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Département Génie des Procédés et d'Environnement

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In fulfillment of the requirements for the State Engineer Degree in Process and Environmental Engineering

Air Pollution measurement and modeling in an Urban Area

DAFRI Hadjer Nour Elhouda

Presented on : 08/07/2025, in front of the jury composed of :

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Mémoire de Projet de Fin d'Etude

Pour l'obtention du diplôme d'ingénieur d'état en Génie des Procédés et Environnement

Mesure et modélisation de la pollution de l'air dans une zone urbaine

DAFRI Hadjer Nour Elhouda

Soutenu le : 08/07/2025, devant le jury composé de :

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ملخص

تهدف هذه الدراسة إلى تقييم تلوث الهواء في منطقة حضرية مزدحمة في الجزائر، عبر مراقبة PM_{10}، $PM_{2.5}$ و $PM_{1.0}$، والمركبات العضوية المتطايرة الكلية، والفورمالديهايد باستخدام جهاز LifeBasis. جُمعت البيانات يوميًا خلال شهري ماي ويونيو 2025، تم استخدام جهاز Mengshen لقياس الضجيج لتقدير كثافة حركة المرور. الهدف هو التنبؤ بمستويات الجسيمات الدقيقة عبر مؤشرات بيئية.

كلمات مفتاحية: تلوث الهواء، الجسيمات الدقيقة، المركبات العضوية المتطايرة، الفورمالديهايد، الضجيج.

Résumé

Cette étude évalue la pollution de l'air dans une zone urbaine très fréquentée d'Alger en surveillant les PM_{10}, $PM_{2.5}$ et $PM_{1.0}$, les Composés Organiques Volatils Totaux (COVT) et le formaldéhyde à l'aide du capteur LifeBasis. Les mesures ont été prises quotidiennement en mai et juin 2025, un sonomètre Mengshen a permis de mesurer le bruit pour estimer la densité du trafic.L'objectif est de prédire les niveaux de particules fines à partir d'indicateurs environnementaux.

Mots clés : Pollution de l'air, particules fines, TCOV, formaldéhyde, bruit.

Abstract

This study evaluates air pollution in a busy urban area of Algiers by monitoring PM_{10}, $PM_{2.5}$, and $PM_{1.0}$, TVOC, and formaldehyde using the LifeBasis monitor. Measurements were collected daily during May and June 2025, the Mengshen sound meter was used to assess noise levels, serving as a proxy for traffic density. The goal is to predict fine particle levels using environmental indicators.

Keywords : Air pollution, particulate matter, VOCs, formaldehyde, noise.

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Finally, I want to thank all the teachers who have shaped my university journey, as well as everyone who contributed, directly or indirectly, to the completion of this work.

Dedication

To my beloved family, Especially to my MOTHER, my dear LOULA, and my BROTHER your boundless love, unwavering support, and countless sacrifices have shaped the person I am today. I am forever grateful for the strength and values you have instilled in me.

I also dedicate this work to the soul deep friendships blossomed at Polytech, To my soul sisters : AMINA, HADJER, KAHINA, MELISSA and SIRINE. In every shared silence and burst of laughter, you have been my refuge, my strength, and my joy. May our bond continue to illuminate our paths and warm our hearts wherever life leads us.

Thank you for believing in me, and for making this journey one filled with light, love, and unforgettable moments. I would like also to extend my sincere gratitude to my classmates from this promotion over the past three years.

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List of Abbreviations and Acronyms

BAMs	Beta Attenuation Monitors (BAMs)
CFCs	Chlorofluorocarbons (CFCs)
dae	Aerodynamic equivalent diameter (dae)
DDL	3,5-diacetyldihydrolutidine (DDL)
DNA	Deoxyribonucleic acid (DNA)
DNPH	2,4-Dinitrophenylhydrazine (DNPH)
EPA	Environmental Protection Agency (EPA)
FID	Flame Ionization Detector (FID)
GC/MS	Gas Chromatography/Mass Spectrometry (GC/MS)
HCHO	Formaldehyde (HCHO)
HPLC	High Performance Liquid Chromatography (HPLC)
hPa	Hectopascal (hPa)
NPs	Nanoparticles (NPs)
PAHs	Polycyclic aromatic hydrocarbons (PAHs)
Pb	Lead (Pb)
PID	Photoionization Detector (PID)
PM	Particulate Matter (PM)
PM0.1	Ultrafine particles (diameter < 0.1 µm) ($PM_{0.1}$)
PM10	Fine particles (diameter < 10 µm) (PM_{10})
PM2.5	Fine particles (diameter < 2.5 µm) ($PM_{2.5}$)
ppb	Parts per billion (ppb)
ppm	Parts per million (ppm)

TEOM Tapered Element Oscillating Microbalance (TEOM)

TSP Total Suspended Particulates (TSP)

TVOC Total Volatile Organic Compounds (TVOC)

VOC Volatile Organic Compounds (VOC)

W/m2 Watt per square meter (W/m^2)

WHO World Health Organization (WHO)

General Introduction

General Introduction

We can choose what we eat or drink, but not what we breathe. Air is a fundamental and unavoidable component of life, yet its quality is increasingly compromised in urban environments. In recent decades, air pollution has become one of the most pressing environmental and public health issues worldwide. The World Health Organization (WHO) estimates that over seven million people die prematurely every year due to exposure to polluted air. Polluted air contributes to the development and aggravation of respiratory diseases such as asthma, bronchitis, and chronic obstructive pulmonary disease (COPD), as well as cardiovascular conditions, strokes, and even certain cancers.

Beyond human health, air pollution also affects ecosystems and climate. Toxic compounds degrade soil and water quality, harm flora and fauna, and contribute to acid rain and global warming. Moreover, the fine particles and gaseous pollutants emitted into the atmosphere can travel long distances and interact with other environmental elements, further amplifying their harmful effects.

Among the major pollutants of concern are particulate matter (PM_{10}, $PM_{2.5}$, $PM_{1.0}$), Volatile Organic Compounds (VOCs), and formaldehyde (HCHO). These substances, which originate primarily from traffic, industrial activity, and domestic combustion, are known to have significant health impacts, especially in dense urban settings. VOCs and formaldehyde are also precursors in photochemical reactions that lead to ozone (O_3) formation, while fine particles can penetrate deep into the lungs and enter the bloodstream, exacerbating systemic inflammation.

In this context, understanding the presence, variability, and behavior of air pollutants is critical for establishing effective mitigation strategies. The present study was conducted in a heavily trafficked urban area of Algiers and aimed to characterize air pollution through both experimental measurements and predictive modeling.

Using the LifeBasis portable air quality analyzer, we measured daily concentrations of PM, VOCs, and formaldehyde during May and June 2025. In parallel, the Mengshen digital sound meter was used to monitor noise levels as a proxy for traffic density. This dataset allowed us to explore temporal trends in pollution and assess the influence of meteorological and environmental variables.

To enhance our understanding and to predict pollution levels under varying conditions, we also developed a numerical model based on artificial neural networks (ANN). This approach allows for the identification of complex nonlinear relationships between environmental indicators and pollutant concentrations. The model was trained and validated using real measurement data, providing a valuable tool for forecasting and air quality management.

This work thus combines environmental monitoring with advanced modeling techniques to contribute to a better understanding of urban air pollution dynamics and to support evidence-based decision-making in public health and urban planning.

Chapter 1

Air Pollution General Overview

1.1 Introduction

Air pollution remains one of the most critical environmental challenges of our time, significantly affecting human health, ecosystems, and the global climate. To fully grasp the complexity of air pollution, it is essential to first understand the physical structure and chemical composition of the Earth's atmosphere and the natural medium in which these pollutants are emitted, transformed, and dispersed.

This chapter provides a general overview of the structure of the atmosphere, including its layered configuration.Furthermore, it describes the main types and sources of air pollution, classified by spatial scale (local, regional, and global) and the role of meteorological factors such as temperature, pressure, humidity, and wind in the regulation of pollutant behavior.

By establishing a foundational knowledge of how the atmosphere functions and how it interacts with pollutants, this chapter serves as a vital starting point for understanding the mechanisms of air pollution and their broader environmental impacts.

1.2 Earth's atmosphere

1.2.1 Definition

The atmosphere is the gaseous envelope surrounding the Earth.It plays a vital role in supporting life by allowing breathing, regulating the planet's climate through the greenhouse effect, and protecting the surface from harmful solar radiation [1].

1.2.2 Atmospheric Layers

The atmosphere envelops Earth in layers defined by altitude based temperature changes. It includes the troposphere, stratosphere, mesosphere, and thermosphere, separated by narrow transition zones : the tropopause, stratopause, and mesopause [4].

The Thermosphere

The thermosphere contains very thin air and is marked by extremely high temperatures, often surpassing 2000°C. This heat is generated as ultraviolet radiation from the Sun is converted into thermal energy. The ionosphere, part of the thermosphere, is where auroras (polar lights) occur, especially near the poles [2].

The Mesosphere

In the mesosphere, temperatures decrease once again with height. Its upper boundary, the mesopause, is known as the coldest region in the atmosphere, with temperatures dropping below 130 K (−143°C). The precise boundaries of this layer vary depending on the season and latitude. Importantly, the mesosphere protects the planet by incinerating most meteoroids before they reach the surface [2].

The stratosphere

It is extending from about 12 to 50 km above the Earth's surface, is the lower part of the stratopause. Unlike the troposphere where temperature decreases with altitude, the stratosphere experiences a temperature increase with height due to the absorption of the Sun's ultraviolet radiation by ozone.The tropopause marks the boundary where this temperature inversion begins [2].

The Troposphere

It is the atmosphere's lowest layer, containing around 75percent of its total gases. It's where all weather events take place and where human life is sustained.Within this layer, temperature decreases by approximately 6.5°C for every kilometer of altitude. The warmest temperatures are found at the Earth's surface, gradually cooling with height. Although sunlight enters from above, this layer is mainly warmed from below, as the Earth's surface absorbs solar energy more effectively than the air. The heat is then transferred upward through air circulation. The tropopause, found at the top of the troposphere, is where temperatures level off, marking the boundary with the stratosphere [2].

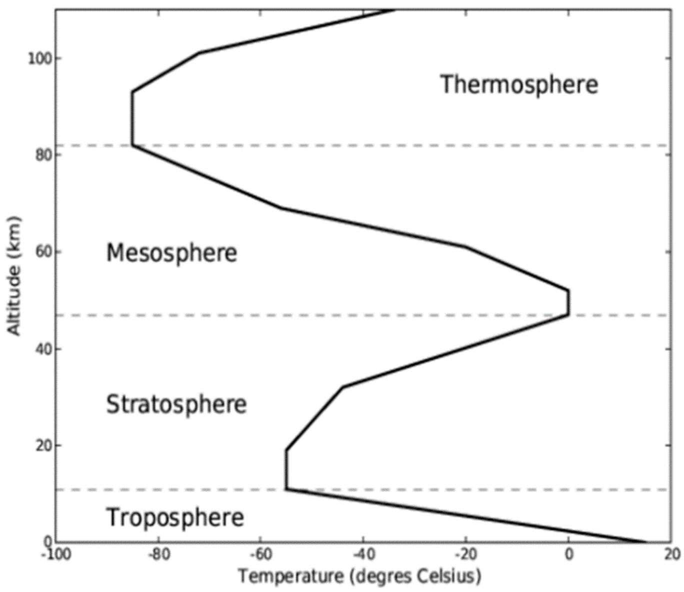

FIG. 1.1 : Temperature profile of the atmosphere layered structure.[4]

1.2.3 The Atmosphere Composition

The Earth's atmosphere is composed mainly of nitrogen (N_2) and oxygen (O_2), which together make up about 99 percent of its mass and volume. These are known as permanent gases due to their stable concentrations. Other gases like carbon dioxide (CO_2), ozone (O_3), and especially water vapor are present in small and variable amounts but play a role in atmospheric processes thanks to their radiative and thermal properties [3].

TAB. 1.1 : Gaseous Atmosphere Components[4].

Constituents	% (by volume)	Residence Time
Nitrogen (N_2)	78.08	> 100 years
Oxygen (O_2)	20.95	> 100 years
Argon (Ar)	0.93	> 100 years
Carbon dioxide (CO_2)	0.04	Variable
Neon (Ne)	1.810^{-3}	> 100 years
Helium (He)	1.810^{-3}	> 100 years
Methane (CH_4)	1.710^{-4}	9 years
Hydrogen (H_2)	5.010^{-5}	10 years
Nitrous oxide (N_2O)	3.010^{-5}	> 100 years
Carbon monoxide (CO)	1.210^{-5}	2 months
Ozone (O_3)	$2–20010^{-6}$	1 to 2 months
Ammonia (NH_3)	$0.1–110^{-6}$	20 days
Sulfur dioxide (SO_2)	210^{-8}	1 day
Nitrogen dioxide (NO_2)	110^{-7}	1 day
Water vapor (H_2O)	0–4	6 to 15 days

1.3 Air pollution

1.3.1 Definition

Air pollution is defined as the presence of harmful substances in the atmosphere at concentrations that can negatively impact human health, ecosystems, and materials. These pollutants may exist as gases, liquids, or particulate matter and can originate from both natural processes and human activities [3].

1.3.2 Air pollution Types

Certain atmospheric pollutants, due to their long lifespan, can travel far from their emission sources and impact various spatial scales. Therefore, when classifying pollution phenomena, it is essential to consider the scale of study. In scientific literature, three main scales are generally distinguished : local, regional, and global [5].

Local Scale Pollution

Occurs near emission sources such as industrial combustion, traffic, domestic heating, and waste incineration. It mainly involves pollutants like particulate matter (PM), nitrogen oxides (NO_x), sulfur dioxide (SO_2), carbon monoxide (CO), volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs), and metals. Affects areas within a few kilometers [**5**].

Regional scale Pollution

Air pollution extends across several tens to hundreds of kilometers, primarily as a result of atmospheric transformations involving primary pollutants. Through complex physico-chemical reactions, these substances give rise to secondary pollutants, such as ozone (O_3), a key component of photochemical smog formed in the presence of NO_x and VOCs. Additionally, nitric and sulfuric acids, formed from NO_x and SO_2 respectively, are major contributors to acid deposition or acid rain, which can degrade soil and water quality across wide areas [**5**].

Global scale Pollution

Pollution phenomena transcend regional boundaries, exerting significant influence on planetary systems and long-term environmental stability. This includes the accumulation of greenhouse gases, particularly carbon dioxide (CO_2), which contributes to global warming and climate change. Furthermore, the emission of chlorofluorocarbons (CFCs) plays a central role in the depletion of the stratospheric ozone layer, leading to increased ultraviolet radiation at the Earth's surface.These global scale impacts underscore the interconnectedness of local emissions and broader ecological consequences [**5**].

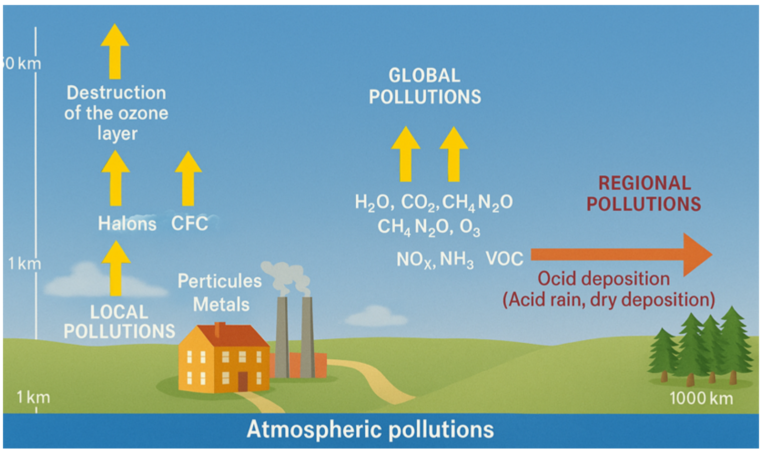

FIG. 1.2 : Pollution Types [5].

1.4 Major air pollutants

Several substances are classified as air pollutants because they do not occur naturally in the air or are present only at very low concentrations, and they are harmful to both human health and the environment. These pollutants fall into two categories : gases and particles.

1.4.1 Gases

The atmosphere contains a wide variety of gaseous pollutants, making it impossible to list or identify all of them. Below is a non exhaustive overview of the main pollutant categories and their key compounds :

Sulfur Dioxide (SO_4)

Sulfur dioxide is a colorless and odorless gas typically present in low concentrations at the Earth's surface. A key characteristic of $SO_4{}^{2-}$ is its ability to undergo complex atmospheric reactions, transforming into fine particulate sulfates after being released into the air. The primary human-made source of sulfur dioxide is the combustion of fossil fuels, particularly coal used in power plants, which contributes to approximately 88 percent of global $SO_4{}^{2-}$ emissions [6].

Nitrogen Oxides (NOx)

Nitrogen oxides, primarily nitric oxide (NO) and nitrogen dioxide (NO_2), are major air pollutants. NO_2 is a visible reddish-brown gas that contributes to smog formation and acid rain. It also reduces visibility by forming ions in atmospheric water droplets [6].

Polycyclic Aromatic Hydrocarbons (PAHs)

PAHs are a group of organic compounds present in biomass and fossil fuels or formed during their combustion. When these fuels are burned, PAHs and other volatile organic compounds (VOCs) become airborne. Among the various PAHs, smaller and lipophilic molecules are more easily absorbed through the respiratory tract. Their health effects vary based on their chemical structure, but many are known to irritate the respiratory lining. Some, such as benzo[a]pyrene and dioxins, are mutagenic and carcinogenic, posing particular risks for mouth, nasopharynx, larynx, and lung cancers [7].

Heavy Metals

Heavy metals, include lead (Pb), mercury (Hg), arsenic (As), cadmium (Cd), and nickel (Ni). In the atmosphere, they are mainly present in particulate form, except for mercury, which is primarily gaseous. Major sources include fossil fuel and wood combustion, cement production, agriculture, industrial processes, and waste incineration. These metals can accumulate in the body and cause various health effects, particularly on the nervous system, kidneys, and liver[5].

Carbon Monoxide (CO)

Carbon monoxide is a colorless, odorless, and highly toxic gas produced by the incomplete combustion of carbon-containing fuels. Major sources include motor vehicle exhaust (about 77 percent), cigarette smoke, and malfunctioning indoor heating systems.

- **The formation reaction is :**

$$2C + O_2 \rightarrow 2CO$$

CO is dangerous due to its strong affinity for hemoglobin—about 250 times greater than that of oxygen—reducing oxygen delivery in the body. Exposure can be fatal and poses serious risks to individuals with heart or respiratory conditions, as well as to developing fetuses[6].

Volatile Organic Compounds (VOCs)

VOCs originate from both anthropogenic sources and biogenic sources.Anthropogenic VOCs accumulate in the atmosphere and undergo various chemical transformations, while biogenic VOCs contribute significantly to tropospheric ozone formation, aerosol production, and ecosystem acidification [8].VOCs will be detailed in the following chapter.

Ozone (O_3)

Ozone is a strong oxidant gas formed naturally in the stratosphere and also created near the Earth's surface through photochemical reactions involving exhaust emissions. It can travel far from its source, carried by wind. Ozone levels are often higher in rural areas compared to cities and can harm human health, forests, and crops by reducing their ability to absorb carbon. It also affects plant growth and alters microbial communities due to its antimicrobial properties. In humans, ozone can damage skin cells by causing DNA damage and impairing normal cellular functions[12].

1.4.2 Particulate Matter

The atmosphere contains tiny suspended solid or liquid particles called aerosols, ranging in size from a few nanometers to nearly 100 microns about the width of a human hair. Globally, millions of tons of aerosols are emitted daily from a wide variety of natural and human made sources [9]. Particulate matter will be detailed in the following chapter.

1.5 Air pollution meteorology effect

The spread of pollutants from their source is essential in controlling whether they build up or disperse in the atmosphere. This process of dispersion is mainly affected by weather conditions which are :

1.5.1 Wind Effect

Wind promotes the dispersion of pollution, especially in flat areas without obstacles. Stronger winds lead to faster and more effective pollution dispersion[11].

1.5.2 Temperature Effect

Sunlight causes warming of the ground and surfaces, leading to convection currents that create vertical and horizontal air movements (since warm air is lighter than cold air). It also influences pollutant chemistry : solar energy, especially ultraviolet rays, can alter air molecules and promote the photochemical formation of tropospheric ozone. Photochemistry studies reactions involving the absorption or emission of light or electromagnetic radiation. These reactions produce many secondary pollutants in the troposphere, with the sun as the light source. Photochemical smog forms through these reactions, often during temperature inversions (valley effect) characterized by warm, dry, cloudless weather and weak winds [10].

1.5.3 Rain Effect

Rain acts as a natural cleanser by removing particulate matter from the atmosphere and dissolving gaseous pollutants. This ”scavenging” improves air quality and visibility. Areas with frequent heavy rainfall generally experience better air quality. However, when rain dissolves gases like sulfur dioxide, it can create acid rain, which may harm vegetation and materials [13].

1.5.4 Humidity Effect

Humidity plays a significant role in air pollution by influencing both chemical reactions and pollutant behavior in the atmosphere. When water vapor binds to airborne particles, it increases light scattering, thereby reducing visibility. Additionally, water vapor can dissolve corrosive gases like sulfur dioxide, forming acidic compounds that pose risks to human health and infrastructure. The amount of water vapor expressed as relative humidity varies with temperature, geographic location, and proximity to water sources, typically peaking during warmer, wetter months. This variability affects pollutant dispersion and transformation, making humidity a key factor in air quality assessment [13].

1.5.5 Inversion Layer

Pollutants disperse in a volume defined by the ground area (S) and the mixing layer height (H). Concentration is :

$$[C] = \frac{g}{SH}$$

If $S = 1\,\mathrm{km}^2$, then :

$$[C] = \frac{g}{H}$$

Normally, H extends up to the free troposphere. However, during a temperature inversion, a stable atmospheric layer forms that blocks vertical dispersion. This reduces the effective air volume available for dispersion, increasing pollutant concentration. Inversions typically result from rapid ground cooling and can occur at altitudes as low as 200 meters[11].

1.6 Atmospheric pressure and temperature Variation

1.6.1 Atmospheric Pressure

Atmospheric pressure decreases exponentially with altitude due to gravity acting on the air in a state of equilibrium. This means the pressure drop at any point is proportional to the local pressure. It is highest at sea level (about 1013 hPa) and gradually decreases with height[1].

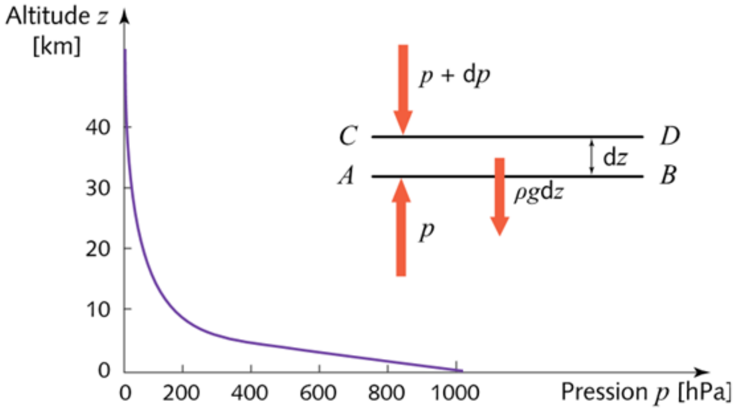

FIG. 1.3 : Pressure Variation with Altitude [1].

1.6.2 Heat transfer in the atmosphere

In the troposphere, temperature decreases linearly with altitude, starting from an average of 15°C at sea level. This temperature gradient results from energy exchanges between the Sun, the Earth, and the atmosphere. Although the Earth receives approximately 1361 W/m² of solar radiation, only about 240 W/m² is absorbed due to reflection (albedo) and the planet's curvature. Based on Stefan-Boltzmann's law, this would correspond to a surface temperature of −18°C. However, the actual average is +15°C, thanks to the greenhouse effect, which traps an additional 150W/m² of infrared radiation. This effect, driven by atmospheric composition, has intensified since the beginning of industrialization [1].

1.7 Conclusion

In this chapter, we have established a foundational understanding of air pollution by exploring the physical processes that govern the Earth's atmosphere.These elements are important for comprehending how pollutants interact with and are transported through the atmosphere.

The next chapter will focus more specifically on key air pollutants that are commonly monitored due to their relevance to environmental quality and public health. Particular attention will be given to particulate matter, total volatile organic compounds (TVOC), and formaldehyde, we aim to provide a clearer picture of their roles within the broader context of air pollution.

Chaptre 2

Air Pollutants General Overview

2.1 Introduction

This chapter focuses on three major air pollutants : Particulate Matter (PM), Total Volatile Organic Compounds (TVOC), and Formaldehyde (HCHO).

hese pollutants are briefly introduced through their general definitions, followed by a discussion of their properties that influence their behavior and persistence in the atmosphere. The chapter also explores their impacts on human health and the environment, as these substances are associated with a wide range of adverse effects. Furthermore, the main techniques used to measure and monitor these pollutants are presented, ranging from real time sensors to analytical laboratory methods. Lastly, we review the regulatory standards and guidelines which define exposure limits and inform public health policies.

2.2 Aerosols

2.2.1 Definition

Aerosols are solid or liquid particles suspended in the atmosphere (excluding water droplets and ice crystals), ranging from submicron to micron size. They vary widely in composition, origin, size, shape, and radiative impact, often existing as complex mixtures in the air [4].

2.2.2 Aerosol Properties

Aerosols are major components of the atmosphere, just like gases, but they exhibit a much greater diversity in composition and originate from a wide range of sources. However, compared to gases, the study of aerosols remains less developed, primarily due to the lack of suitable analytical tools [14].

Aerosol Structure

Based on current knowledge, the aerosol appears to be composed of the following elements :

- **Core :** Primarily composed of soot carbon (amorphous carbon) and metals or metal oxides. This central part gives the aerosol its characteristic black color[14].
- **Electrolyte Coating :** A thick layer of water soluble electrolytes, such as sulfates, surrounds the core[14].
- **Organic Layer :** On top of the electrolyte coating lies a layer of organic compounds. These originate from adsorbed volatile organic compounds (VOCs), which may have undergone photochemical reactions. The precise thickness and continuity of this layer are still not well defined[14].

- **External Water Layer :** Water partially dissolves the electrolyte layer and binds to organic compounds via hydrophilic functional groups[14].

The outer surface of the aerosol plays a role as it interfaces with the surrounding environment. It includes accessible and potentially reactive compounds that can interact with other atmospheric components. These surface compounds may also penetrate the human body, and if they are toxic, can pose significant health risks even at low concentrations [14].

Figure 2.1 provides a synthesis of the current understanding of pollution aerosol composition. It is important to note that this interpretation remains partially speculative due to the lack of definitive evidence.

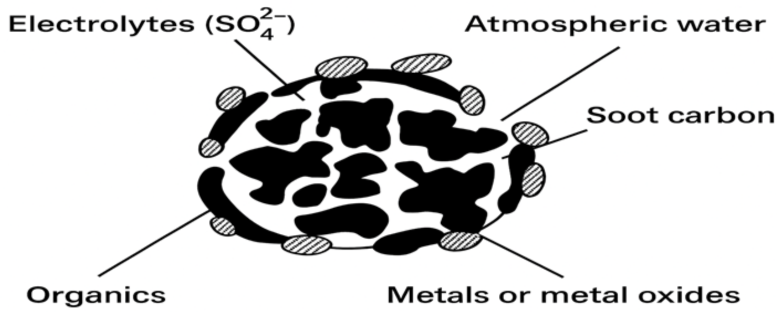

Fig. 2.1 : Aerosol Structure [14].

Particles Classification

- Size Classification (Granulometry)

A widely used method for classifying atmospheric particles relies on their granulometric distribution, specifically particle diameter. This parameter is important for characterizing the penetration capacity of particles into the respiratory system.

However, the most commonly used parameter in environmental studies is the equivalent aerodynamic diameter (dae), defined as the diameter of a spherical particle with a density of 1 g/cm^3, which settles in air at the same velocity as the particle being studied.

The aerodynamic diameter determines how particles are transported through the air, how they are removed from the atmosphere, and how they deposit in the respiratory tract [15].

Several classes of particles are distinguished in the literature based on their sizes, namely :

- **Total Suspended Particles (TSP) :** Includes all particles with diameters between 0.01 and 100 µm, regardless of size[15]

- **Coarse Particles (PM_{10}) :** Diameter < 10 µm. Settle quickly due to gravity. Common in urban pollution and often reported during pollution peaks[15]

- **Fine Particles ($PM_{2.5}$) :** Diameter < 2.5 µm. The particles stay in the air longer (up to several weeks) and are mainly removed by rain or fog. Their concentration is a serious public health concern[15]

- **Ultrafine Particles (UFPs / $PM_{0.1}$) :** Diameter < 0.1 µm (100 nm). Short atmospheric lifetime. Their small size and high toxicity make them particularly harmful to health [15].

- **Nanoparticles (NPs) :** Can be primary (emitted directly) or secondary (formed in the atmosphere through chemical reactions and condensation) [15].

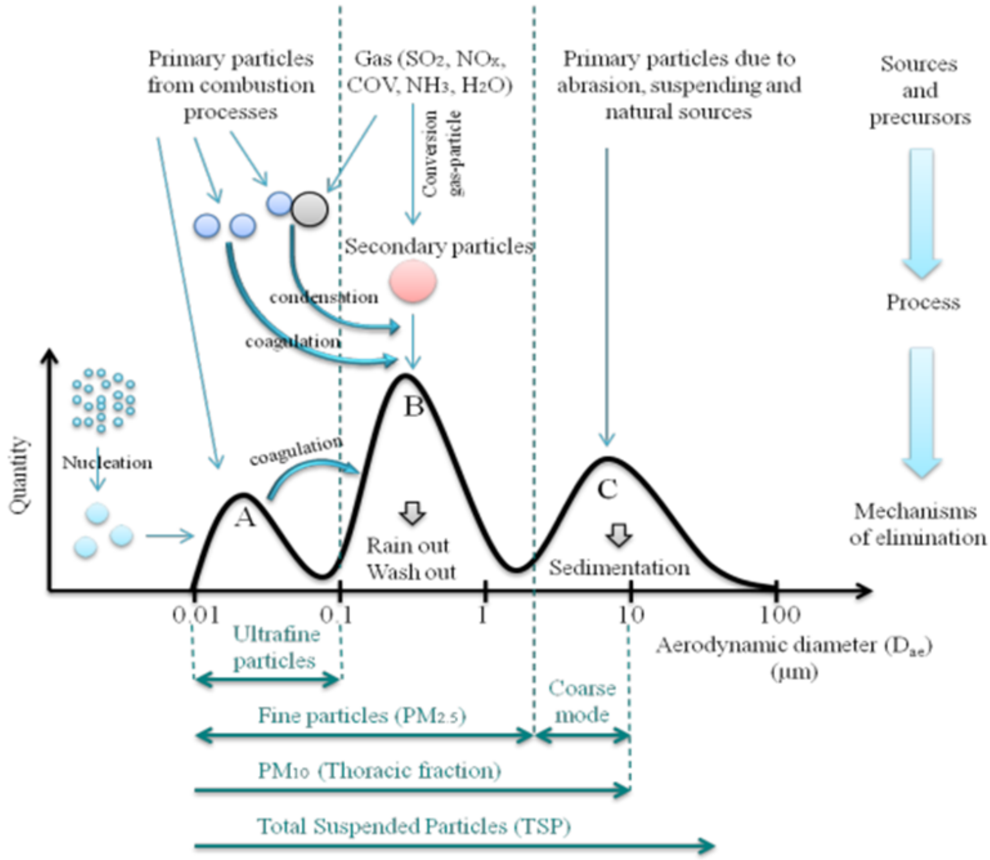

FIG. 2.2 : Aerosol Particle Size Distribution and Formation Mechanisms[16].

2.2.3 Particulate matter Effects

- **On The Respiratory**

  Fine particulate matter ($PM_{2.5}$) is considered one of the most critical environmental risk factors for public health. According to the Global Burden of Disease (GBD 2015), $PM_{2.5}$ ranks as the fifth leading cause of death worldwide, contributing to approximately 4.2 million deaths and 10.31 million disability adjusted life years (DALYs) annually. The World Health Organization (WHO) reports that 9 out of 10 people living in urban areas are exposed to $PM_{2.5}$ concentrations exceeding 10 $\mu g/m^3$ [17].

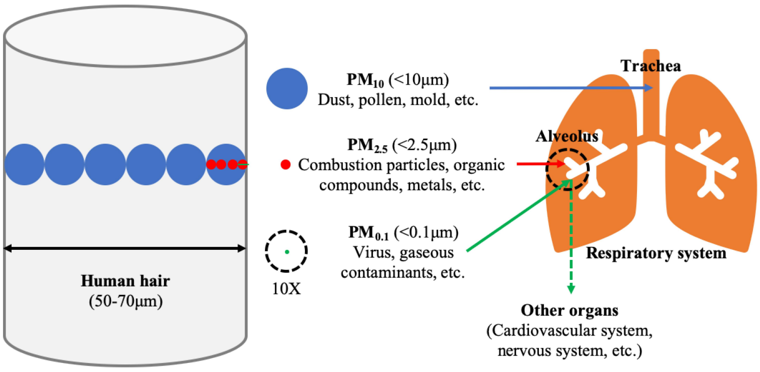

FIG. 2.3 : respiratory infections[17].

- **On Cardiovascular system**

  $PM_{2.5}$ (fine particulate matter) poses a serious risk to cardiovascular health due to its ability to penetrate deep into the lungs, cross the alveolar capillary barrier, and enter the bloodstream. Once in circulation, it can reach the heart and blood vessels, where it induces oxidative stress, inflammation, and endothelial dysfunction. These effects are largely attributed to toxic constituents such as polycyclic aromatic hydrocarbons (PAHs) and heavy metals, which cause DNA damage and can lead to vascular injury. Prolonged exposure to PM2.5 has been strongly associated with increased risks of ischemic heart disease, stroke, heart failure, and elevated cardiovascular mortality. Globally, air pollution is responsible for approximately 19 percent of cardiovascular deaths and contributes to over 6 million premature deaths annually. Notably, even moderate levels of PM2.5 exposure have been linked to a significant rise in cardiovascular disease cases in many countries. The underlying mechanisms include oxidative damage, chronic inflammation, altered coagulation, and autonomic nervous system disruption, which collectively promote atherosclerosis, myocardial inflammation, and acute cardiac events[18].

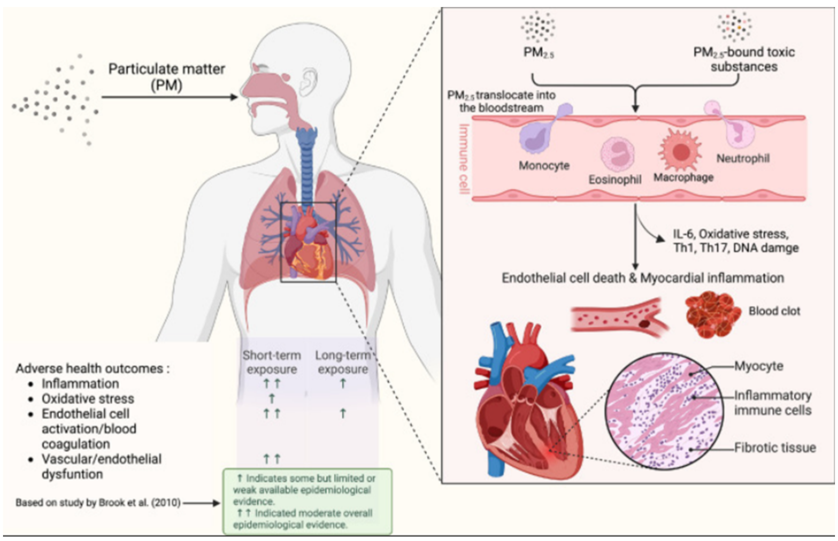

FIG. 2.4 : $PM_{2.5}$and Its Role in Cardiovascular Disease Pathophysiology[18].

- **On Vegetation**
  Particulate matter (PM) affects vegetation through its chemical composition and physical deposition. Harmful substances like acids and heavy metals damage leaves and soil, while dust can disrupt photosynthesis by altering leaf reflectance and increasing temperature. PM also blocks stomata, hindering gas exchange and slowing plant growth. Some plants have natural defenses like waxy surfaces or sunken stomata, which offer partial protection[19].

2.3 Volatile Organic Compounds (VOCs)

2.3.1 Definition

The European directive of March 11, 1999 (No. 1999/13/EC), concerning the reduction of emissions of volatile organic compounds (VOCs), defines :

- **An organic compound** as any compound containing at least one carbon atom and one or more of the following elements : hydrogen, halogens, oxygen, sulfur, phosphorus, silicon, or nitrogen excluding carbon oxides, carbonates, and inorganic bicarbonates.

VOCs exist in the gas phase under standard temperature and pressure conditions. They are characterized by their relatively long atmospheric lifetime and sufficient reactivity to participate in photochemical reactions. Hence, the term **NMVOC** (Non-Methane Volatile Organic Compounds) is often used [20].

2.3.2 VOCs Classification

VOCs are a large and diverse group of substances with varying physical (e.g., melting and boiling points) and chemical (e.g., reactivity, flammability) properties, all determined by their chemical structure.

Structural differences such as bond types, chain lengths, and functional groups can significantly alter these properties. Even isomers, which share the same molecular formula, can behave very differently. VOCs are typically classified by their chemical structure, as shown in table 2.1.

Tab. 2.1 : VOCs pollutants Classification [21].

Class	**Examples of Compounds**	**Boiling Point Range (°C)**
- Very Volatile Organic Compounds (VVOCs)	- Propane, Butane, Methyl-chloride	0 to 50–100
- Volatile Organic Compounds (VOCs)	- Formaldehyde, Toluene, Acetone, Isopropyl alcohol	50–100 to 240–260
- Semi-Volatile Organic Oompounds (SVOCs)	- Pesticides (Chlordane, DDT), Plasticizers (Phthalates)	240–260 to 380–400

2.3.3 VOCs Effects

- **Health Effects**

Some volatile organic compounds (VOCs) are photochemically reactive in the atmosphere, contributing to photo-oxidant pollution and the greenhouse effect, while others have biological effects or produce odors.

From a health perspective, many VOCs, especially solvents, can be irritating to the skin, eyes, respiratory system, and nervous system. Certain compounds, such as benzene, are known to be carcinogenic or mutagenic. Additionally, some VOCs cause odor nuisances for communities near emission sources[22].

- **Environmental Effects**

Volatile organic compounds (VOCs), such as toluene, ethylbenzene, and benzene, originate from incomplete combustion, solvents, industrial emissions, and natural sources. In the atmosphere, VOCs react with oxidants like $OH\cdot$, $NO_3\cdot$, and ozone, forming secondary pollutants that are often more toxic.

During the day, VOCs contribute to the conversion of NO into NO_2, which leads to ozone formation through photolysis. This photochemical cycle, driven by sunlight and nitrogen oxides especially from traffic results in ozone accumulation, particularly on summer afternoons.

Atmospheric VOC transformations also lead to the formation of toxic gases such as aldehydes, ketones, acids, and nitrated compounds. These degrade air quality both locally and regionally and contribute to climate change through radiative effects [23].

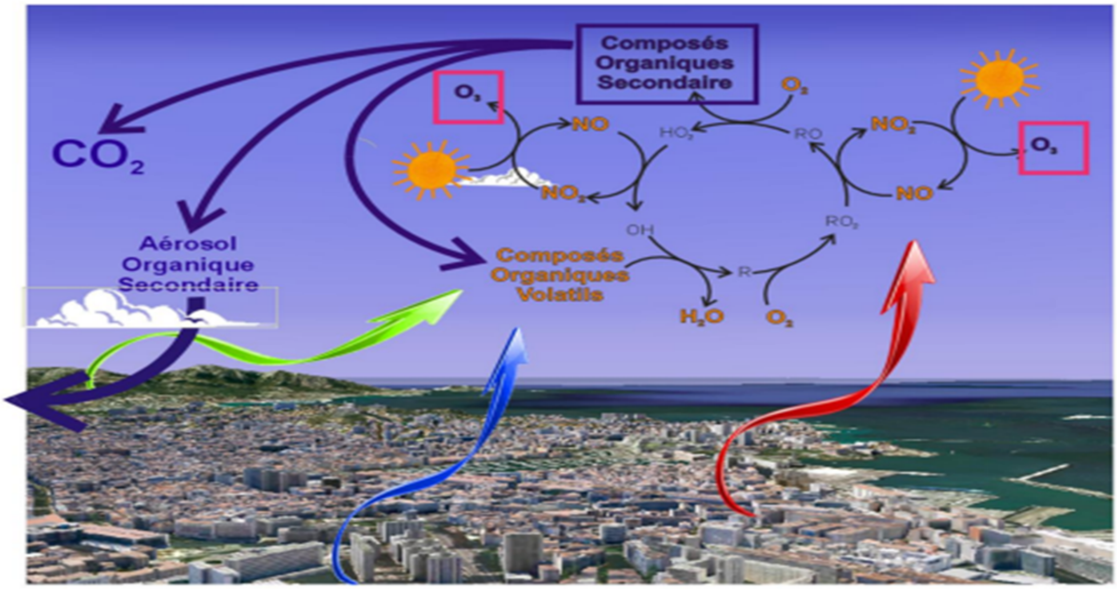

FIG. 2.5 : OH Initiated VOC Oxidation Leading to Ozone and Organic Matter Oxidation [23].

2.4 Formaldehyde

2.4.1 Definition

Formaldehyde is a highly reactive, colorless gas with a pungent odor. It is flammable, irritating, and toxic, and dissolves well in water and polar solvents. Its strong electrophilic nature makes it prone to polymerization and capable of forming explosive mixtures in air. At temperatures above 150°C, it decomposes into methanol and carbon monoxide, and under sunlight, it is easily photooxidized to carbon dioxide.

Pure formaldehyde is obtained in liquid form through the catalytic oxidation of methanol. This reaction takes place in a controlled, closed system, producing formaldehyde efficiently [24].

2.4.2 Formaldehyde Properties

The properties of formaldehyde are mentioned in the table 2.2

TAB. 2.2 : Formaldehyde Properties [24].

Property	**Value**
Chemical Name	Formaldehyde
IUPAC Name	Methanal
Other Names	Methylene oxide, Methylaldehyde, Formic aldehyde, Oxomethane
Chemical Formula	CH_2O (or HCHO)
Molecular Weight	30.03 g/mol
Appearance	Clear, colorless liquid
Density	0.8153 g/cm^3 (at −20°C)
Melting Point	93–96°C (at 37% aqueous concentration)
Boiling Point	−15°C (at 37% aqueous concentration)

2.4.3 Formaldehyde Effects

Formaldehyde exposure can lead to a range of health problems, depending on the concentration and duration of exposure. It commonly causes respiratory symptoms such as coughing, wheezing, and shortness of breath. Skin contact may trigger allergic reactions including rashes and dermatitis.

Other reported symptoms include headaches, dizziness, fatigue, sleep disturbances, and general weakening of the immune system. At higher concentrations, formaldehyde can cause severe health effects such as chest tightness, cardiovascular issues, and pulmonary edema, which may be life threatening.

Long term exposure is linked to an increased risk of certain cancers, including nasopharyngeal cancer, sinonasal cancer, and myeloid leukemia [25].

Figure 2.6 presents the minimum inhalation and oral exposure levels associated with carcinogenicity and other adverse health outcomes.

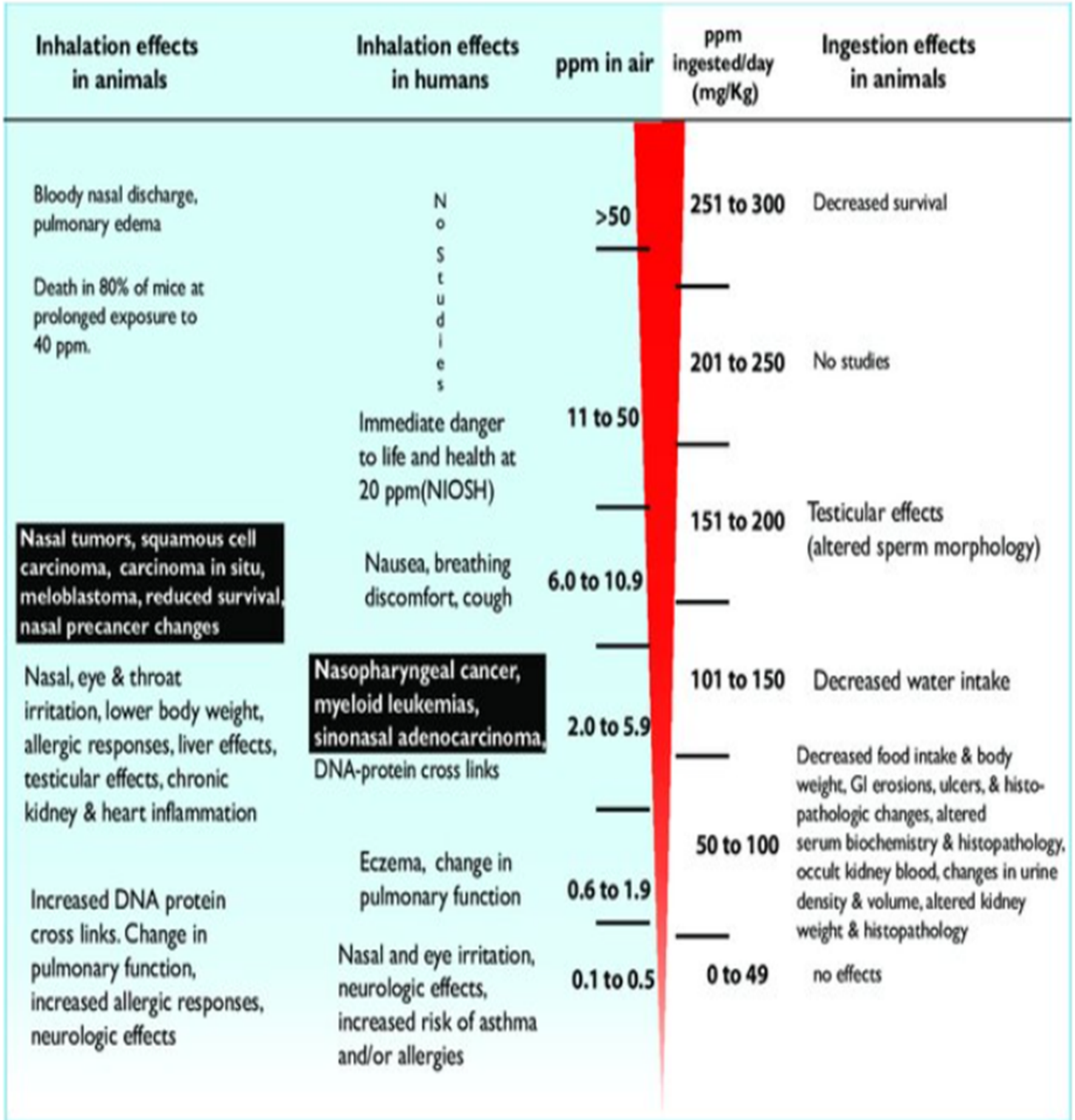

Fig. 2.6 : Formaldehyde Effects[26].

2.5 Pollutants sources

2.5.1 Aerosol Sources

Aerosol sources are categorized into natural and anthropogenic types :

- Natural Sources

- **Mineral Dust :** Emitted from arid regions like the Sahara and Central Asia ; transported globally [27].

- **Volcanic Activity :** Releases ash and sulfur gases (SO_2, H_2S), forming secondary sulfate aerosols [27].
- **Marine Aerosols :** Generated by wind over ocean surfaces. Include sea salts and biological material, mostly in the supermicron range (>1 µm). Emissions range from 1000–6000 Tg/year [27].

- Anthropogenic Sources

- **Biomass Burning :** Linked to residential heating and cooking. Emits soot, organic matter, and inorganic salts. Composition varies with biomass type and combustion conditions [28].
- **Fossil Fuel Combustion :** Includes road traffic and power generation, major source of particulate emissions [28].
- **Industrial Activities :** Mining, cement production, and metallurgy contribute significantly to local aerosol levels [28].

2.5.2 Volatile Organic Compounds (VOCs) Sources

- **Primary Sources :**
  Primary sources directly emit VOCs into the atmosphere and can be anthropogenic (industrial, residential, traffic related) or biogenic (vegetation, soils, oceans)[29].
- **Secondary Sources :**
  Secondary VOCs form in the atmosphere via oxidation of primary VOCs. While biogenic sources dominate globally, urban areas are mostly influenced by anthropogenic emissions [29].

2.5.3 Formaldehyde Sources

- **Natural Sources :** Formamdehyde is present in smog, resulting from the reaction between sunlight and atmospheric hydrocarbons. Furthermore, it has been detected in interstellar space and can be produced through abiotic reactions such as CO hydrogenation [30].
- **Anthropogenic Sources :**
  Anthropogenic sources of formaldehyde primarily include fuel combustion from vehicles and industrial emissions from refineries and factories involved in stone, clay, and glass production [30].

2.6 Pollutants Measurments

This section focuses on the equipment used to measure particulate matter (PM) concentration, which can be expressed in terms of mass, number, or surface area [31]. Additionally, this section highlights the main techniques used for VOCs and formaldehyde measurement, emphasizing their strengths, limitations, and typical applications. While traditional methods are often complex and unsuitable for detecting rapid fluctuations in concentration [32]. The following tables summarize these measurement methods.

2.6.1 Particulate Matter Measurement Methods

Beta Attenuation Monitors (BAMs)

BAMs measure the attenuation of beta radiation as it passes through a filter tape that collects particulate matter. The degree of attenuation correlates with the mass of the particles collected [31].

Tapered Element Oscillating Microbalance

TEOM instruments measure the mass of particles collected on a filter attached to a vibrating element. The change in the oscillation frequency of the element corresponds to the mass of the collected particles [31].

The Life Basis Detector

It is a compact, portable air quality monitor designed to track different pollutants such as particulate matter (PM1.0, PM2.5, PM10), Vocs and formaldehyde .The device features a rechargeable battery, a color LCD screen with alerts, and requires calibration before use [33]. It is the reference method that will be detailed in the methodology chapter.

2.6.2 VOCs Measurement Methods

Continuous Measurement Using Flame Ionization Detector (FID)

The FID is widely used in France and internationally for continuous monitoring of total VOC concentrations. It operates by ionizing organic compounds in a hydrogen-air flame and measuring the resulting ion current, which is proportional to the number of carbon-hydrogen bonds present [34].

Photoionization Detector (PID)

Photoionization Detectors use ultraviolet light to ionize VOC molecules, and the resulting current is measured to determine VOC concentrations [34] .

2.6.3 Formaldehyde Measurement Methods

Colorimetric Method (Hantzsch Reaction)

In this method, formaldehyde reacts with acetylacetone and ammonium acetate under acidic conditions to form a fluorescent compound called DDL (3,5-diacetyldihydrolutidine). The intensity of the fluorescence is proportional to the concentration of formaldehyde [32].

Electrochemical and Chemical Sensors

These sensors detect formaldehyde through redox reactions that generate an electrical signal proportional to the concentration of the gas [32].

2.7 Particulate Matter Air Quality Regulations

2.7.1 In Algeria

Algerian regulations do not differentiate between types of fine particulate matter, treating them collectively. The established thresholds are as follows :

- Target Value for Air Quality : 50 $\mu g/Nm^3$
- Limit Value : 80 $\mu g/Nm^3$

In contrast, European standards clearly define and regulate specific particle categories, such as PM_{10} and $PM_{2.5}$ [35].

2.7.2 In Europe

At the European level, air quality directives set binding pollutant concentration limits. Each member state must ensure that these thresholds are not exceeded annually. Failure to comply may result in financial penalties unless natural events or cross-border pollution can be proven as contributing factors.

TAB. 2.3 : Particulate Matter European Regulatory Limits [36]

Pollutant	**Guideline Value ($\mu g/m^3$)**	**Averaging Time**
PM_{10}	50	24-hour
	20	Annual
$PM_{2.5}$	25	24-hour
	10	Annual

2.7.3 Global Level

The World Health Organization (WHO) has issued air quality guidelines aimed at protecting public health worldwide. Based on extensive scientific data, these recommendations cover four major pollutants : ozone, sulfur dioxide, nitrogen dioxide, and particulate matter (PM). For PM, the WHO distinguishes between PM_{10} and $PM_{2.5}$, providing two sets of indicative values. Although these guidelines are not legally binding, they serve as important reference points for establishing air quality standards [37].

Tab. 2.4 : Particulate Matter WHO Air Quality Guideline Values [37]

Pollutant	Guideline Value (µg/m³)	Averaging Time
PM_{10}	50 20	24-hour Annual
$PM_{2.5}$	25 10	24-hour Annual

2.8 VOC Air Quality Regulations

2.8.1 In Algeria

Environmental regulation is based on two main laws.The most current is Law No. 03-10 of July 19, 2003, concerning environmental protection within the framework of sustainable development. It includes several implementation decrees, notably on air quality.

Executive Decree No. 06-138 of April 15, 2006 regulates atmospheric emissions of gases, vapors, and particles from fixed sources, especially industrial installations. It sets the limit value for total non-methane VOC emissions at :

- 150–200 mg/Nm^3 for older industries [38].

2.8.2 International VOC Regulations

Internationally, two main protocols address VOC emissions :

- **Geneva Protocol (1991)** : Aims to reduce VOC and air pollutant emissions from industrial and domestic sources to limit the formation of photochemical oxidants.

- **Gothenburg Protocol (1999)** : Targets multiple pollutants (SO_2, NO_x, NH_3, VOCs) to reduce acidification, eutrophication, and ground-level ozone, setting emission limits for various fixed sources [39].

2.8.3 Guideline Values and Recommendations

The World Health Organization (WHO) has established Air Quality Guidelines to help reduce the health effects of air pollution. These include reference values for both indoor and outdoor air.

- These guideline values represent pollutant concentrations below which no significant risk to human health is expected. However, they are not legally binding.
  - **Non-carcinogenic VOCs** : e.g., styrene, tetrachloroethylene, toluene
  - **Carcinogenic VOCs** : e.g., benzene, trichloroethylene, PAHs [40].

2.9 Formaldehyde Regulation

2.9.1 In Algeria

- **Decree No. 07-144 (2007)** :
  - Lists formaldehyde (concentration $\geq 90\%$) under classified installations (Rubrique 1244).
  - Requires prior authorization, environmental impact studies, and safety measures for its use or storage [41].

2.9.2 In Occupational Environments (France)

Until December 2021, two **indicative** occupational exposure limit values (OELs) in France were used as preventive references :[42]

- 8-hour indicative OEL : 0.5 ppm or 0.62 mg/m^3
- 15-minute indicative OEL : 1 ppm or 1.23 mg/m^3

Decree No. 2021-1849 amended Article R. 4412-149 of the French Labor Code to implement binding regulatory values in line with Directive (EU) 2019/983:

- 8-hour OEL : 0.3 ppm or 0.37 mg/m^3
- 15-minute OEL : 0.6 ppm or 0.74 mg/m^3 [42].

2.10 Conclusion

This critical review establishes that particulate matter (PM), volatile organic compounds (VOCs), and formaldehyde represent three distinct yet interconnected atmospheric challenges, each requiring specialized characterization approaches.

These findings highlight the urgent need for accurate monitoring and assessment of these pollutants. In the following chapter, we will present our methodology for measuring their concentrations, building upon this scientific foundation to evaluate air quality in our study area.

Chaptre 3

Techniques and modeling using artificial intelligence Overview

3.1 Introduction

In recent decades, artificial neural networks (ANNs) have emerged as a powerful class of computational models inspired by the structure and functioning of the human brain. By simulating the interconnected neurons of biological neural systems, ANNs are capable of learning complex relationships and patterns from data, making them valuable tools in fields such as pattern recognition, classification, regression, control systems, and artificial intelligence.

This chapter presents a comprehensive overview of artificial neural networks, beginning with the fundamental components of a neural network, such as the artificial neuron and its functional steps. It also explores the different types of neural architectures, the principles of learning, and the main categories of learning algorithms. Lastly, the advantages and limitations of neural networks are discussed to provide a balanced understanding of their potential and practical considerations.

3.2 Artificial Neural Networks (ANN)

An artificial neural network commonly referred to as a neural network is a computational or mathematical model inspired by the structure and functioning of biological neural networks found in the brain. It consists of multiple artificial neurons, which are nonlinear processing units, connected through synaptic weights (also called simply weights) [43].

At the core of an artificial neural network lies the artificial neuron, which is a mathematical model simulating the behavior of its biological counterpart. Each artificial neuron operates according to three fundamental steps :

- **Multiplication :** Each input is multiplied by a specific weight.
- **Summation :** All weighted inputs are summed, often along with a bias term.
- **Activation :** The result is passed through an activation (or transfer) function, which determines the output of the neuron [43].

3.3 Artificial Neural Networks Categories

Artificial neural networks can be divided into two main categories :

3.3.1 Static Multilayer Neural Networks

This type of network is generally organized into layers of neurons. Each neuron in a layer receives its inputs from the neurons of the previous layer or directly from the network input. In this case, there is no feedback of information, meaning the information flows in only one direction from input to output. These networks can be used for classification problems or the approximation of complex nonlinear functions.

The most well known static neural networks are :

- Multilayer Perceptrons (MLP)
- Modular networks
- Kohonen networks

The architecture of an MLP is organized into successive layers, including an input layer, an output layer, and one or more intermediate layers called hidden layers, as they are not visible from outside the network. Each layer is composed of a certain number of neurons.Each neuron in a given layer is connected to all the neurons in the next layer, and there are no connections between neurons within the same layer [44].

A neuron can only send its result to a neuron located in a subsequent layer (see Figure 3.1).

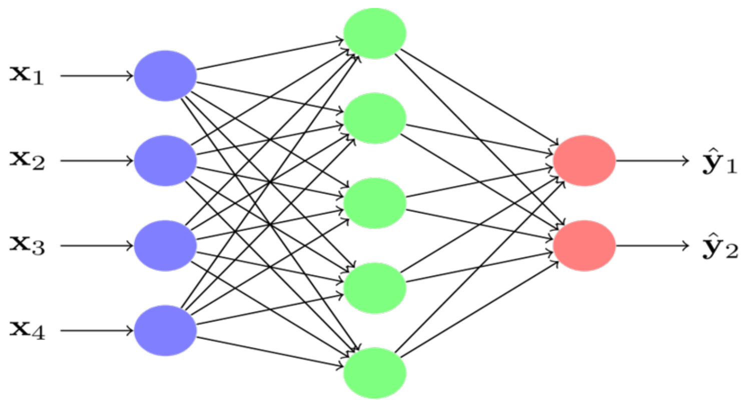

Fig. 3.1 : Multilayer Perceptron (MLP) Network[46]

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3.3.2 Dynamic Neural Networks

Dynamic neural networks, also referred to as recurrent neural networks (RNNs), are structured in such a way that each neuron receives, in addition to external inputs, a portion or the entirety of the network's internal state namely, the outputs of other neurons.

In such networks, interactions between neurons occur in both directions, allowing for a feedback mechanism.

The overall state of the network is therefore influenced not only by current inputs but also by its previous states, enabling it to process temporal sequences and retain memory over time [44].

The most widely used types of dynamic neural networks include :

- Time delay neural networks
- Output feedback neural networks
- Hopfield networks

3.4 Neural Network Learning

Learning refers to the process through which a neural network acquires the ability to perform specific tasks by adjusting its internal parameters, particularly the synaptic weights. These adjustments are made using a parametric adaptation algorithm, commonly referred to as a *learning algorithm*. The purpose of learning is to improve the network's future performance by leveraging knowledge gained from previous experiences.

The main objective of learning algorithms is to minimize the decision error made by the neural network by adjusting the weights with each presentation of a training vector [44].

3.5 Learning Types

Learning algorithms are typically categorized into three main classes :

- **Unsupervised Learning**

Unsupervised learning is based solely on the input data, without requiring knowledge of the corresponding desired outputs. It reflects the neural network's ability to learn patterns and structure from data without external supervision.

In this learning mode, the network automatically organizes the input data it receives in a way that minimizes a specific performance criterion. As inputs are presented, the network internally groups them by forming categories through self organization.

This type of learning is also known as competitive learning, because the neurons in the network compete with each other to represent the input vector.

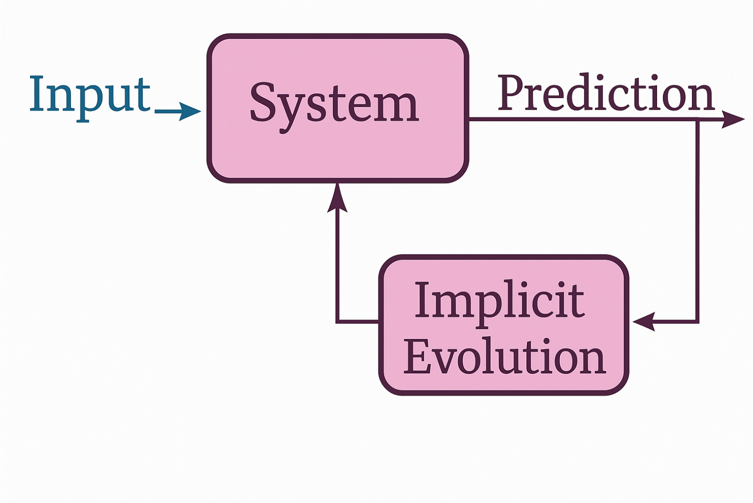

FIG. 3.2 : Unsupervised Learning[46]

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- **Imposed or Forced Learning**
  In this type of learning, the network is simply informed whether the output is correct or incorrect. This feedback triggers a selective adjustment of the connection weights [44].
- **Supervised Learning**

  Supervised learning refers to situations where both input and corresponding desired output examples are available. The goal is to develop a model that can predict the correct output based on a given input[44].

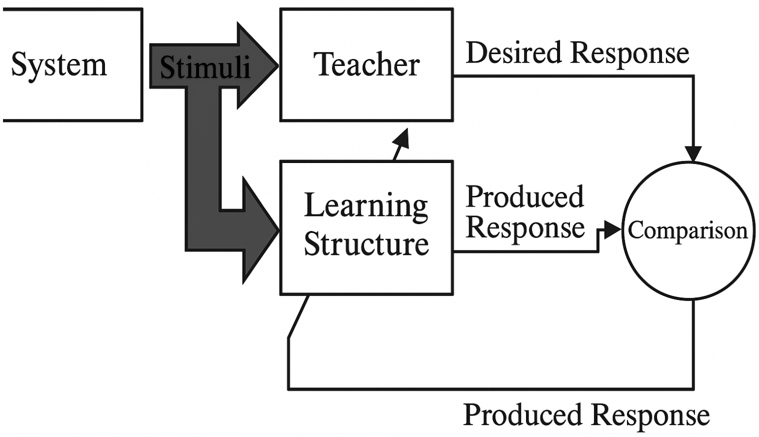

FIG. 3.3 : Supervised learning [46]

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3.6 Neural Modeling Formality

The procedure for developing a neural network that adheres to a static modeling approach can be summarized in the following steps :[50]

1. Data selection
2. Splitting the dataset
3. Data normalization
4. Choosing the type of neural network
5. Selecting the number of neurons in the hidden layer
6. Choosing the transfer function
7. Parameter estimation or training
8. Validation and generalization

3.7 ANNs Advantages and Disadvantages

The combined use of neural networks allows us to benefit from their strengths while being aware of their limitations. Table 3.1 summarizes the main advantages and disadvantages of artificial neural networks.

TAB. 3.1 : ANNs Advantages and Disadvantages [44].

Advantages	Disadvantages
No mathematical model required. No rule-based knowledge needed. Several learning algorithms available.	Black box. Adaptation to environments and retraining is often necessary.

Chaptre 4

Methodology

4.1 Introduction

In the present study, we aim to measure and evaluate atmospheric pollution levels in a selected urban site in Algiers. This work forms part of a broader effort to understand air quality in densely populated regions, where anthropogenic emissions are predominant. Our focus is primarily on particulate matter,VOCs and formaldehyde.

This section provides a detailed description of the experimental site, the instruments and sensors employed in the monitoring campaign, and the methodologies adopted for data collection and analysis. We also explain the rationale behind the selection of our methods and the parameters measured. The ultimate goal is to ensure the reliability and relevance of the collected data, which will serve as the foundation for subsequent interpretation and discussion in the following chapter.

4.2 Study Urban Area Description

The present study was conducted in an urban location in Bab Ezzouar within the city of Algiers, Algeria. The geographic coordinates of the site are approximately about 36.711901° N latitude and 3.171825° E longitude (see Figure 4.1)

This site was chosen based on several criteria, including its continuous exposure to heavy road traffic, its proximity to academic institutions and residential zones, and its relevance for evaluating pollution levels in a typical urban Algerian setting. Over recent years, this corridor has become increasingly congested due to urban expansion, population growth, and rising numbers of vehicles. As a result, it represents a significant hotspot for emissions of atmospheric pollutants such as volatile organic compounds (VOCs), formaldehyde, and particulate matter.

The location offers an ideal context for studying urban air quality because it captures the cumulative impact of multiple emission sources, including vehicular exhaust, nearby commercial activities, and possibly local industrial emissions. In addition, it serves as a transit route for thousands of daily commuters, making it representative of the exposure levels encountered by the local population.

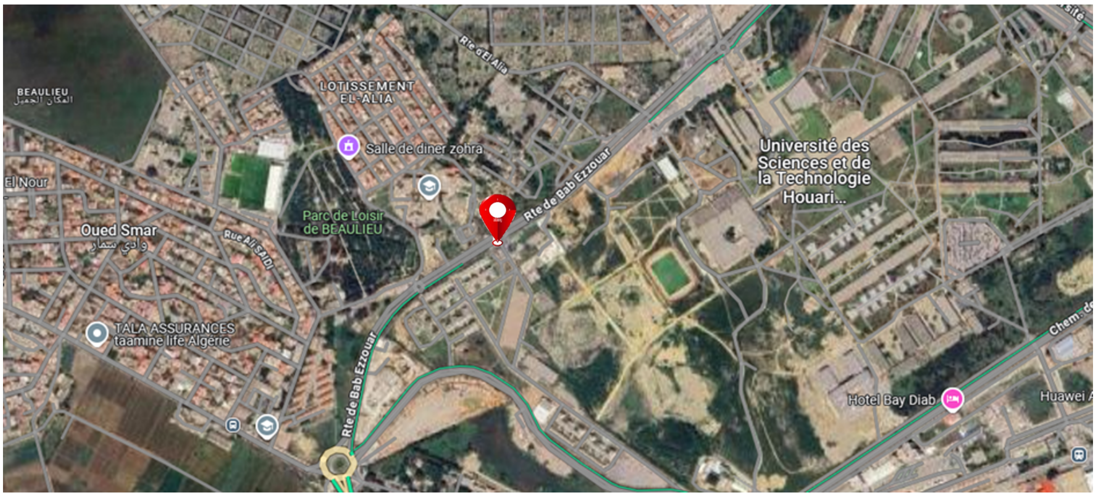

Fig. 4.1 : Study location site

4.3 Measurement Protocol

A measurement protocol outlines the procedures and conditions under which environmental data are collected to ensure consistency, accuracy, and reproducibility. For air quality monitoring, this includes specifying the sampling location, height, duration, frequency, calibration steps, and environmental conditions. A clear protocol helps validate the data and ensures comparability across time.

4.3.1 Measurement Device : LifeBasis Air Quality Sensor

The LifeBasis Portable Air Quality Sensor is a compact and precise device designed for real time monitoring of multiple atmospheric pollutants (see figure 4.2). It is capable of measuring five key pollutants, including :

- $PM_{2.5}$
- $PM_{1.0}$
- PM_{10}
- Formaldehyde (HCHO)
- Total Volatile Organic Compounds (TVOCs)

Additionally, the device provides data on ambient temperature and humidity. The figure 4.2 summarizes the measurable parameters of the device

Fig. 4.2 : Life Basis Air Quality Analyzer

Air Quality Index (AQI)

- **Definition :** The Air Quality Index (AQI) is a standardized tool used to report daily air quality levels. It provides information on how clean or polluted the air is and highlights the possible health effects associated with current pollutant concentrations [45].

- **Based on $PM_{2.5}$:**
  The LifeBasis device estimates the Air Quality Index (AQI) using $PM_{2.5}$ values. The table 4.1 defines air quality levels based on average $PM_{2.5}$ concentrations.

Tab. 4.1 : AQI Classification Based on $PM_{2.5}$ Concentration

Air Quality Level	**$PM_{2.5}$ (µg/m^3)**
Excellent	0–35
Good	36–75
Slight Pollution	76–115
Moderate Pollution	116–150
Severe Pollution	151–250
Serious Pollution	>500

- **Based on Formaldehyde (HCHO) :**
  The table 4.2 defines air quality levels based on average HCHO concentrations :

Tab. 4.2 : AQI Classification Based on Formaldehyde Concentration

Pollution Level	**HCHO (mg/m³)**
Safe Range	< 0.100
Mild Contamination	0.101–0.200
Moderate Pollution	0.201–0.300
Heavy Pollution	> 0.301

- **Based on TVOCs :**
  The table 4.3 defines air quality levels based on average TVOCs concentrations :

Tab. 4.3 : AQI Classification Based on TVOCs Concentration

Pollution Level	**TVOC (mg/m³)**
Safe Range	< 0.600
Hazardous	> 0.601

4.3.2 Measurement Procedure

To collect accurate and stable data, the following procedure was implemented for each measurement session :

1. The measurement were conducted six times per day from 08:00 a.m until 18:00 p.m, with each individual measure period lasting approximately 20 to 30 minutes.
2. Turn on the device by pressing the power button for 3 seconds.
3. Place the detector in the measurement location.
4. Ensure the device is positioned at a height between 80 and 150 cm above ground level.
5. Wait for 5–10 minutes for the readings to stabilize before recording any values.

4.3.3 Measurement Device : Mengshen digital precision instrument

This device precisely measures sound pressure levels (noise) and displays the results in decibels (dB). It operates using a condenser microphone that captures fluctuations in air pressure caused by sound waves and converts them into interpretable electrical signals.

Fig. 4.3 : Mengshen digital precision instrument

4.3.4 Measurement Procedure

- We used the Mengshen digital sound level meter alongside the LifeBasis air quality monitor to simultaneously measure traffic noise levels and air pollution concentrations. The measurements using the Mengshen digital sound level meter were conducted at the same site and during the same time intervals as the LifeBasis air quality monitor.

4.4 Weather conditions

Meteorological conditions play a significant role in atmospheric pollution mechanisms, as they directly influence pollutant concentrations at the given location. The meteorological archive diagrams are organized into three distinct charts :

- **Temperature and Relative Humidity :** Displayed at hourly intervals, allowing for a detailed temporal analysis of thermal and humidity variations.
- **Cloud Cover and Sky Conditions :** Represented using background colors grey for cloud cover and light blue for clear skies. The intensity of the grey shading corresponds to the density of cloud cover.
- **Wind Speed and Direction :** Expressed in degrees, where 0° = North, 90° = East, 180° = South, and 270° = West. In the historical archive meteogram, the green line indicates wind speed, while the wind rose illustrates the direction of wind movement [46].

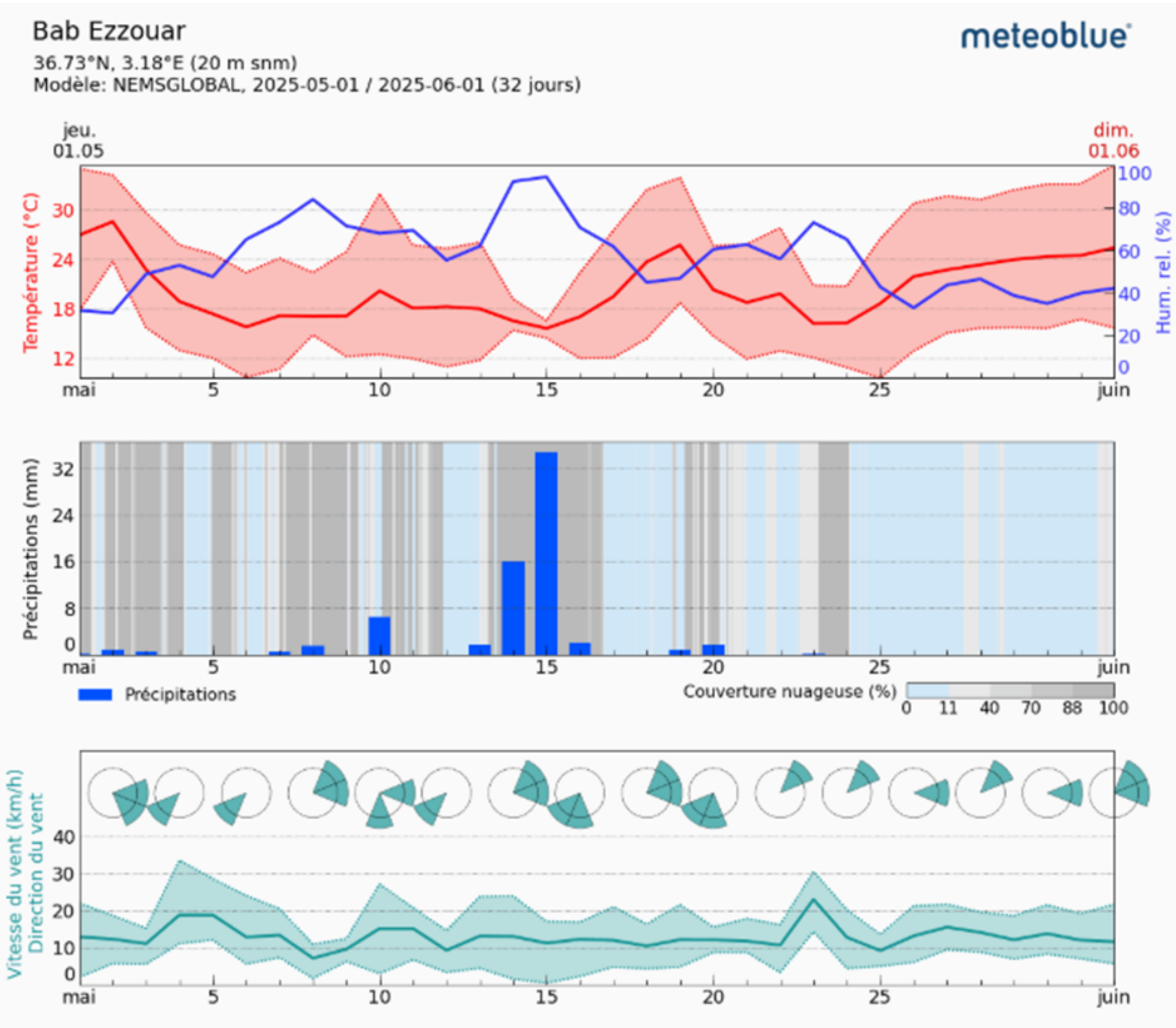

Fig. 4.4 : The meteorological condition diagrams

4.5 Numerical Modeling for PMi Prediction Rates Based on Various Parameters

In this contribution, we aim to develop a better predictive model using an Artificial Neural Network (ANN) method to predict concentration rates.

4.5.1 Database Collection

To enhance the modeling of fine particulate matter (PMi), we used an artificial intelligence method to develop predictive models for nonlinear problems in calculating PMi concentrations based on : Temperature (T), relative humidity (RH), total volatile organic compounds (TVOCs), formaldehyde (HCHO), and PMi size were used as input variables, while the concentrations of PMi were used as the output variables of the prediction model.

The dataset is structured as a rectangular matrix of size (189, 6) for the input range and (189, 1) for the output range, distributed as follows : 75 percent for the training phase and 25 percent for the testing and validation phase.

4.5.2 Artificial Neural Networks (ANN) Modeling Process

The selection and collection of data on which artificial intelligence methods are trained represent the first step in neural modeling. The second step involves choosing input and output variables and preprocessing the data. Then comes the normalization and division of the dataset into three phases : training, testing, and validation.

The next step is the selection of neural network parameters (type of neural network, number of hidden layers and neurons in each layer, transfer function, learning algorithm, and number of iterations), which allow the network to learn the relationship between selected inputs and outputs.

The third step is dedicated to training, testing, and validating the selected network. Finally, the network's performance can potentially be compared with other types of modeling approaches [50].

4.5.3 Statistical Performance Criteria (Model Analysis and Evaluation)

The accuracy and reliability of models developed using artificial intelligence techniques are typically assessed using various statistical indicators. In this study, eight performance metrics were used to evaluate the predictive ability of the proposed models[50].

The commonly used statistical performance criteria are :

- Mean Squared Error (MSE)

- Root Mean Squared Error (RMSE)
- Normalized Root Mean Squared Error (NRMSE)
- Mean Absolute Error (MAE)
- Mean Absolute Percentage Error (MAPE)
- Absolute Relative Error (ERA)
- Correlation Coefficient (R)
- Coefficient of Determination (R^2)

$$\mathrm{MSE} = \frac{1}{n}\sum_{i=1}^{n}(Y_i - \hat{Y}_i)^2 \tag{1}$$

$$\mathrm{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(Y_i - \hat{Y}_i)^2} \tag{2}$$

$$\mathrm{NRMSE} = \frac{\sqrt{\frac{1}{n}\sum_{i=1}^{n}(Y_i - \hat{Y}_i)^2}}{\overline{Y}} \tag{3}$$

$$\mathrm{MAE} = \frac{1}{n}\sum_{i=1}^{n}\left|Y_i - \hat{Y}_i\right| \tag{4}$$

$$\mathrm{MAPE} = \frac{100}{n}\sum_{i=1}^{n}\left|\frac{Y_i - \hat{Y}_i}{Y_i}\right| \tag{5}$$

$$\mathrm{ERA} = \left|\sum_{i=1}^{n}\frac{Y_i - \hat{Y}_i}{Y_i}\right| \tag{6}$$

$$R = \frac{\sum_{i=1}^{n}(Y_i - \overline{Y})(\hat{Y}_i - \overline{\hat{Y}})}{\sqrt{\sum_{i=1}^{n}(Y_i - \overline{Y})^2}\cdot\sqrt{\sum_{i=1}^{n}(\hat{Y}_i - \overline{\hat{Y}})^2}} \tag{7}$$

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(Y_i - \hat{Y}_i)^2}{\sum_{i=1}^{n}(Y_i - \overline{Y})^2} \tag{8}$$

Chaptre 5

Results and Discussion

5.1 Daily Pollutants Variation

This measurement campaign allowed for the collection of data over 32 days.The pollutant concentrations were recorded daily between 8:00 a.m and 6:00 p.m and the average of these hourly measurements was considered as the temporal concentration for each day, The data shows noticeable variation in pollutant concentrations. Several days recorded elevated levels of PM, TVOC, and HCHO, while others showed significantly lower values.

The table 5.1 presents the daily concentrations of the measured pollutants (PM, TVOC, and HCHO)

TAB. 5.1 : Daily pollutant concentrations (May–June 2025)

Date	**PM2.5** ($\mu g\,m^{-3}$)	**PM1.0** ($\mu g\,m^{-3}$)	**PM10** ($\mu g\,m^{-3}$)	**HCHO (mg/m³)**	**TVOC (mg/m³)**
01/05/2025	35.167	22.33	47.833	0.073	0.745
02/05/2025	11.5	8	15	0.033	0.313
03/05/2025	15.33	9.83	21.5	0.058	0.573
04/05/2025	22.6	16	30.3	0.056	0.529
05/05/2025	18.83	9.16	17.6	0.034	0.208
06/05/2025	27.16	17	37.1	0.064	0.534
07/05/2025	32.5	20.5	45.8	0.096	0.656
08/05/2025	34.1	22.83	49.83	0.094	0.709
09/05/2025	8.5	6	11.33	0.033	0.32
10/05/2025	24.66	18.33	34.66	0.06	0.671
11/05/2025	10.33	7.66	13.66	0	0
12/05/2025	35.6	20.6	46.83	0.088	0.825
13/05/2025	7.83	5.166	10.33	0	0
14/05/2025	13	7.16	10.33	0	0
15/05/2025	9.33	7	12.83	0	0
16/05/2025	7	4.16	9	0.033	0.25
17/05/2025	20	16	30.2	0.078	0.83
18/05/2025	37.33	24.5	45.1	0.080	0.8
19/05/2025	37.83	23.8	50.5	0.11	0.78
20/05/2025	25.8	16.6	37.8	0.07	0.69
21/05/2025	29.5	18.6	37.5	0.083	0.61
22/05/2025	38.6	30.2	62.6	0.11	0.825
23/05/2025	6.66	4.6	9.6	0	0
24/05/2025	22.1	16.5	30.1	0.071	0.7
25/05/2025	36.5	26.1	50.6	0.08	0.76
26/05/2025	26.1	19.5	37.33	0.06	0.702
27/05/2025	29.1	18.8	42.3	0.099	0.706
28/05/2025	34.83	21.6	46.1	0.089	0.692
29/05/2025	31	21.5	43.83	0.081	0.83
30/05/2025	13.5	7.5	16.5	0.047	0.44
31/05/2025	31.83	18.83	42.5	0.061	0.516
01/06/2025	31.33	21	40.66	0.083	0.75
02/06/2025	36.1	24.3	49.5	0.1	0.59

Assessment of Particulate Matter atmospheric concentrations

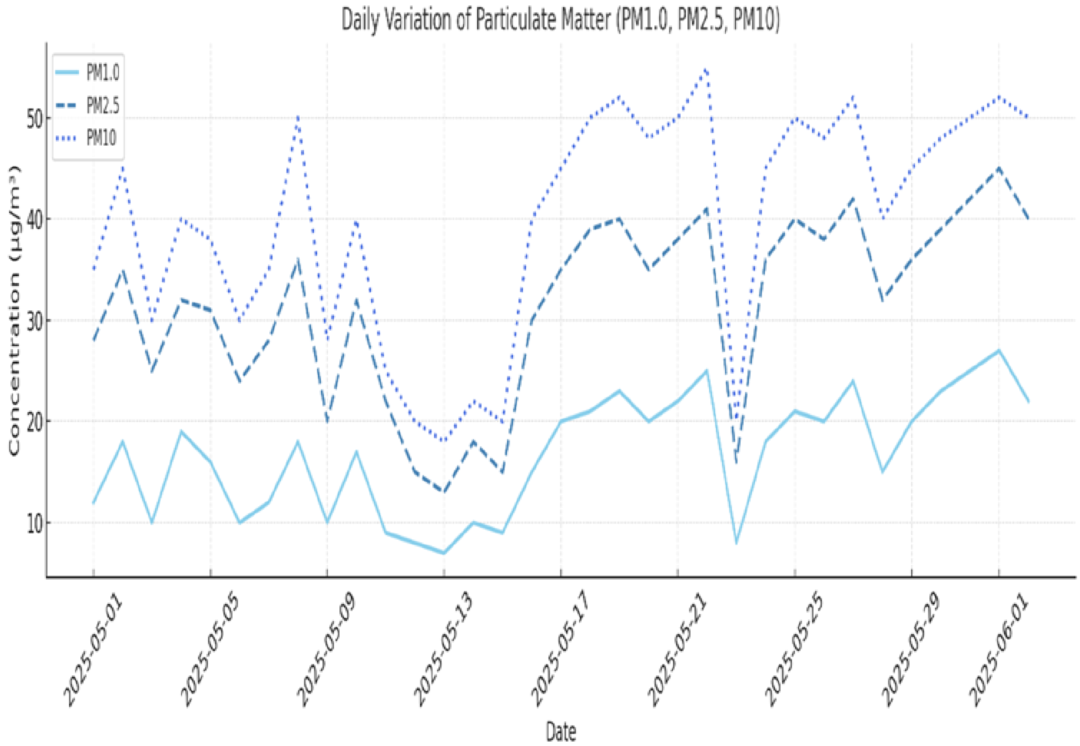

Fig. 5.1 : Daily Particulate Matter Concentrations

The graph illustrates the temporal variation of $PM_{1.0}$, $PM_{2.5}$, and PM_{10} concentrations measured daily over a 32 days. All three pollutant fractions exhibit noticeable day to day fluctuations, with PM_{10} consistently presenting the highest concentrations, followed by $PM_{2.5}$, and then $PM_{1.0}$, which is expected due to their respective aerodynamic diameters and accumulation dynamics in the atmosphere.

Two distinct pollution periods were observed : one around May 7–8, and another near the end of May (May 22–23), during which concentrations of all PM fractions peaked simultaneously. These peaks occurred during periods characterized by the absence of rainfall, low wind speeds, and relatively stable temperatures, favoring the accumulation of airborne particulates due to reduced dispersion, When it comes to particulate matter (PM), heat indirectly contributes to higher concentrations by enhancing atmospheric stagnation and reducing vertical mixing. This allows pollutants to accumulate near the ground [51].

In contrast, significant reductions in PM concentrations were observed coinciding with pronounced precipitation events mainly because rain exerts a strong scavenging effect. Falling raindrops collide with airborne particles and carry them to the ground (below-cloud scavenging), or incorporate them while forming in the cloud (in-cloud scavenging), leading to a significant reduction in PM concentrations during and after rainfall events [52].

Assessment of TVOC temporal atmospheric concentrations

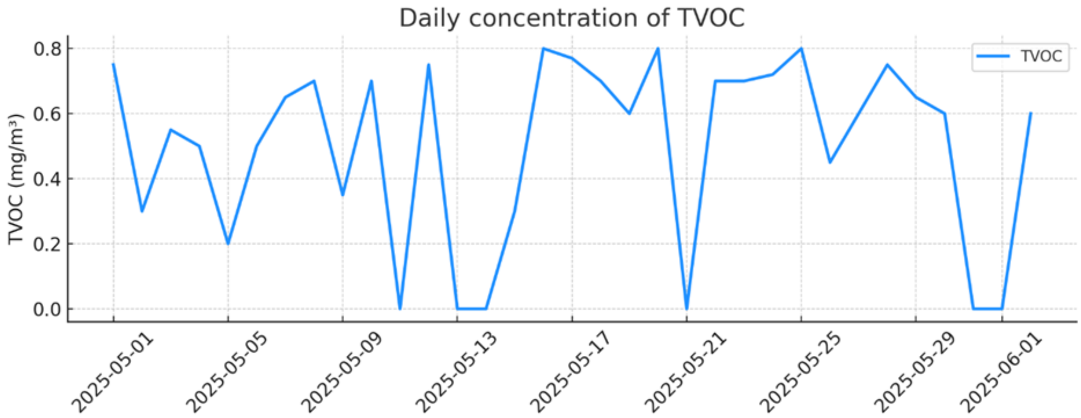

FIG. 5.2 : Daily TVOC Concentrations

The analysis of daily TVOC (Total Volatile Organic Compounds) concentrations reveals that elevated TVOC levels (up to 0.8 mg/m³) were predominantly recorded during dry and warm periods, characterized by temperatures above 25°C and particularly in urban environments. As temperatures rise, the volatility of organic compounds increases, causing greater emissions of Total Volatile Organic Compounds (TVOCs) [53] .

In contrast, substantial drops in TVOC levels, reaching zero values, were associated with rain periods and high relative humidity, notably on 13-15 May, 20 May, the impact of rain is less direct, but still relevant.

Assessment of HCHO temporal atmospheric concentrations

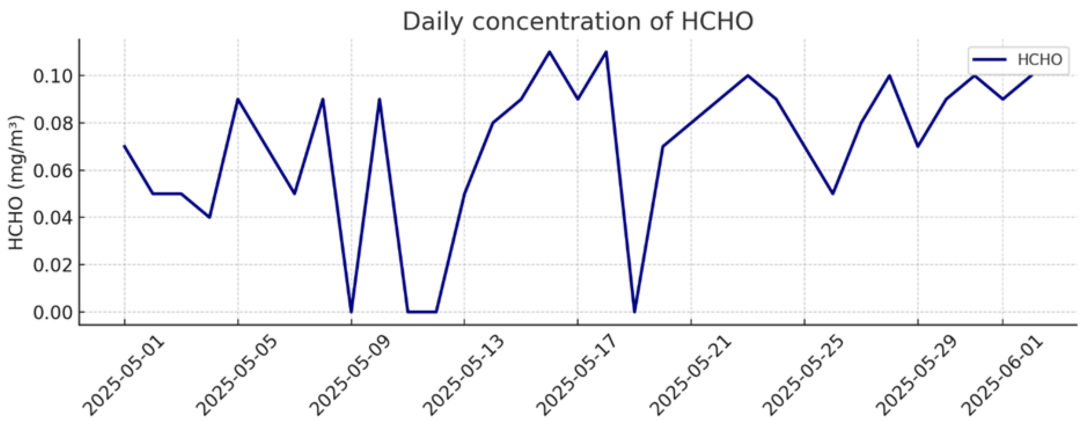

FIG. 5.3 : Daily HCHO Concentrations

The daily variation of formaldehyde (HCHO) concentrations, as presented in the graph, reveals significant fluctuations, with values ranging from 0 to over 0.10 mg/m³. Notably, periods of zero or near zero HCHO levels are observed particularly around May 11 and May 15, when rainfall reached its maximum.

The simultaneous occurrence of heavy rain and reduced HCHO concentrations suggests a cleansing effect by precipitation, which effectively scavenges formaldehyde from the atmosphere and it is partially water soluble and can be removed by absorption into raindrops [48].

Additionally, HCHO concentrations tend to rise following dry, warm days with increased solar radiation. These conditions, seen especially after mid May, are conducive to secondary formation of formaldehyde through photochemical reactions involving volatile organic compounds (VOCs) and sunlight [48]. This explains the gradual increase in HCHO levels observed between May 20 and June 1, coinciding with higher temperatures and reduced precipitation.

Absolute and Relative Change Definitions

Absolute change refers to the simple difference in the indicator over two periods in time[47] :

$$\text{Absolute Change} = \text{New Value} - \text{Original Value}$$

Relative change expresses the absolute change as a percentage of the value of the indicator in the earlier period[47] :

$$\text{Relative Change (\%)} = \left(\frac{\text{New Value} - \text{Original Value}}{\text{Original Value}} \right) 100$$

5.2 Air Pollutants Temporal Distribution

This section begins with an analysis of the temporal distribution of air pollutants, focusing on differences between weekends and weekdays in order to highlight potential variations linked to human activity patterns. Subsequently, we examine how pollutant concentrations vary between dry and rainy days, with the aim of reaffirming the influence of meteorological conditions on air quality levels.

5.2.1 Air Pollutants Temporal Distribution : Weekdays vs Weekends

Assessment of Particulate Matter Atmospheric concentrations

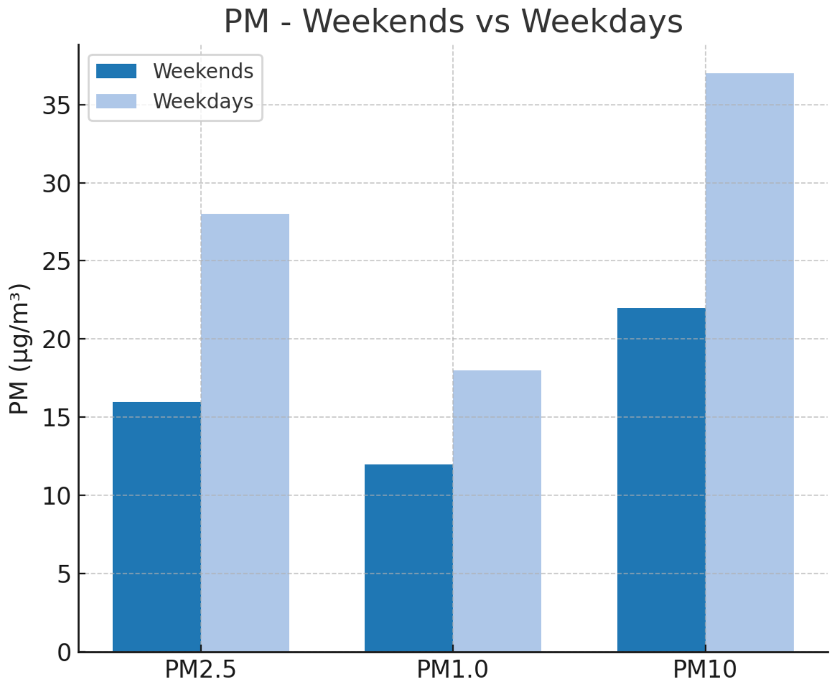

Fig. 5.4 : PM Distribution

The chart presents measured concentrations of three particulate matter (PM) size fractions $PM_{2.5}$, $PM_{1.0}$, and PM_{10}, comparing weekend and weekday values. The data indicate in both weekdays and weekends, the concentration of PM_{10} is the highest, followed by $PM_{2.5}$, and then $PM_{1.0}$, which has the lowest concentration.

The table 5.2 presents a comparative analysis of particulate matter (PM) concentrations between weekends and weekdays. The results show a consistent and substantial increase in $PM_{2.5}$, $PM_{1.0}$, and PM_{10} concentrations during weekdays. Specifically, $PM_{2.5}$ levels increased by approximately +72.58% , $PM_{1.0}$ by +67.14% and PM_{10} by +70.89%compared to weekend values.

Tab. 5.2 : PM concentrations Comparison between weekends and weekdays

Pollutant	**Weekends (µg/m³)**	**Weekdays (µg/m³)**	**Absolute change**	**Relative change (%)**
$PM_{2.5}$	16.10	27.89	+11.69	+72.58%
$PM_{1.0}$	10.97	18.34	+7.36	+67.14%
PM_{10}	22.03	37.66	+15.62	+70.89%

Assessment of TVOC Atmospheric Concentrations

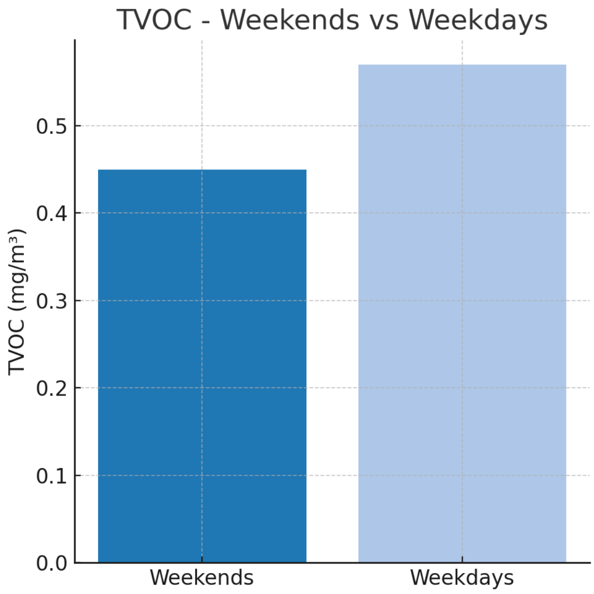

FIG. 5.5 : TVOC Distribution

The data demonstrate that :

The increase in total volatile organic compound concentrations (TVOC) from weekends to weekdays, the average level of TVOC rising from 0.46 mg / m3 on weekends to 0.56 mg/m^3 on weekdays, indicating a notable increase of 0.10 mg/m^3, which corresponds to a +21.95% increase in weekday levels compared to weekends.

TAB. 5.3 : TVOC levels Comparison between weekends and weekdays

Pollutant	**Weekends** (mg/m^3)	**Weekdays** (mg/m^3)	**Absolute Change** (mg/m^3)	**Relative Change (%)**
TVOC	0.46	0.56	+0.10	+21.95%

Assessment of HCHO Atmospheric Concentrations

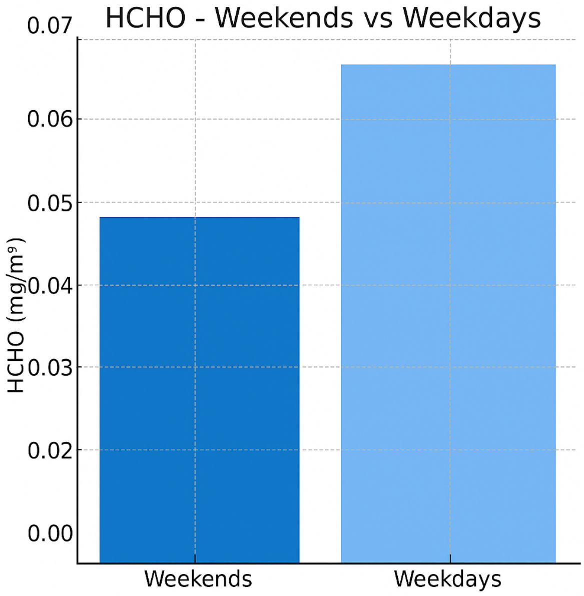

FIG. 5.6 : HCHO Distribution

The measured concentration of formaldehyde (HCHO) exhibits a notable increase of 42.01% from weekends to weekdays. Specifically, average HCHO levels rose from 0.047 mg/m^3 during weekends to **0**.067mg/m^3 on weekdays, representing an absolute increase of 0.019 mg/m^3.

TAB. 5.4 : HCHO levels comparison between weekends and weekdays

Pollutant	**Weekends** (mg/m^3)	**Weekdays** (mg/m^3)	**Absolute Change** (mg/m^3)	**Relative Change (%)**
HCHO	0.047	0.067	+0.019	+42.01%

Assessment of Pollutants Atmospheric Concentrations

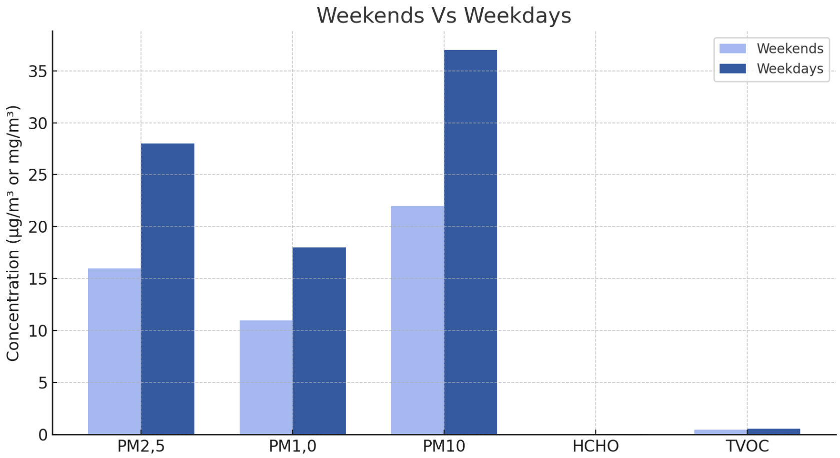

Fig. 5.7 : Pollutants Distribution

This graph compares the average concentrations of various air pollutants $PM_{2.5}$, $PM_{1.0}$, PM_{10}, HCHO, and TVOC between weekends and weekdays.

All measured pollutants exhibit higher concentrations on weekdays compared to weekends, reflecting this graph highlights the significant influence of anthropogenic activities, particularly vehicular traffic, industrial operations, and construction, which are more intense during the workweek[50].

Between weekends and weekdays. Particulate matter concentrations are dominant in both periods, indicating their substantial contribution to overall air pollution levels.

Tab. 5.5 : Pollutant concentrations comparison of between weekends and weekdays

Pollutant	Unit	Weekends	Weekdays	Absolute change	Relative change (%)
$PM_{2.5}$	$\mu g\,m^{-3}$	16.10	27.89	+11.78	+72.58%
$PM_{1.0}$	$\mu g\,m^{-3}$	10.97	18.34	+7.36	67.14%
PM_{10}	$\mu g\,m^{-3}$	22.03	37.66	+15.62	+70.89%
HCHO	mg/m^3	0.047	0.067	+0.019	+42.01%
TVOC	mg/m^3	0.46	0.56	+0.10	+21.95%

5.2.2 Air Pollutants Temporal Distribution :Rainy Vs Dry Days

Assessment of Particles Matter Atmospheric Concentrations

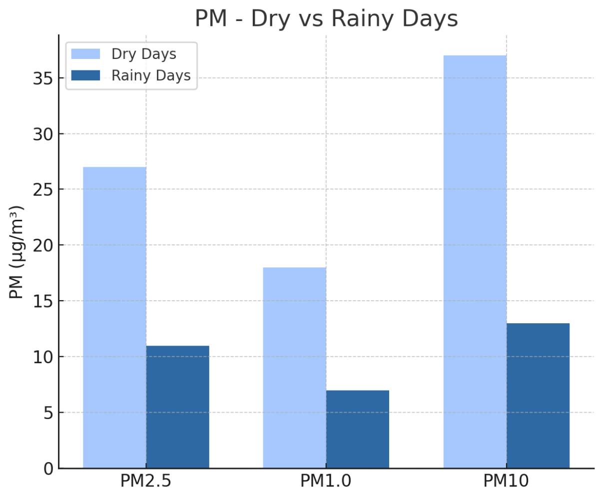

FIG. 5.8 : Particles Matter Concentrations

The data indicate a clear and substantial increase in particulate matter (PM) concentrations during dry days compared to rainy days for all measured size fractions $PM_{2.5}$, $PM_{1.0}$, and PM_{10}.

PM_{10} concentrations are the highest among all particle sizes on both dry and rainy days, rising from 13.04 µg/m^3 during rainy conditions to 37.35 µg/m^3 on dry days an increase of +158.69%. This is largely attributed to *coarse particles* which remain suspended in the atmosphere longer during dry conditions.

$PM_{1.0}$ and $PM_{2.5}$ which include *finer particles* also show sharp increases on dry days (+163.18% and +158.69%, respectively).

TAB. 5.6 : Particulate matter concentrations comparison between dry and rainy days.

Pollutant	Dry Days (µg/m^3)	Rainy Days (µg/m^3)	Absolute change	Relative change (%)
$PM_{2.5}$	27.37	10.58	+16.79	+158.69%
$PM_{1.0}$	18.16	6.90	+11.26	+163.18%
PM_{10}	37.35	13.04	+24.31	+186.42%

Assessment of TVOC Atmospheric Concentrations

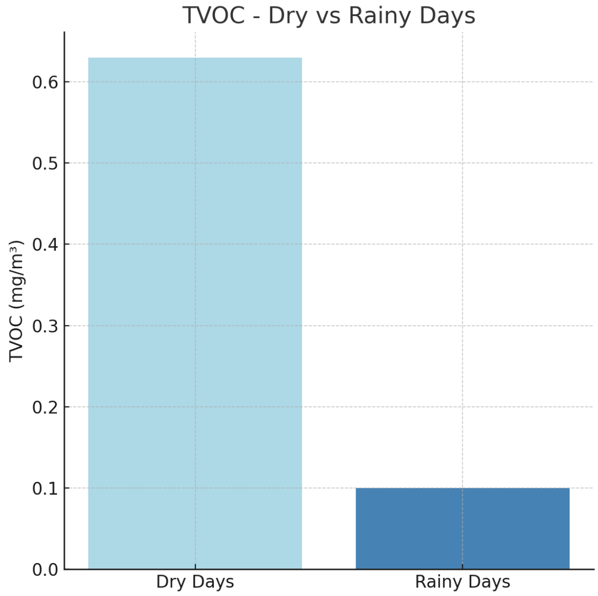

FIG. 5.9 : TVOC Distribution

The comparative analysis of Total Volatile Organic Compounds (TVOC) concentrations between dry and rainy days reveals a marked reduction in ambient levels during precipitation events. On dry days, average TVOC concentrations are substantially elevated (approximately 0.63 mg/m^3) compared to rainy days (approximately 0.10 mg/m^3), reflecting an approximate relative decrease of 84 percent under wet atmospheric conditions.

TAB. 5.7 : Comparison of TVOC concentrations between dry and rainy days

Pollutant	**Dry Days** (mg/m^3)	**Rainy Days** (mg/m^3)	**Absolute Difference** (mg/m^3)	**Relative Increase (%)**
TVOC	0.63	0.10	+0.53	+530%

Assessment of HCHO Atmospheric Concentrations

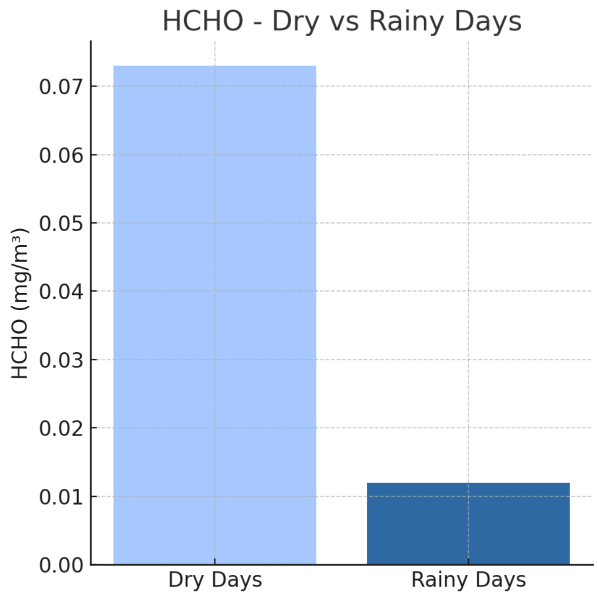

FIG. 5.10 : HCHO Distribution

The observed graph demonstrates a substantial disparity in ambient formaldehyde (HCHO) concentrations between dry and rainy days.

During dry days, HCHO levels reach approximately 0.073 mg/m³, compared to only 0.012 mg/m³ on rainy days. This corresponds to an absolute difference of 0.061 mg/m³ and a relative increase of approximately 508.33 percent under dry conditions.

TAB. 5.8 : Comparison of HCHO concentrations between dry and rainy days

Pollutant	**Dry Days** (mg/m^3)	**Rainy Days** (mg/m^3)	**Absolute Difference** (mg/m^3)	**Relative Increase (%)**
HCHO	0.073	0.012	+0.061	+508.33%

Assessment of Pollutants Atmospheric Concentrations

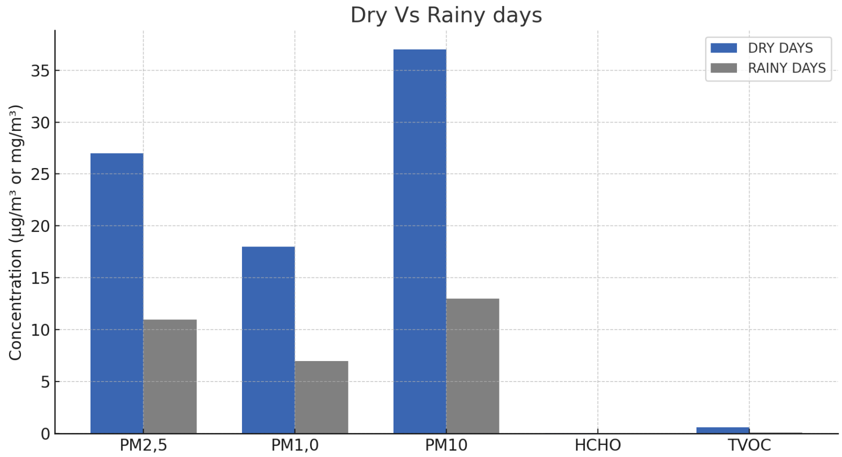

FIG. 5.11 : Pollutants Distribution

The graph illustrates significant variations in air pollutant concentrations between dry and rainy days.

Among all measured pollutants, particulate matter (PM) exhibits the highest concentrations during both dry and rainy periods.

In contrast to PM, HCHO and TVOC consistently record the lowest concentrations in both weather conditions.

These findings underscore the critical role of rainfall in reducing pollutant levels and reaffirm that PM remains the dominant pollutant type across all weather scenarios.

TAB. 5.9 : Pollutants concentrations comparison between dry and rainy days

Pollutant	Unit	Dry Days	Rainy Days	Absolute Difference	Relative Increase (%)
$PM_{2.5}$	$\mu g/m^3$	27.37	10.58	+16.79	+158.69
$PM_{1.0}$	$\mu g/m^3$	18.16	6.90	+11.26	+163.18
PM_{10}	$\mu g/m^3$	37.35	13.04	+24.31	+186.42
TVOC	mg/m^3	0.63	0.10	+0.53	+530
HCHO	mg/m^3	0.073	0.012	+0.061	+508.33

5.3 Comparative Study

5.3.1 $PM_{2.5}$ Daily variation

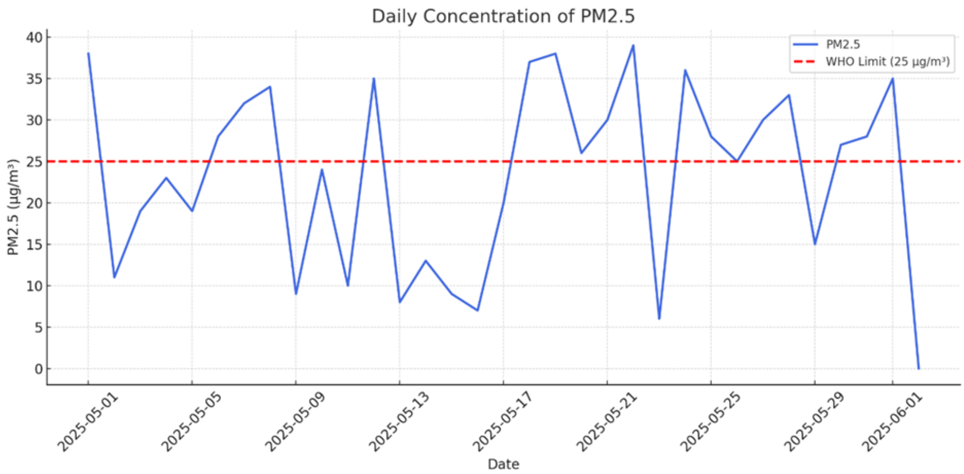

FIG. 5.12 : $PM_{2.5}$ Daily variation

The graph presents the daily variation of $PM_{2.5}$, The red dashed line indicates the World Health Organization (WHO) daily guideline limit for $PM_{2.5}$ exposure, set at 25 µg/m^3.

A significant number of days within the observation period display $PM_{2.5}$ concentrations exceeding the WHO recommended limit. This highlights the presence of suboptimal air quality conditions with potential implications for public health, particularly for vulnerable populations.

Several pollution peaks are identifiable (around May 1, May 8–9, May 18, and May 22),These periods often surpass 30 µg/m^3, indicating periods of potentially harmful exposure.

Conversely, days with lower $PM_{2.5}$ concentrations (May 3, May 15, and June 1) may correspond to during rainfall events,$PM_{2.5}$ concentrations significantly drop, tied directly to wet deposition and enhanced atmospheric mixing.

5.3.2 PM_{10} Daily variation

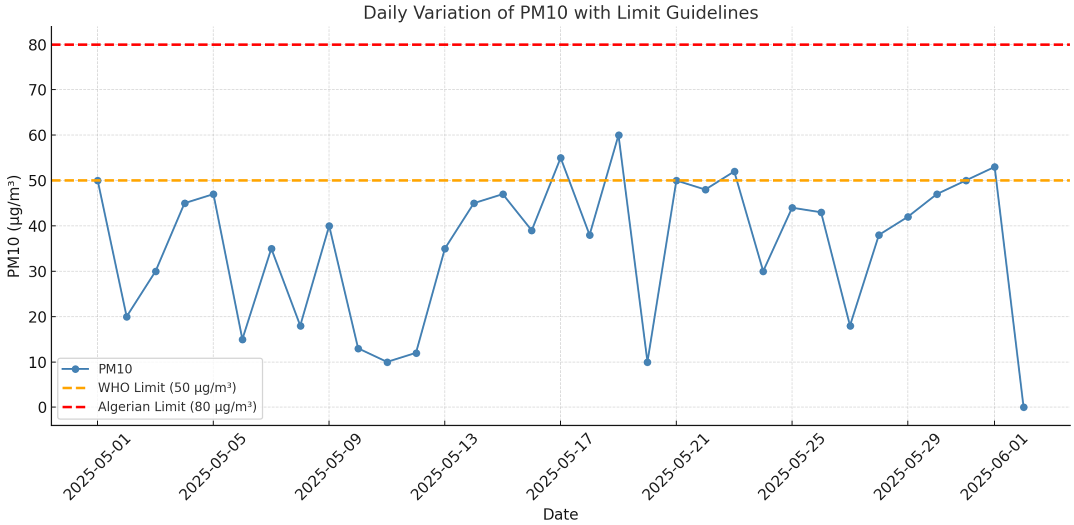

Fig. 5.13 : PM_{10} Distribution

The graph illustrates the temporal evolution of PM_{10} concentrations over the month of May 2025, benchmarked with both the World Health Organization (WHO) daily guideline of 50 µg/m³ and the Algerian national limit of 80 µg/m³.

The temporal variation of PM_{10} concentrations from May 1 to May 31, 2025, reveals substantial fluctuations, with daily values ranging from approximately 9 to 50,6 µg/m³. Throughout the observation period, multiple exceedances of the World Health Organization (WHO) daily guideline of 50 µg/m³ were recorded. Notably, however, none of the values surpassed the Algerian national threshold of 80 µg/m³.

5.4 Modeling Using Artificial Intelligence Method

5.4.1 Data Collection

The variables collected encompass a range of atmospheric and air quality parameters known to influence particulate matter concentrations. Specifically, the dataset includes :

- Acoustic noise levels (dB)
- Ambient temperature (°C)
- Relative humidity (%)
- Total Volatile Organic Compounds (TVOCs, in mg/m^3)
- Formaldehyde concentration (HCHO, in mg/m^3)
- Particulate Matter (PM) sizes : PM_1, $PM_{2.5}$, and PM_{10} (in μg/m^3)

5.4.2 PMi Prediction using Artificial Neural Networks (ANN)

In our work, we use the ANN technique, implemented in MATLAB®, to predict the concentrations of PMinbased on different parametres.

The optimization of the ANN architecture involves determining :

- The number of layers and the number of neurons in each hidden layer
- The learning algorithm, by comparing the performance of the neural networks on the training, testing, and validation sets in terms of Root Mean Square Error (RMSE)
- The activation function for the hidden layer and the output layer [50].

5.5 ANN Parameters Selection

The structure of the optimized ANN (OANN) for predicting PMi concentration levels is summarized in the table

<table>
<tr><td rowspan="2">Network Type</td><td rowspan="2">Learning Algorithm</td><td>Input Layer</td><td colspan="3">Hidden Layers</td><td rowspan="2">Output Layer</td></tr>
<tr><td rowspan="2">Nb. of neurones</td><td>Paramétrés</td><td>Hidden Layers 1</td><td>Hidden Layers 2</td></tr>
<tr><td rowspan="2">FFNN-BP (Fonction newff of MATLAB)</td><td rowspan="2">Levenberg-Marquardt. (Fonction trainlm of MATLAB)</td><td>Nb. de neurones</td><td>6</td><td>12</td><td>1</td></tr>
<tr><td>6</td><td>Fonction d'activation</td><td>(Fonction tansig of MATLAB).</td><td>(Fonction tansig of MATLAB).</td><td>(Fonction purelin of MATLAB).</td></tr>
</table>

FIG. 5.14 : Optimized ANN (OANN) structure

5.5.1 Results Interpretation

The performance results of the neural network model established for the training, testing, validation, and overall phases (Training + Testing + Validation) for the prediction of PM_i concentration levels are presented in Figures 5.15 to 5.18. These figures clearly show that the majority of the points lie along the first bisector, with a coefficient of determination approaching the ideal :

$$[\alpha \text{ (slope)},\ \beta \text{ (intercept)},\ R^2] = [0.99,\ 0.18,\ 0.99506] \quad \text{(Overall)}$$

This confirms the robustness of the neural network model.

The following figures present regression plots comparing experimental values $[\mathrm{PM}_i]_{\mathrm{exp}}$ to calculated values $[\mathrm{PM}_i]_{\mathrm{cal}}$ for four phases : training, testing, validation, and all phases combined. Each graph includes :

- The black circles (○) represent the data points for each experimental–calculated pair.
- The red line corresponds to the best linear fit derived from the data, indicating the relationship between $[\mathrm{PM}_i]_{\mathrm{exp}}$ and $[\mathrm{PM}_i]_{\mathrm{cal}}$.
- The black dotted line represents the ideal case :

  $$[\mathrm{PM}_i]_{\mathrm{exp}} = [\mathrm{PM}_i]_{\mathrm{cal}},$$

  indicating a perfect match between experimental and calculated values.

The best fit regression line is defined by the following equation :

$$[\mathrm{PM}_i]_{\mathrm{cal}} = \beta + \alpha \cdot [\mathrm{PM}_i]_{\mathrm{exp}}$$

where :

- β is the intercept, indicating any systematic bias in the predictions.
- α is the slope, representing the sensitivity of the predicted values to the experimental values.

Ideally, $\alpha \approx 1$ and $\beta \approx 0$ indicate a strong linear correlation and unbiased prediction performance. The closer the regression curve is to the diagonal, the more accurate the model is in predicting particulate matter concentrations.

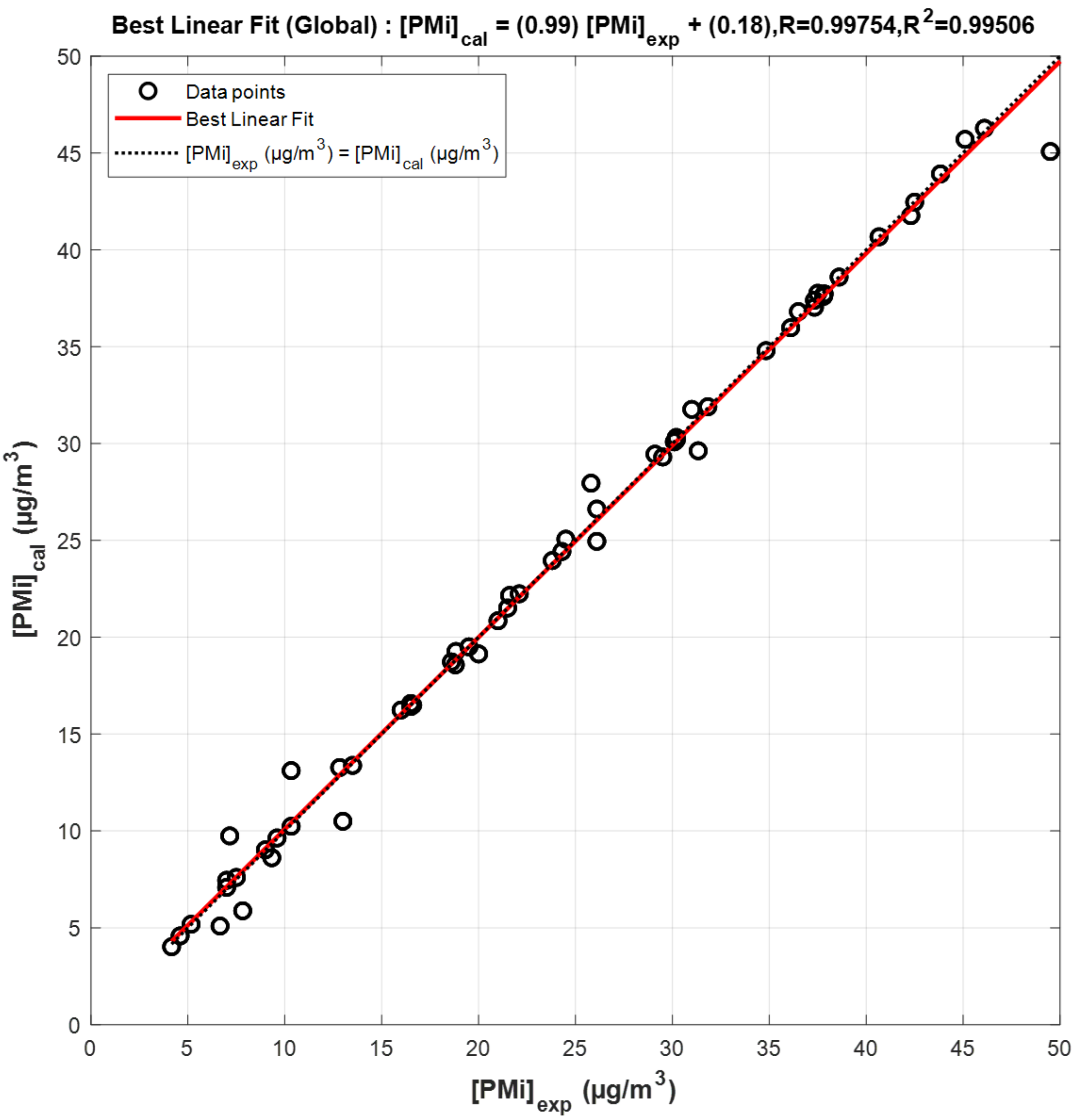

Fig. 5.15 : Globale phase Linear regression curve

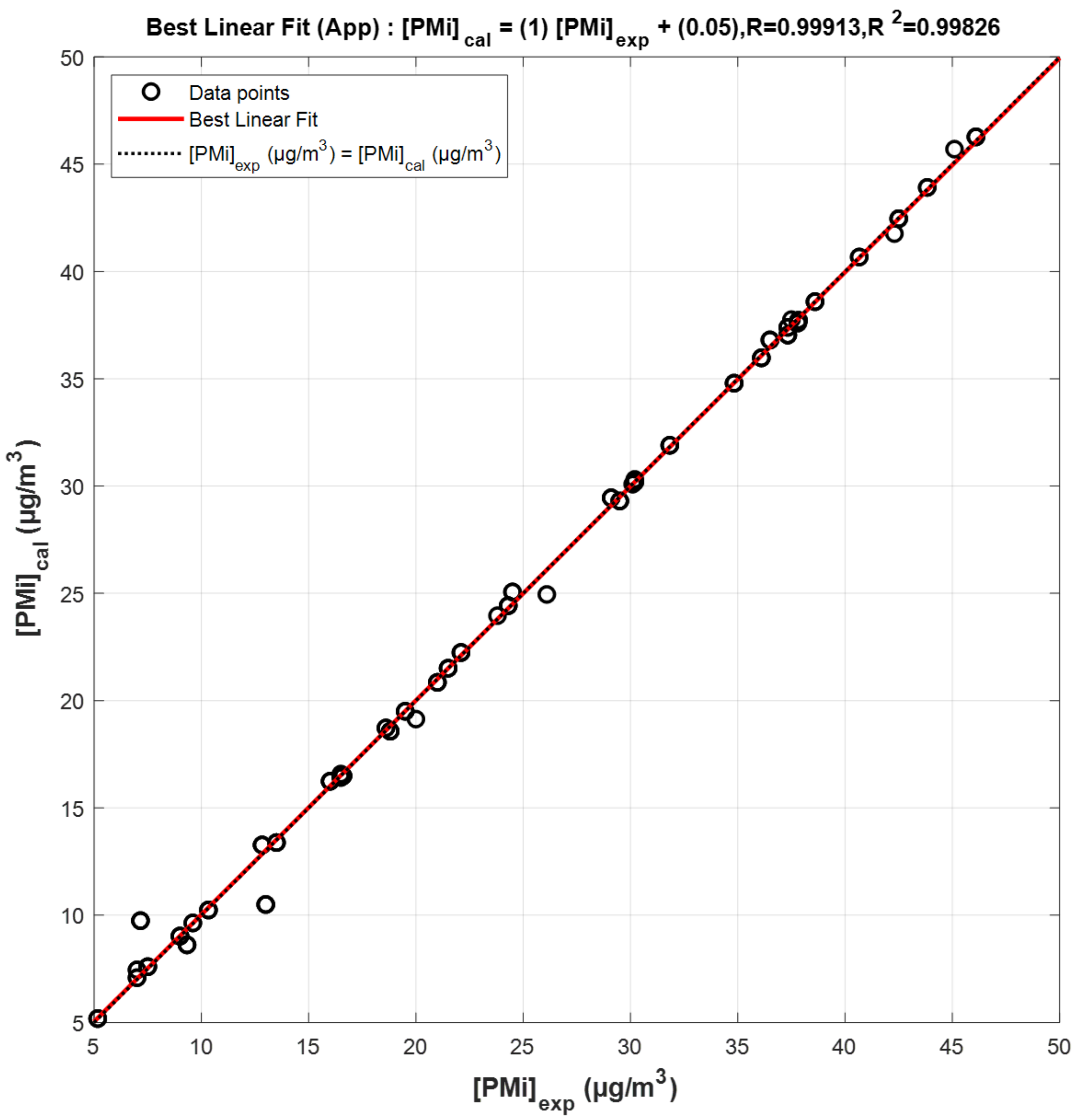

FIG. 5.16 : Training phase Linear regression curve

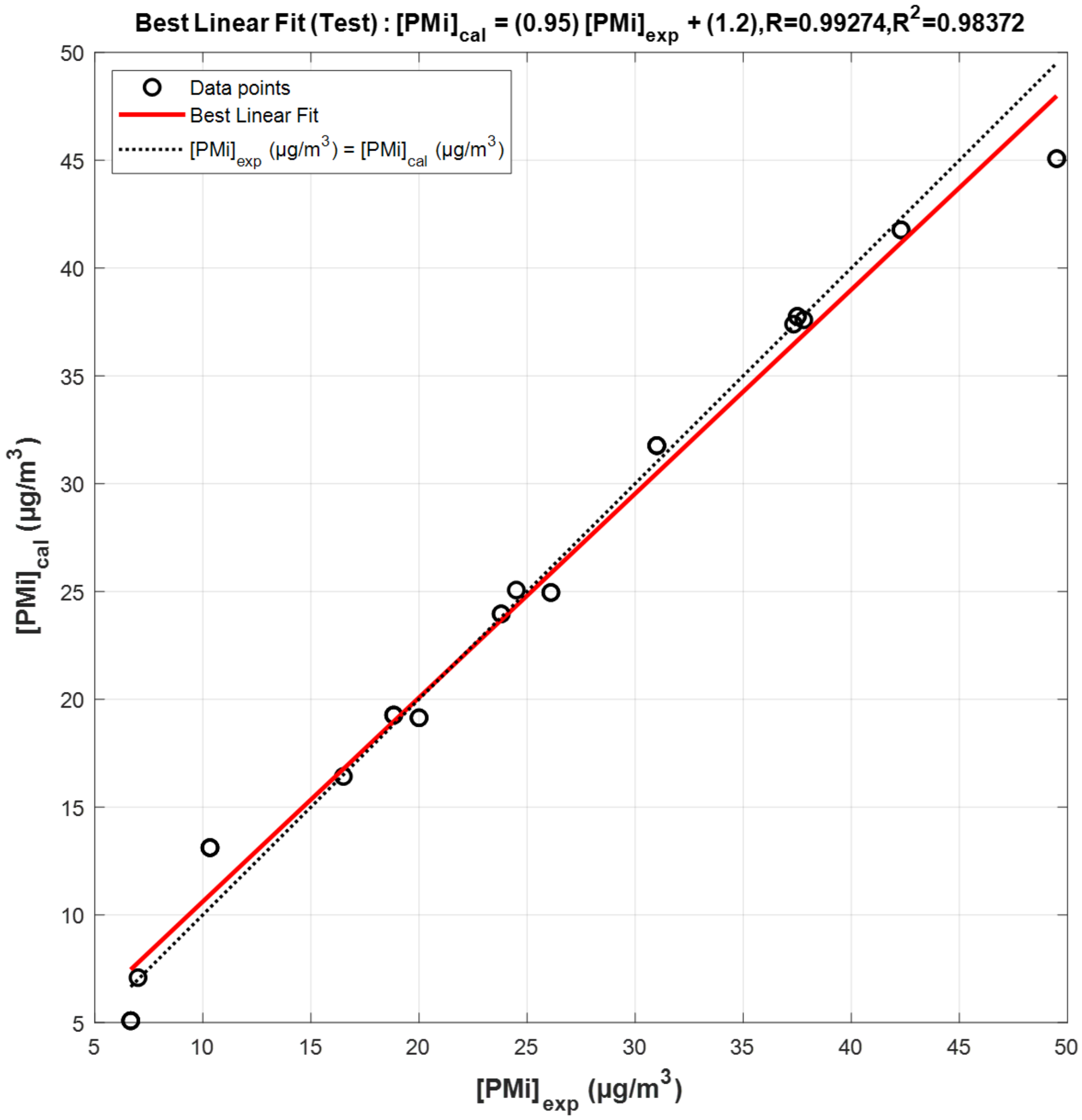

FIG. 5.17 : Testing phase Linear regression curve

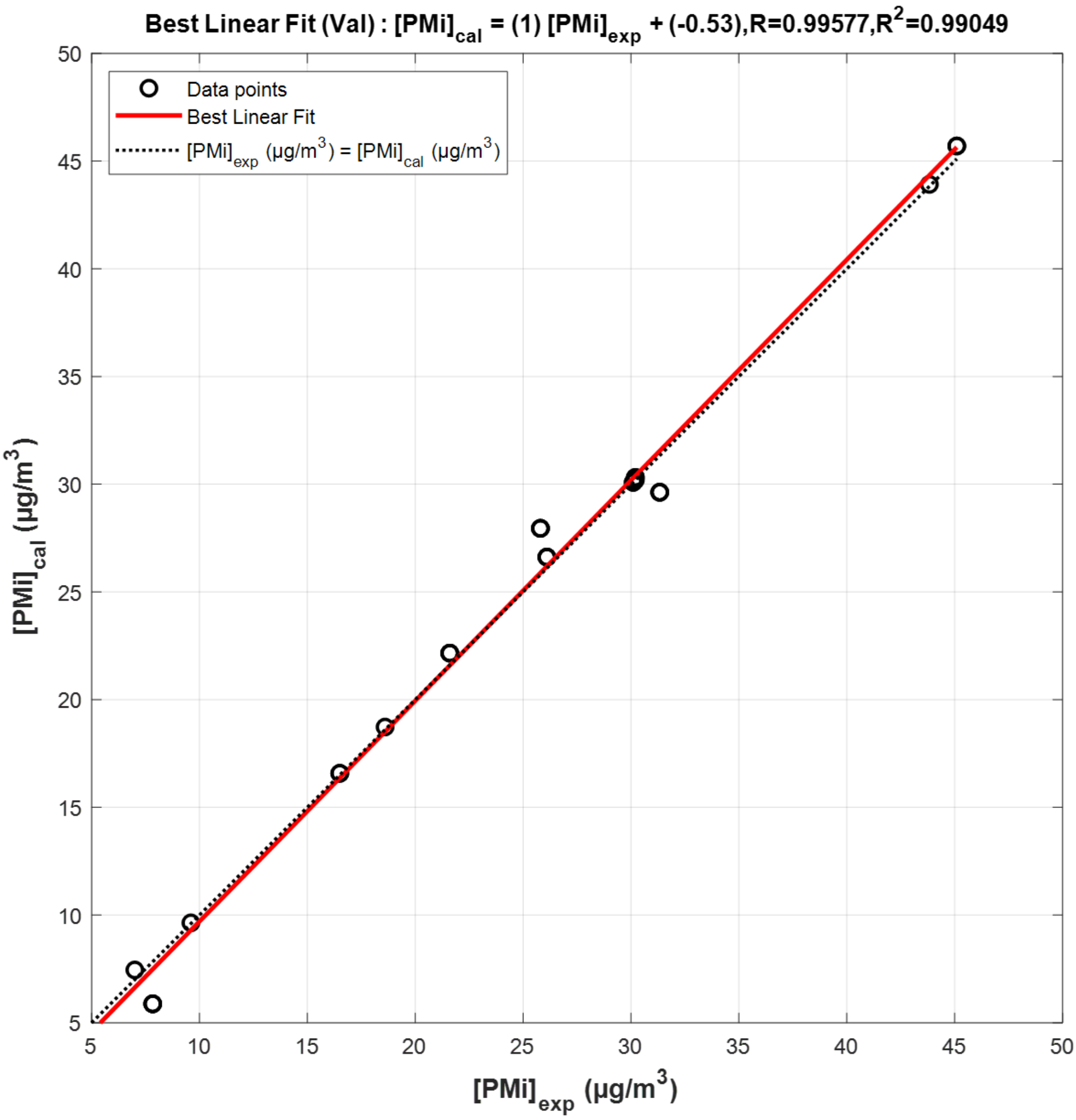

FIG. 5.18 : Validation phase Linear regression curve

To analyze the performance of the ANN more precisely, all error metrics MSE, RMSE, NRMSE, MAE, MAPE, ERA, and R^2 are calculated for the predicted concentration values of PMi. The calculation results are presented in table 5.10. The ANN demonstrates, on one hand, its ability to predict PMi concentrations accurately, and on the other hand, the robustness of the neural model.

Tab. 5.10 : Statistical Error Results

Error Type	**Training Phase**	**Testing Phase**	**Validation Phase**	**Globale Phase**
MSE	7.559210^{-4}	1.0186	0.0155	0.4750
RMSE	0.6060	1.6341	1.1074	0.9782
NRMSE	0.0011	0.0405	0.0053	0.0272
MAE	0.2819	1.1185	0.7753	0.5091
ARD	0.3673	2.6704	1.2264	0.9568
α	1	0.95	1	0.99
β	0.05	1.2	-0.53	0.18
R	0.9991	0.9927	0.9957	0.9975
R^2	0.9b982	0.9837	0.9904	0.9950

Chapitre 6

General Conclusion

General Conclusion

Air pollution continues to pose a serious challenge to both environmental sustainability and public health. Long-term exposure to pollutants such as particulate matter (PM_{10}, $PM_{2.5}$, $PM_{1.0}$), Volatile Organic Compounds (VOCs), and formaldehyde (HCHO) can lead to chronic respiratory diseases, cardiovascular complications, neurological disorders, and even cancer. In addition to these health risks, air pollution contributes to environmental degradation through acidification, reduced visibility, and the acceleration of climate change processes.

In this study, we conducted a detailed assessment of urban air pollution in a heavily trafficked area of Algiers. The first part of the project involved collecting real-time measurements of PM_{10}, $PM_{2.5}$, $PM_{1.0}$, TVOCs, and formaldehyde using a portable LifeBasis air quality analyzer, over the months of May and June 2025. Simultaneously, we used a Mengshen digital sound meter to record noise levels as an indirect indicator of traffic intensity.

Our results showed that $PM_{2.5}$ concentrations reached with a daily average of approximately 36.3 µg/m^3. These levels frequently exceeded the World Health Organization's (WHO) recommended limit of 25 µg/m^3 over 24 hours. As for formaldehyde, average concentrations were found to be around 0.32 mg/m^3, occasionally surpassing the WHO short-term exposure limit of 0.1 mg/m^3. Pollution levels were generally higher during weekdays compared to weekends, and notably lower on rainy days, illustrating the cleansing effect of precipitation.

To further understand and predict the behavior of air pollutants, we developed an artificial neural network (ANN) model trained on the collected data. The model used environmental parameters such as temperature, humidity, noise level, and day type (weekday or weekend) to forecast PM concentrations. The ANN achieved a high correlation coefficient ($R = 0.9975$) between predicted and measured $PM_{2.5}$ values. These results confirm the effectiveness of machine learning techniques in capturing the complex dynamics of urban air pollution and offer a promising tool for forecasting and management purposes.

For future work, extending the measurement period over several months or seasons would provide more comprehensive view of annual pollution patterns. Additional sensors installed in various urban zones would also improve the data spatial resolution. Finally, incorporating more predictive variables such as wind speed, solar radiation, and traffic flow data could further enhance the ANN model robustness and accuracy .

This project demonstrates the value of combining environmental monitoring with artificial intelligence to better understand, anticipate, and ultimately mitigate the effects of urban air pollution on both human health and environment.

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