating the robustness of this general methodology for environmental characterization.

### Results

The study area was defined by three zones in the city center of Huatusco: Ignacio Zaragoza Park [19°09'00.5"N, 96°57'38.1"W], the Emiliano Zapata Esplanade [19°08'48.8"N, 96°58'04.0"W], and Agustín Chicuéllar Alameda [19°09'08.5"N, 96°58'23.5"W], as shown in Figure 2.

#### Box 5



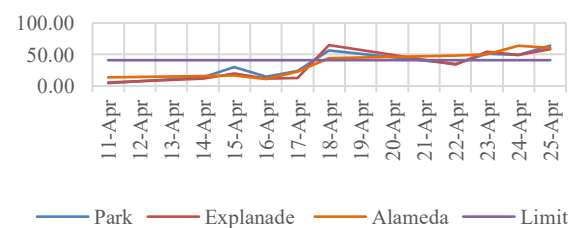
**Figure 2**

Designated Study Areas

Data collection began on April 11, continued from April 14 to 18, and concluded during the week of April 22 to 25. For particulate matter [PM<sub>2.5</sub>], the average concentrations measured were 34.29  $\mu\text{g}/\text{m}^3$  at the park, 32.26  $\mu\text{g}/\text{m}^3$  at the Emiliano Zapata Esplanade, and 34.69  $\mu\text{g}/\text{m}^3$  at the Agustín Chicuéllar Alameda. Figure 3 illustrates the temporal behavior of these concentrations and shows their proximity to the permissible limits established by the standard NOM-025-SSA1-2021.

#### Box 6

Average PM 2.5 Concentrations in  $\mu\text{g}/\text{m}^3$

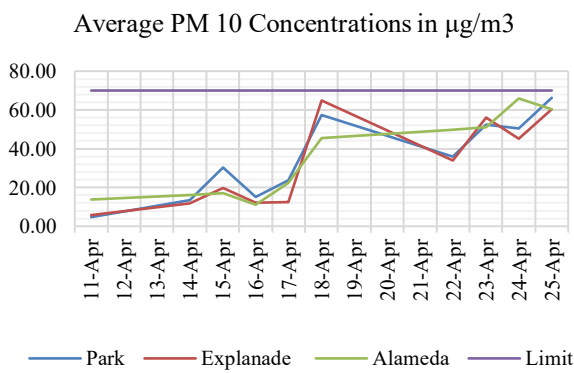


**Figure 3**

Distribution of PM 2.5 particulate matter with respect to the limit established in NOM-025-SSA1-2021

For particulate matter PM10, the weekly average concentrations recorded were 34.95  $\mu\text{g}/\text{m}^3$  at the park, 32.21  $\mu\text{g}/\text{m}^3$  at the Esplanade, and 35.33  $\mu\text{g}/\text{m}^3$  at the Alameda. Although the distribution of PM10 was similar to that of PM2.5, the concentrations for this pollutant did not exceed the limit established by the standard. The distribution of PM10 throughout the study days is presented in Figure 4.

**Box 7**

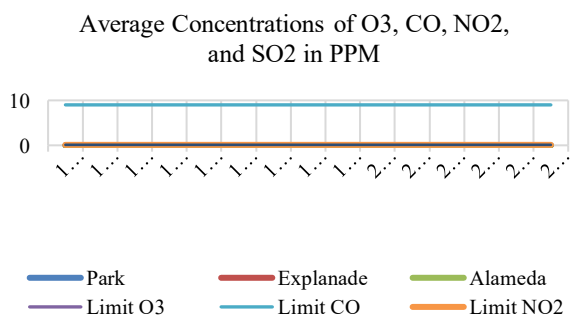


**Figure 4**

Distribution of PM 10 particulate matter with respect to the limits established in NOM-025-SSA1-2021.

Regarding the pollutant parameters for Ozone [O3], Nitrogen Dioxide [NO2], Carbon Monoxide [CO], and Sulfur Dioxide [SO2], no significant variations were observed during the entire week of measurements. This could be attributed to two potential factors: either the pollution levels in the monitored areas were not substantially high, or the pollutant concentrations were below the minimum detection limit of the sensors, as illustrated in Figure 5.

**Box 8**

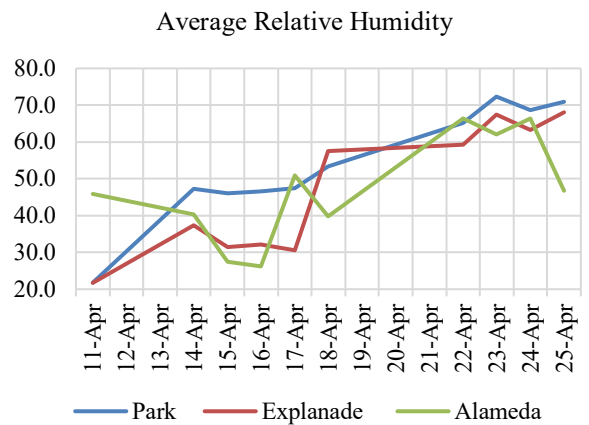


**Figure 5**

Distribution of Ozone, Carbon Monoxide, Nitrogen Dioxide, and Sulfur Dioxide with respect to the limits established in NOM-020-SSA1-2022, NOM-021-SSA1-2024, NOM-023-SSA1-2023, and NOM-022-SSA1-2025, respectively.

The average meteorological variables recorded during the study were as follows. For relative humidity, the values were 53.95% at the park, 46.89% at the Esplanade, and 47.20% at the Alameda. The atmospheric pressure averaged 876.48 hPa at the park, 875.85 hPa at the Esplanade, and 871.88 hPa at the Alameda.

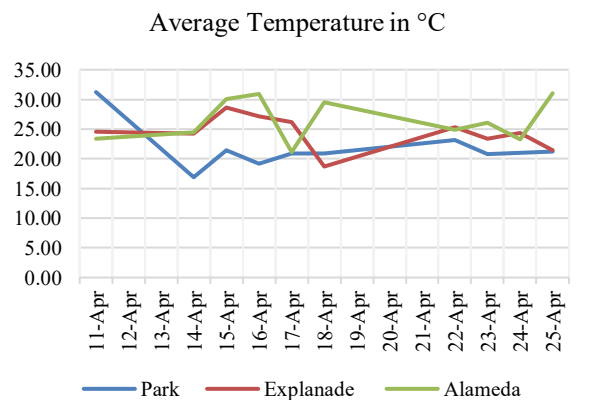
**Box 9**



**Figure 6**

Distribution of relative humidity during the study in the areas of interest.

Finally, the average temperatures were 21.74 °C at the park, 24.64 °C at the Esplanade, and 26.58 °C at the Alameda.



**Figure 7**

Changes in temperature recorded through the collection of air quality parameters. Source: Own elaboration.

**Conclusions**

Based on the analysis of the data collected between April 11 and 25 at the Park, Esplanade, and Alameda locations, the following conclusions are drawn:

**PM2.5 Concentrations:** Daily and inter-site variations were observed in the average PM2.5 concentrations. Exceedances of the regulatory limit of 41  $\mu\text{g}/\text{m}^3$  were recorded at all three locations on several days: specifically, on April 18, 23, 24, and 25 at the Park and Esplanade, and on April 18, 22, 23, 24, and 25 at the Alameda. The highest values were concentrated towards the end of the monitoring period.

**PM10 Concentrations:** Average daily PM10 concentrations remained below the established limit of 70  $\mu\text{g}/\text{m}^3$  across all measurements taken during the study period. Although no exceedances occurred, a trend towards higher values was observed during the final days of the period [April 22-25].

**Gas Concentrations [O<sub>3</sub>, CO, NO<sub>2</sub>, SO<sub>2</sub>]:** The data indicate that the average daily concentrations for Ozone [O<sub>3</sub>], Carbon Monoxide [CO], Nitrogen Dioxide [NO<sub>2</sub>], and Sulfur Dioxide [SO<sub>2</sub>] were 0 ppm at all three locations throughout the evaluation period. Consequently, these values remained well below their respective regulatory limits [90 ppm for O<sub>3</sub>, 9 ppm for CO, 0.106 ppm for NO<sub>2</sub>, and 0.11 ppm for SO<sub>2</sub>].

**Relative Humidity [RH%]:** The Park station consistently recorded the highest RH% values, while the Alameda station generally showed the lowest values.

**Atmospheric Pressure [hPa]:** A consistent pattern was observed: The Park station recorded the highest-pressure values, followed by the Esplanade, and finally the Alameda with the lowest values.

**Temperature [°C]:** The Alameda station tended to record the highest average temperatures, while the Park station consistently recorded the lowest among the three locations.

While the results confirm the technical feasibility of our prototype, its transition from a controlled experiment to a large-scale urban deployment requires consideration of broader challenges. The work on drone logistics in Colombia highlights that the primary hurdles for urban UAV adoption are often not technological, but regulatory and social, including public concerns over privacy, noise, and safety [12].

A successful implementation of our air quality system would therefore necessitate a clear operational framework that addresses these issues. Furthermore, the accuracy of any sensor-based system is highly dependent on its calibration within the specific operational context. This is underscored by the findings in [2], which demonstrated that a state-of-the-art object detection model required retraining with simulation-specific data to perform effectively, proving that general models often fail in specialized environments.

This suggests that future work on our system should include rigorous field calibration to account for the unique atmospheric and pollutant characteristics of Huatusco. Finally, the emphasis on developing a low-cost solution aligns with the challenges of technological adoption in Mexico, where economic barriers can hinder the implementation of high-cost systems, as noted in studies of the agricultural sector [13].

## Declarations

## Conflict of interest

The authors declare no interest conflict. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this article.

## Author contribution

*Sánchez-Reyes, Javier Ángel:* Conceptualization, Methodology, Software, Validation, Formal Analysis, Investigation, Data Curation, Writing – Original Draft, Writing – Review & Editing, Visualization, Project Administration.

*Sánchez-Medel, Luis Humberto:* Conceptualization, Methodology, Resources, Data Analysis, Supervision, Writing – Review & Editing.

*Sánchez-Sosol, Silvia:* Investigation, Formal Analysis, Writing – Review & Editing.

*Piña-Martínez, Ana Laura:* Methodology, Investigation, Visualization.

## Availability of data and materials

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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## Abbreviations

AI: Artificial Intelligence

CO: Carbon Monoxide

CONAHCYT: National Council of Humanities, Sciences and Technologies [Consejo Nacional de Humanidades, Ciencias y Tecnologías]

hPa: Hectopascal

INECC: National Institute of Ecology and Climate Change [Instituto Nacional de Ecología y Cambio Climático]

INEGI: National Institute of Statistics and Geography [Instituto Nacional de Estadística y Geografía]

IoT: Internet of Things

NOM: Official Mexican Standard [Norma Oficial Mexicana]

NO<sub>2</sub>: Nitrogen Dioxide

O<sub>3</sub>: Ozone

Pb: Lead [Plomo]

PM: Particulate Matter

PM<sub>2.5</sub>: Particulate Matter with a diameter of 2.5 micrometers or less

PM<sub>10</sub>: Particulate Matter with a diameter of 10 micrometers or less

PNMA: National Air Monitoring Program [Programa Nacional de Monitoreo Atmosférico]

RH: Relative Humidity

SEMARNAT: Secretariat of Environment and Natural Resources [Secretaría de Medio Ambiente y Recursos Naturales]

SINAICA: National Air Quality Information System [Sistema Nacional de Información de la Calidad del Aire]

SO<sub>2</sub>: Sulfur Dioxide

UAV: Unmanned Aerial Vehicle

WHO: World Health Organization

YOLO: You Only Look Once

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