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The CODASC database for analyzing the impact of morpho-climatic characteristics of canyon streets on air pollutant concentrations

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Abstract

Canyon-type urban streets are one of the urban forms in which critical and harmful situations for health and the urban environment are emerging today, such as urban heat islands, areas of poor ventilation, and retention zones for pollutants emitted by road traffic, heating, and industrial activities. The higher pollution levels are due to inappropriate relationships between morphological and microclimatic parameters specific to urban street canyons. Previous studies have highlighted the most common factors, namely the aspect ratio (H/W), the orientation of the street to the prevailing winds, and vegetation. In the city of Algiers, the urban street canyon is particularly noticeable in two dominant urban fabrics: the medieval organic fabric and the colonial fabric dating back to the French occupation. This paper aims to explain the effect of different factors specific to urban canyons in Algiers on the concentration trends of air pollutants by adopting the CODASC database, which contains data on normalized average air pollutant concentrations (C+) related to different street canyon models, according to aspect ratios H/W values, wind flow direction (α), tree stand density (ρs), and tree crown porosity (PVol). In order to validate the developed methodology, measurements of particle pollution concentrations were carried out at several points on the studied streets, using an analyzer equipped with the GP2Y1010AU0F microsensor. Based on the collected data, a statistical model was developed to assist in the reconfiguration of canyon-type streets in order to increase the dispersion of pollutants and consequently, reduce their concentrations. The results showed that Larbi Ben M'Hidi Street is more polluted than Mohammed Azzouzi Street due to the impact of the maximum values of the aspect ratio and tree density on wind behavior. The study's findings could provide a strategic guide for pollution mitigation, to be used by urban planners in the design and implementation phases of sustainable urban development projects in Algiers.

Keywords: air pollutant concentrations, canyon streets, city of Algiers, CODASC database, morpho-climatic parameters

1. Introduction

Air quality continues to deteriorate in large urban cities, particularly in developing countries. This is due to a combination of various urban factors, such as construction, manufacturing, and transportation (Tao et al., 2020; Wu, Li et al., 2021). As the effects of rapid urbanization and human activities on the urban microclimate change and their impact on public health continue to intensify, urban pollution has become a global environmental issue, particularly with regard to human health in cities (OECD, 2014; Hankey & Marshall, 2017; Boppana et al., 2019; WHO, 2021; Cevik Degerli & Cetin, 2023; Zeren Cetin, Varol et al., 2023; Zeren Cetin, Varol, Ozel et al., 2023; Uslu et al., 2024). Previous studies have addressed urban air pollution, proposing various mitigation techniques, such as the establishment of low-emission zones, tree planting, and the adoption of electric vehicles or sustainable transportation options (Yuan et al., 2014; Hong et al., 2017; Yang et al., 2020; Huang et

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al., 2021; Voordeckers, Lauriks et al., 2021; da Silva et al., 2022; Cetin, Cebi Kilicoglu et al., 2023; Cebi Kilicoglu & Zeren Cetin, 2024; Zeren Cetin, 2024a).

The issue of air quality can be addressed at various scales, including that of the urban canopy (Vardoulakis et al., 2003). At this scale, one of the predominant urban forms is the canyon street, where air quality is particularly sensitive due to the combined effects of morphological and microclimatic parameters (Peng et al., 2019; Miao et al., 2020; Buccolieri et al., 2022; Miao et al., 2023). Some of these parameters play a crucial role in local climatic conditions and bio-comfort zones. Consequently, Cetin, Sevik et al., (2023), Cetin, Adiguzel et al., (2023), and Zeren Cetin (2024b) have emphasized that taking such factors into account when managing urban environmental effects is an optimal approach for making strategic decisions in urban and landscape planning. For instance, understanding the spatial and temporal variations of environmental parameters, particularly the phenomenon of pollutant concentrations in urban zones, is essential for effective landscape and urban planning aimed at mitigating air pollution and, consequently, optimizing overall air quality (Zeren Cetin, 2024c).

In Algeria, and more specifically in Algiers, the capital, urban air pollution has been a growing concern since independence from French colonial rule in 1962, largely due to significant economic, demographic, and urban development (Belamri et al., 2017; Nejjari et al., 2003). These developments are closely linked to four major factors: road traffic, industry, construction, and waste generation (Rahal et al., 2014; Benselhoub et al., 2015; Oucher et al., 2015). Among these factors, road traffic is a major source of air pollutant emissions in Algiers, particularly the substantial emission of fine particles (PM2.5 and PM10). In this context, relevant studies by (Ali-Khodja et al., 2008; Belhout et al., 2018; Boughedaoui et al., 2004; Kerbachi et al., 1998, 2006; Oucher & Kerbachi, 2012; Talbi et al., 2018) have shown that PM10 and PM2.5 levels in the city are extreme, exceeding both international (WHO, 2016) and national standards (Journal Officiel de la République Algérienne Démocratique et Populaire N°10, 2006). This constitutes a significant threat and negatively impacts human health in urban areas of Algiers (Kerchich & Kerbachi, 2012; Terniche et al., 2018).

The study of air pollutant concentration under the urban canopy, particularly at the canyon street scale, has been the subject of several studies worldwide (Vardoulakis et al., 2003). This issue has been extensively investigated using CFD fluid dynamics simulations, which rely on a variety of numerical parameters, such as computational domain size, grid type, grid resolution, mesh refinement, boundary conditions, turbulence model, algorithm resolution, time step, and convergence criteria (Neofytou et al., 2006; Sabatino et al., 2008; Vranckx et al., 2015; Abhijith et al., 2017; Wu, Hang et al., 2021; da Silva et al., 2022; Zheng et al., 2022; Wang et al., 2022; Hang et al., 2022). The primary focus of these studies is on developing models for pollutant dispersion and concentration, as well as turbulence and wind flow within canyons with different morpho-climatic characteristics.

At the national level, specifically in the urban center of Algiers, few studies have addressed the issue of air quality (Rahal et al., 2014). Most of these studies have focused on establishing an inventory of air pollutant emissions, their sources, origins, impacts on health and the environment, as well as their types and sizes, using conventional measurement and monitoring techniques (Oucher et al., 2015; Abderrahim et al., 2016; Talbi et al., 2018; Belhout et al., 2021; Ibrir et al., 2021). Particulate matter concentrations are not continuously assessed in Algeria, specifically in Algiers, by air quality monitoring networks. To address this shortcoming, analyzers based on micro-sensor technology have been developed. Indeed, this technology allows for the creation of low-cost, low-power, and miniaturized electronic assemblies (Rahal, 2020; Rahal et al., 2020; Rahal, Benabadji et al., 2021; Rahal, Rezak et al., 2021; Benabadji et al., 2024). These sensors have demonstrated their usefulness for static and mobile deployments (Rai et al., 2017; Baron & Saffell, 2017; Maag et al., 2018). Furthermore, this type of air pollution sensor has been successfully integrated into various deployments to provide detailed air pollution information for quantitative studies (Yi et al., 2015). Additionally, to date, no studies have investigated the concentration of pollutants and its relationship with the morpho-climatic parameters of the urban area of Algiers, particularly at the canopy scale, where the urban fabric is characterized by a specific geometry of canyon streets that varies depending on the nature of the urban fabric in each of the two cities: the medieval city (Casbah) and the 19th-20th century city (French city). The objective of this analysis is to assess the effect of the interaction between key indices determining canyon geometry, such as H/W, L/H, W, and those of the urban microclimate, including wind (direction, speed, and orientation relative to the prevailing wind). Secondary parameters, such as the vehicle fleet, the typology of building facades facing canyon streets, the configuration and density of the immediate environment surrounding the canyon, and tree establishment (shape, type, and density), are also considered. These factors influence wind trajectories, dispersion, and pollutant concentration within the canyon streets, shaping specific patterns. Therefore, the present study aims to analyze and interpret the dispersion/concentration models of pollutants in selected canyons in the city center of Algiers. To achieve this purpose, we adopt a method based on the pollutant concentration measurement data provided by the CODASC database from the university of Karlsruhe in Germany (CODASC, 2022). This database contains data on the concentration of traffic-related pollutants for different urban canyon configurations, considering aspects such as aspect ratio, wind direction, and tree planting. In addition, these were obtained from wind tunnel experiments (Gromke, 2013). We have carefully selected canyon streets in Algiers city that exhibit similarities to those in the CODASC database, taking into account the morphological parameters, including canyon aspect ratio, wind direction, and street plantings. Therefore, in order to validate the results obtained from the CODASC database, we recorded measurements of the concentrations of fine particles, temperature, and humidity using an APOMOS analyzer equipped with a micro-sensor. These measurements were taken at different points on walls A and B of the studied streets. Additionally, we collected other data, such as hourly traffic volume, number of trees per linear meter (Nb_tree), aspect ratios (H/W), and wind speed (using an anemometer). Based on the collected data, a statistical model was developed to assist in the reconfiguration of canyon-type streets in order to increase the dispersion of pollutants and consequently, reduce their concentrations. The results of this study could provide guidelines for urban planning and development projects in Algiers, helping to mitigate urban pollution and enhance scientific understanding and data on Algiers, particularly in terms of air quality assessment, prediction, and improvement.

2. Methodology

2.1. Case Study

2.1.1. Geographic Location of the Studied Canyon Streets

The city of Algiers is a significant urban area due to its strategic geographic location, substantial urban and economic development, and rapid population growth, which reached nearly 3.6 million inhabitants in 2019 (Boubezari, 2021). Additionally, transportation, construction, and industry are the primary factors that simultaneously affect air quality in urban areas of Algiers through the emission of air pollutants (Belamri et al., 2017; Belhout et al., 2018, 2021; Rahal et al., 2014; Talbi et al., 2018). Road traffic in Algiers is frequently congested due to several specific factors, including increasing motor vehicle usage, rugged topography, centralized urban organization, narrow and inadequate roads, and the presence of the port (Tabti-Talamali & Baouni, 2018). As a result, many researchers have identified road traffic as the main source responsible for the deterioration of air quality in Algiers (Oucher & Kerbachi, 2012; Talbi et al., 2018). The scope of this study is highly localized, focusing on Canyon Streets. The urban center of Algiers is predominantly characterized by this type of street. Therefore, we have selected Mohammed Azzouzi Street and Larbi Ben M'Hidi Street, which are located in two dominant urban fabrics: the medieval organic fabric and the colonial fabric. Figure 1 below shows the location of the selected urban canyons.

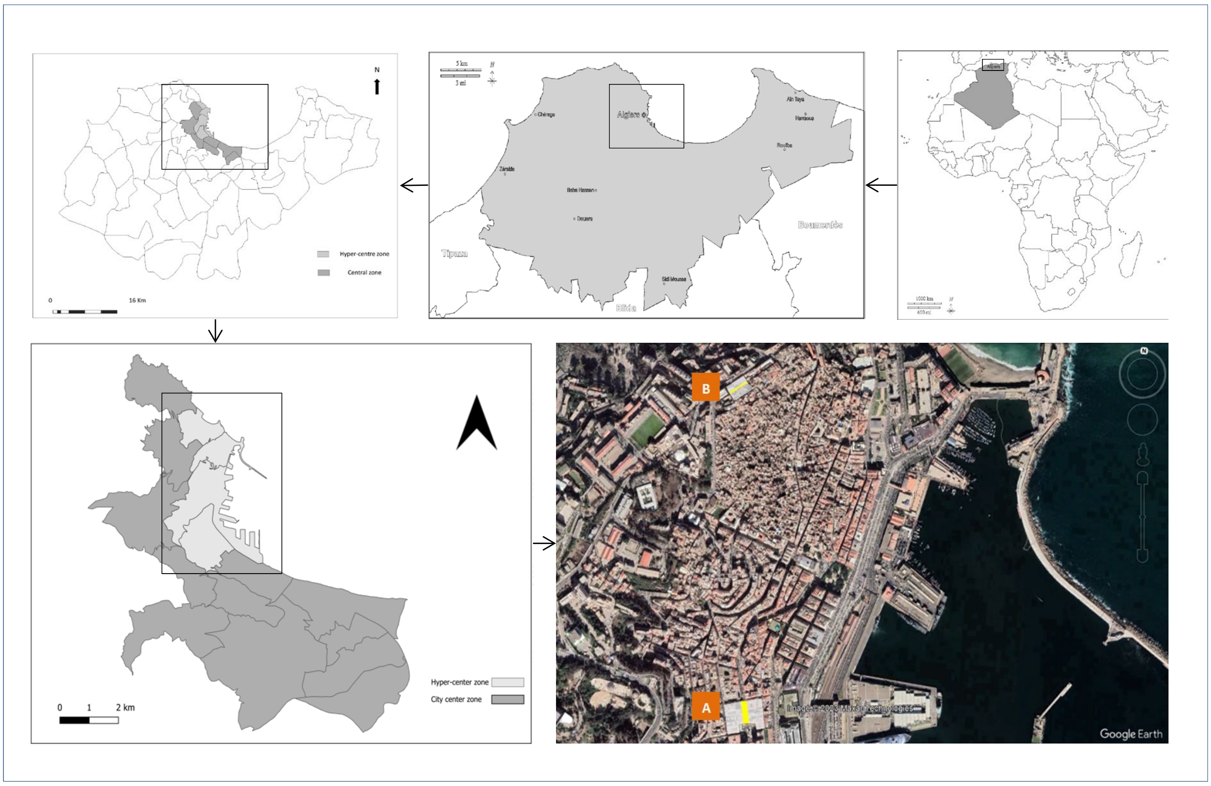
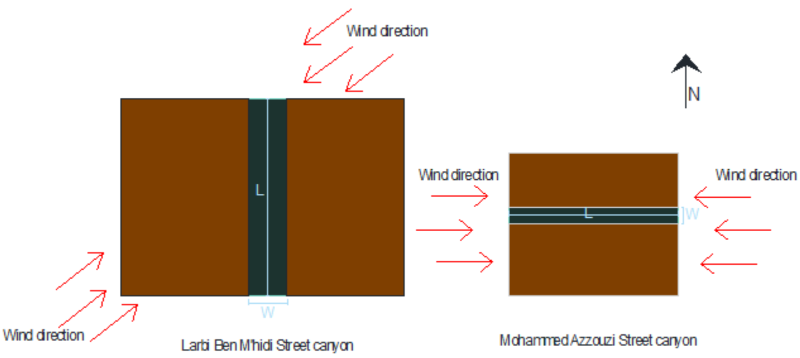


Figure 1 The location of the selected canyon streets in the hyper-central zone of Algiers: (A) Larbi Ben M'Hidi Street; (B) Mohammed Azzouzi Street

2.1.2. Criteria for Selecting Canyon Streets

This work focuses on two canyon street configurations located in two distinct urban fabrics that characterize the city center of Algiers: Mohammed Azzouzi Street and Larbi Ben M'Hidi Street, located in the medieval organic fabric (the Medina) and the colonial fabric, respectively (see Figure 1).

The selection criteria for these two canyon streets are based on those of the CODASC database developed by the University of Karlsruhe in Germany (see Sections 2.2 and 2.3). The characteristics of the climatic and geometric parameters defining the two selected canyons, which share similarities with those in the CODASC database, include the canyon aspect ratio (AR= 1 and AR= 2), wind direction penetrating the street (α= 0° and α= 45°), and trees along streets (zero trees and low vegetation density i.e. stand density loose ρs = 0,5 and crown porosity PVol = 96.0% [λ = 200m-1]). The advantage of using the CODASC database is that it is not specific to a particular climate, since it was created from simulations carried out in a wind tunnel by varying several parameters (Gromke, 2013; CODASC, 2022). Consequently, the morpho-climatic characteristics of the streets chosen in Algiers are thus adapted to the criteria of the CODASC database. The 2D and 3D plans of the selected canyons are shown in Figure 2.



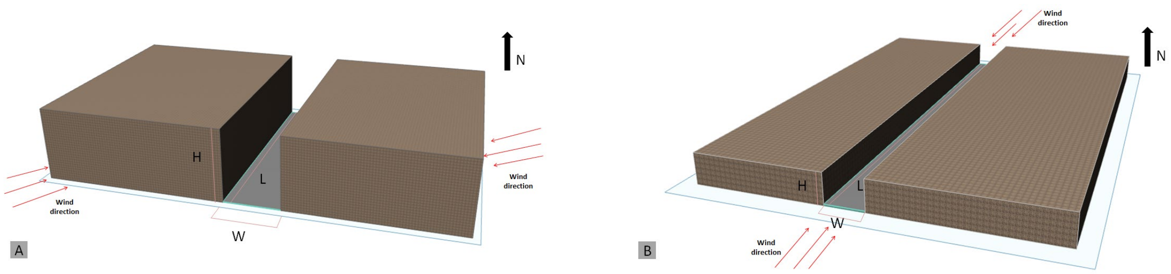


Figure 2 2D and 3D plans of the selected canyon streets with the prevailing wind direction (A) Larbi Ben M'Hidi Street with an aspect ratio (AR=2) and inclined wind (α=45°) (B) Mohamed Azzouz Street with an aspect ratio (AR=1) and parallel wind (α=0°) (Source: Authors)

2.2. Theoretical Framework

To achieve the objective outlined above, the concentration patterns of pollutants within Larbi Ben M'Hidi and Mohammed Azzouzi streets are analyzed, taking into account the specific morphological and microclimatic parameters of the canyons. The approach of this study is primarily based on the CODASC database, which provides statistical data and simulated parametric models related to pollutant concentrations in various canyon street configurations derived from wind tunnel studies (See details at the following link: https://www.umweltaerodynamik.de/bilder-originale/CODA/CODASC.html). After selecting streets with characteristics similar to those in the CODASC database, we can extract pollutant concentration patterns for these two canyon streets. In this case, areas of higher or lower pollutant concentrations, both polluted and clean, can be identified. Canyon geometry and urban microclimate variables will be used as explanatory factors for air pollutant concentration profiles in urban canyons, alongside relevant previous studies. Figure 3 outlines the procedures adopted to achieve the objective described above.

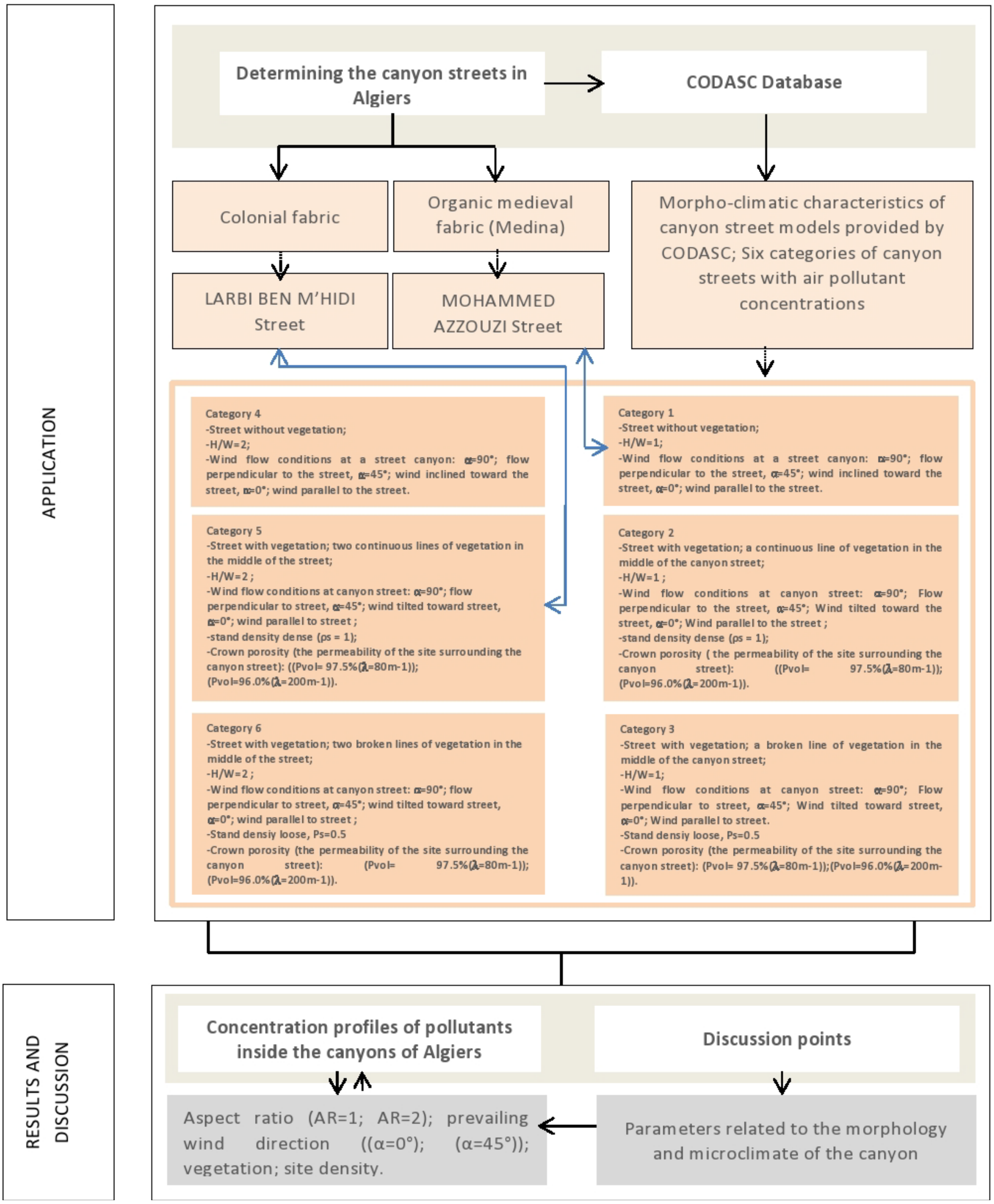


Figure 3 Method design diagram (Source: Authors, using the CODASC database)

2.3. Morpho-Climatic Characteristics of Canyon Streets from the CODASC Database with Similarities to Those Selected in Algiers

The two tables below present the characteristics of the parameters related to the morphology and microclimate of the two selected canyon streets in the city of Algiers, as well as those from the CODASC database.

Table 1 Morphological and Climatic Parameters of the Canyon Streets in the City of Algiers

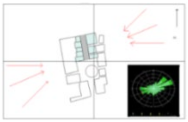
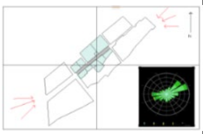
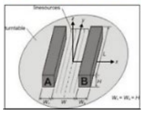
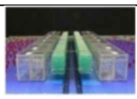
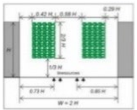
Larbi Ben M'Hidi Street					
2D and 3D canyon plans	**Morpho-climatic characteristics**				
	Aspect ratio (AR)	**Prevailing winds in Algiers**	**Dominant wind direction of the street**	**Vegetation density**	**Density of the area surrounding the street**
 	AR=2	 The wind blows from the southwest (SW) to the northeast (NE)	 Wind inclination towards the street at an angle of α= 45°	Vegetated street	Impermeable site with high density
Mohammed Azzouzi Street					
2D and 3D canyon plans	**Morpho-climatic characteristics**				
	Aspect ratio (AR)	**Prevailing winds in Algiers**	**Dominant wind direction of the street**	**Vegetation density**	**Density of the area surrounding the street**
 	AR=1	 The wind blows from the southwest (SW) to the northeast (NE)	 Wind parallel to the street at α= 0°	Street without vegetation	Impermeable site with high density

Table 2 Morphological and Climatic Parameters of the Canyon Streets Provided by the CODASC Database

Canyon streets from the CODASC database							
Category 1: Corresponding to Mohammed Azzouzi street				**Category 5: Corresponding to Larbi Ben M'Hidi street**			
Canyon plans	**Aspect ratio (H/W)**	**Wind flow entering the canyon street**	**Tree planting**	**Canyon plans**	**Aspect ratio (H/W)**	**Wind flow entering the canyon street**	**Tree planting**
 	H/W= 1	Wind parallel to the street (α= 0°)	Without Trees : Pvol=100%	  	H/W= 2	Wind inclined towards the street (α=45°)	With trees : Low vegetation density, i.e. stand density loose (ps = 0,5) and crown porosity (PVol = 96.0% [λ = 200m-1]).

2.4. Validation Methods

In situ measurements and multiple linear regression statistical analysis were conducted in the selected canyons to validate the direct application of the CODASC database in terms of pollutant concentration variations across different canyon-type street configurations, compared to those in the city of Algiers with similar morpho-climatic characteristics. In situ measurements of pollutant concentrations and microclimatic parameters were taken at various points within the studied canyons during the evening rush hour at 3 points at wall A and at 3 other points at wall B of Larbi Ben M'hidi street and the same approach was adopted for Mohammed Azzouzi Street on a summer working day, July 31, 2022, using an APOMOS (Air Pollution Monitoring System) fine particle analyzer. The locations of the measurements points within the studied canyons are shown in Figures 4 and 5 below.

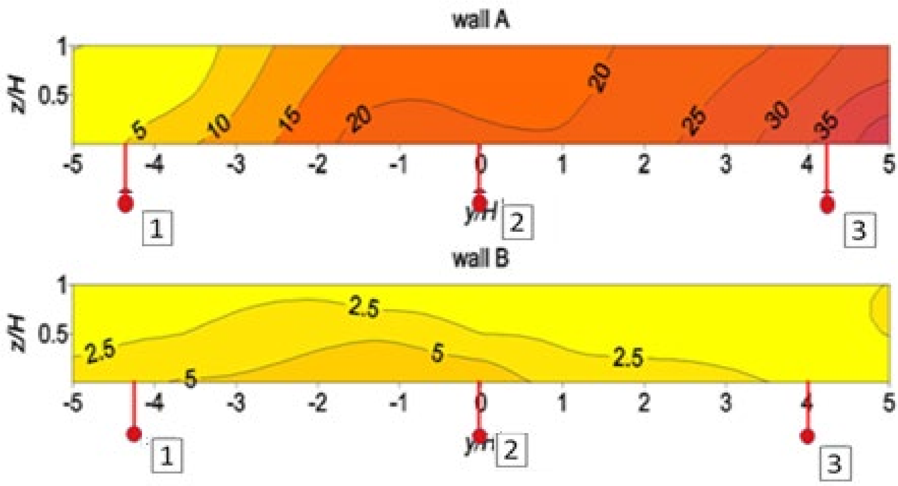


Figure 4 Position of the fine particle concentration measurement points at Larbi Ben Mhidi Street (Source: Authors, using the CODASC database)

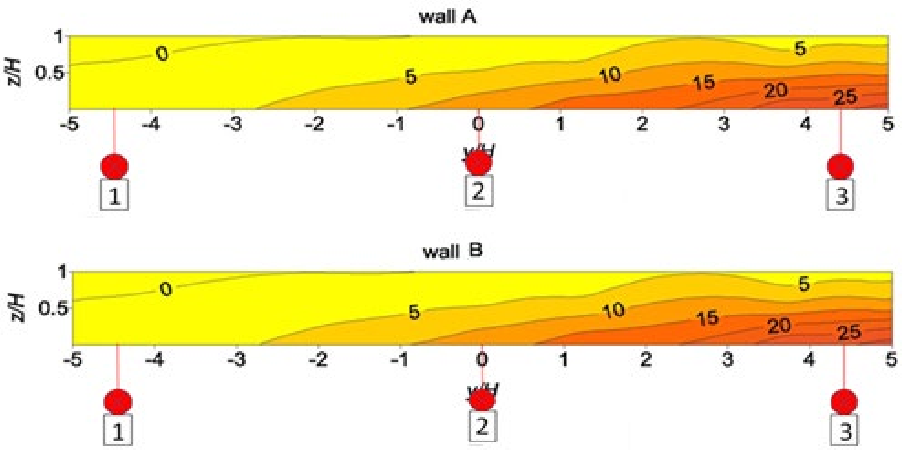


Figure 5 Location of the fine particle concentration measurement points on Mohammed Azzouzi Street (Source: Authors, using the CODASC database)

2.5. The APOMOS Analyzer

The APOMOS analyzer used in this study is equipped with the GP2Y1010AU0F particle sensor and the DHT22 temperature and humidity sensor. These components are controlled by the PIC16F1825 microcontroller.

The GP2Y1010AU0F sensor is equipped with an infrared emitting diode and a phototransistor arranged diagonally. Thus, it detects light reflected from dust in the air. It is particularly effective for detecting fine particles (Tasić et al., 2016). The low cost of the APOMOS system components allows for the production of multiple units to assess particle pollution. This solution is attractive for developing countries that lack air quality measurement networks and the budgets required to purchase conventional analyzers. Figure 6 shows two units of the APOMOS system for assessing particle pollution.

Figure 6 Particle analyzers equipped with the GP2Y1010AU0F micro-sensor

The APOMOS analyzer was calibrated with a conventional analyzer of the Ethera Nemo type which is shown in Figure 7.

Figure 7 Classic Ethera Nemo type analyzer

3. Results and Discussion

3.1. Concentration of Pollutants in the Selected Canyon Streets

The results of the topology of the normalized average pollutants concentration within the selected canyon streets, corresponding to those in the CODASC database, are displayed in the urban canyon model. The model shows AR= 2, PS= 0.5, and PVol= 96.0% for Larbi Ben M'Hidi canyon street, and AR= 1, PS= 0, and PVol= 100% for Mohammed Azzouzi canyon street. Regarding the wind flow, it is inclined toward the street with α= 45° in the first case and parallel to the street with α= 0° in the second case (Figure 8, 9, 10).

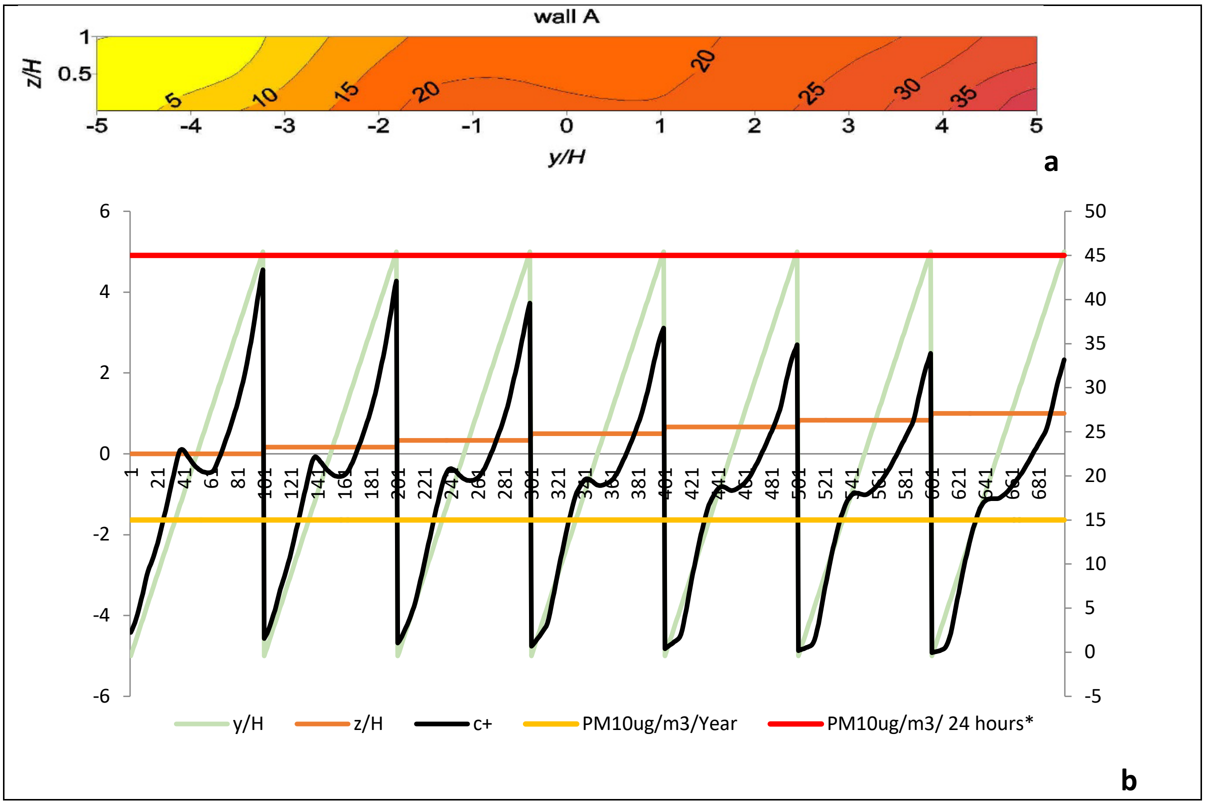


Figure 8 (a): Model of the average standardized pollutant concentrations (C+) characterizing Larbi Ben M'Hidi Canyon Street (b): Profiles of normalized average pollutant concentrations (C+) compared to the Y/H and Z/H axes on wall A of Larbi Ben M'Hidi Canyon Street, with profiles defining the air quality standards for fine particulate matter (PM10) recommended by the WHO in 2021

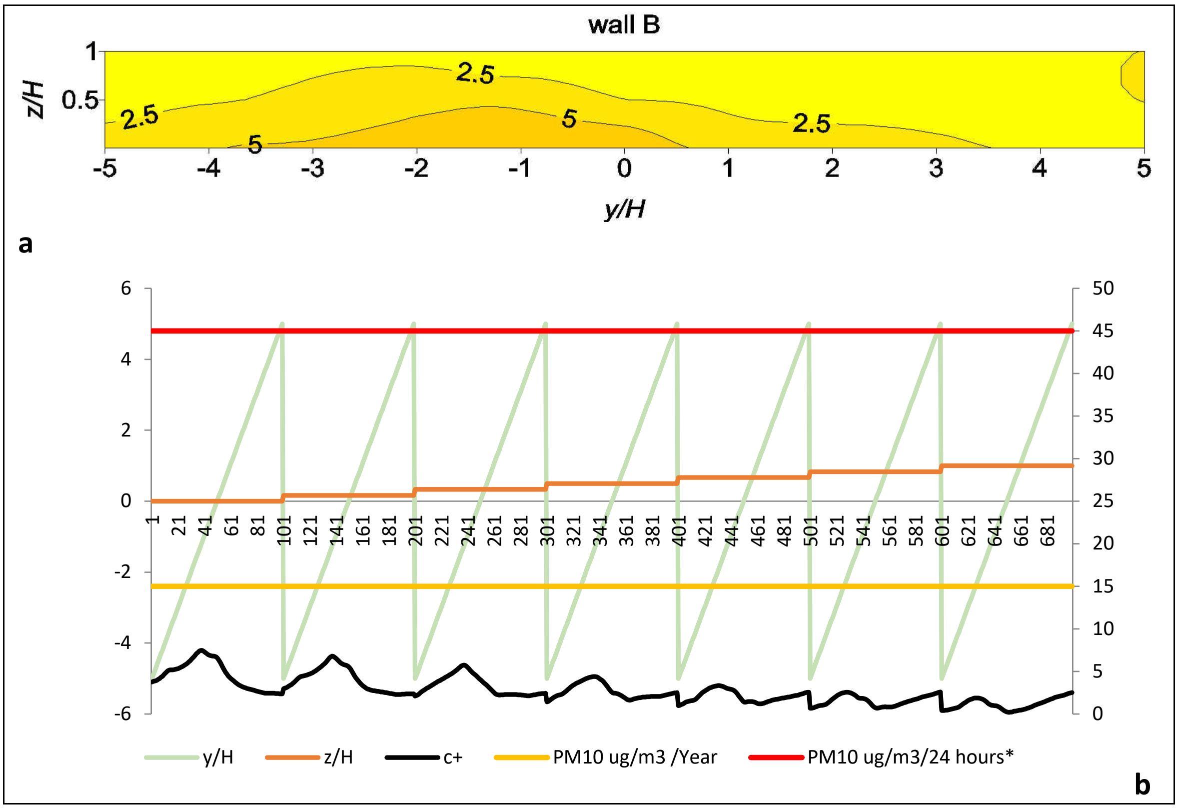


Figure 9 (a): Model of the average standardized pollutant concentrations (C+) characterizing Larbi Ben M'Hidi Canyon Street (b): Profiles of normalized average pollutant concentrations (C+) compared to the Y/H and Z/H axes on wall B of

Larbi Ben M'Hidi Canyon Street, with profiles defining the air quality standards for fine particulate matter (PM10) recommended by the WHO in 2021

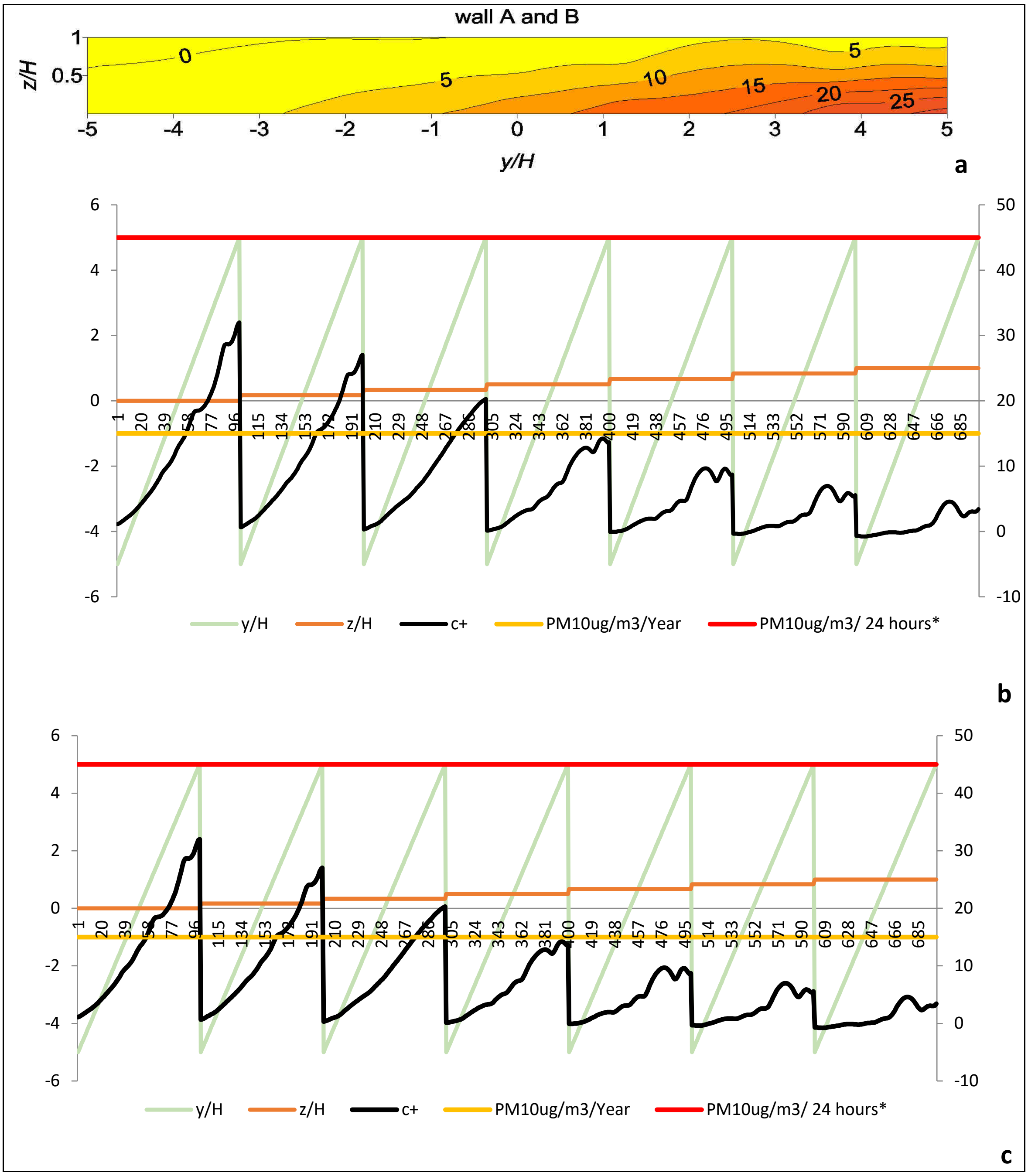


Figure 10 (a): Model of the average standardized pollutant concentrations (C+) characterizing Mohammed Azzouzi Canyon Street (b) and (c): Profiles of normalized average pollutant concentrations (C+) compared to the Y/H and Z/H axes on walls A and B of Mohammed Azzouzi Canyon Street, with profiles defining the air quality standards for fine particulate matter (PM10) recommended by the WHO in 2021

3.2. Validation Results

3.2.1. Comparison of Measured Pollutant Concentration Profiles with Those Presented by CODASC Database

Figure 11 shows measurements taken on Sunday, July 31, 2022, which is a weekday in Algiers. Vehicle traffic on the selected streets was estimated at 971 UVP during the evening rush hour for Larbi Ben M’hidi Street, a major traffic route, and 0 UVP on Mohammed Azzouzi Street, a pedestrian street.

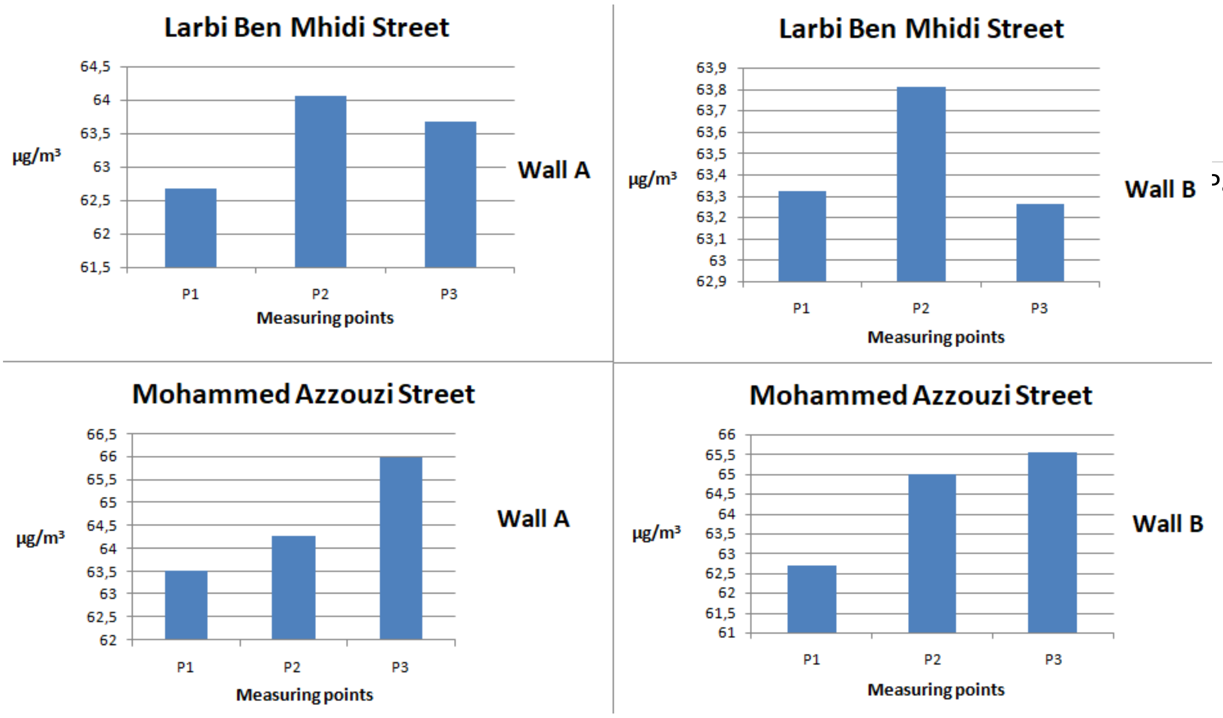
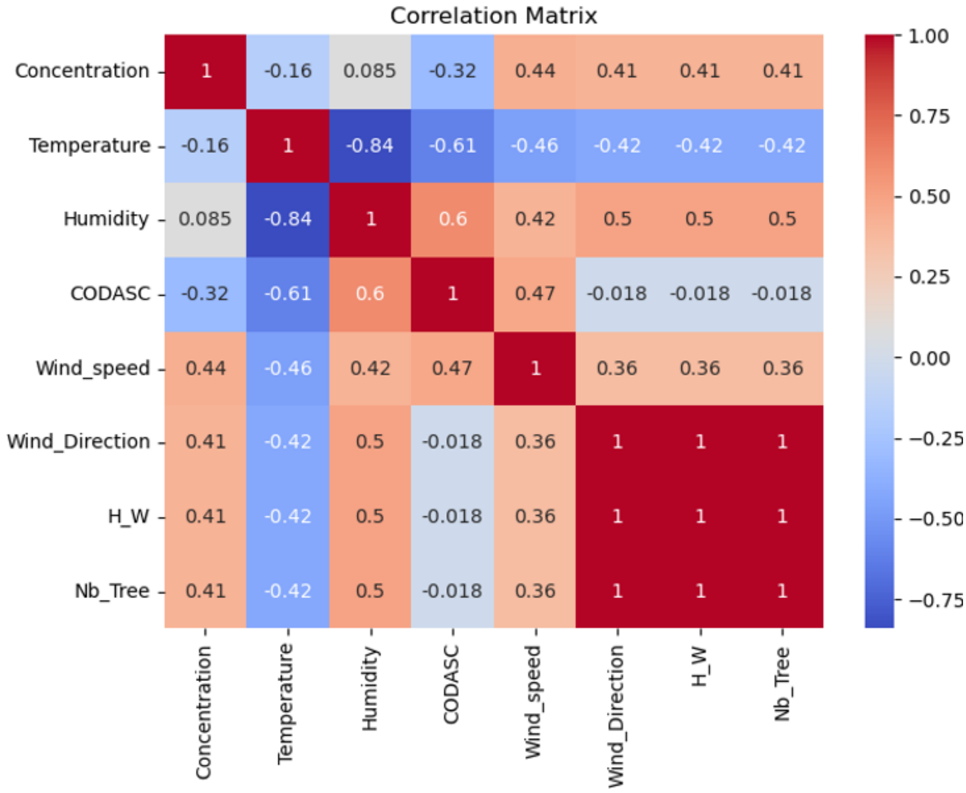


Figure 11 Concentration of Fine Particle Pollution Collected by the APOMOS Analyzer on Larbi Ben Mhidi and Mohammed Azzouzi Streets on Sunday, July 31, 2022

The measurement results show that the variations in concentrations in the selected streets largely correspond to the variations shown by the CODASC database.

3.2.2. Multiple Linear Regression Statistical Analysis Model

The statistical model developed is based on all the data measured within the selected urban canyons, with a simulation of these data using a multiple linear regression test. The result of this simulation reveals significant correlations between the measured particulate concentrations and the street characterization data, CODASC data, and meteorological data, as shown in the correlation matrix presented in Figure 12.



	Concentration	Temperature	Humidity	CODASC	Wind_speed	Wind_Direction	H_W	Nb_Tree
Concentration	1	-0.16	0.085	-0.32	0.44	0.41	0.41	0.41
Temperature	-0.16	1	-0.84	-0.61	-0.46	-0.42	-0.42	-0.42
Humidity	0.085	-0.84	1	0.6	0.42	0.5	0.5	0.5
CODASC	-0.32	-0.61	0.6	1	0.47	-0.018	-0.018	-0.018
Wind_speed	0.44	-0.46	0.42	0.47	1	0.36	0.36	0.36
Wind_Direction	0.41	-0.42	0.5	-0.018	0.36	1	1	1
H_W	0.41	-0.42	0.5	-0.018	0.36	1	1	1
Nb_Tree	0.41	-0.42	0.5	-0.018	0.36	1	1	1

Figure 12 Correlation matrix between the parameters influencing the concentration of particulate pollution in the streets studied

A multiple linear regression was performed to simulate particulate pollution concentration values using data from the CODASC database, street characteristics, and meteorological data. Comparison between recorded and simulated values showed a coefficient of determination of 99.80%, as shown in Figure 13.

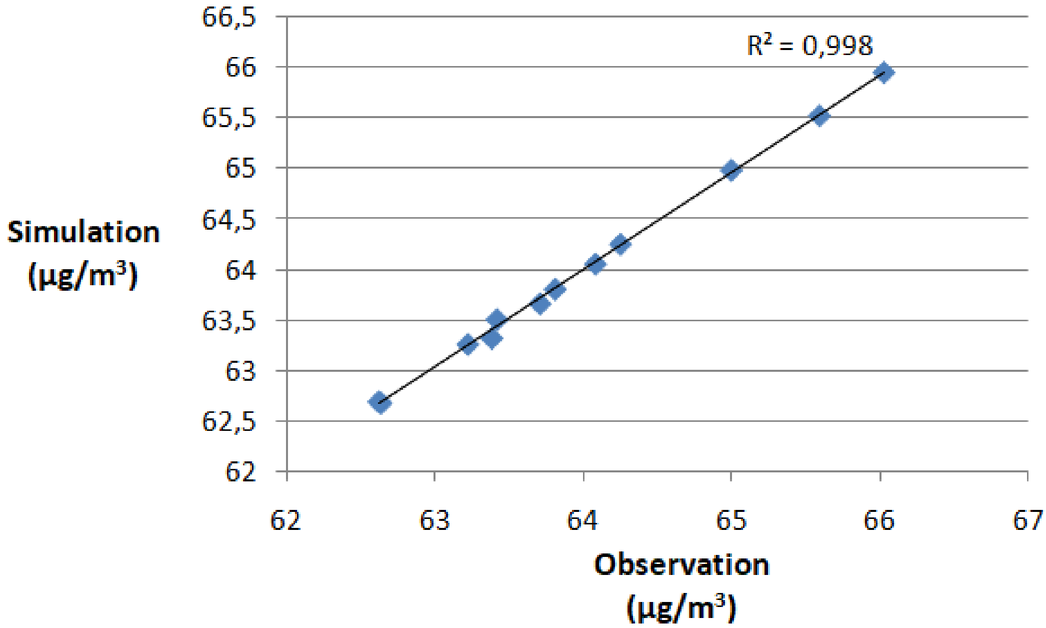


Figure 13 Scatter plot comparison between observed and simulated particle pollution concentrations in the streets studied

3.3. Confrontation of Pollutant Concentrations and Morpho-Climatic Characteristics

3.3.1. Aspect Ratio (AR) =H/W = 1 and 2

The concept of aspect ratio (AR) is one of the morphological parameters specific to Canyon Streets. It is related to the height of the building (H) and the width of the street (W), and the equation that expresses it is AR=H/W (Hassan et al., 2022). A very deep Canyon Street corresponds to an H/W value greater than 2, a semi-deep Canyon to an H/W value equal to 1, and a wide Canyon to an H/W value less than 1 (Fouzia & Bourbia, 2011; Athamena, 2012). A long Canyon Street corresponds to a ratio of L/H<7, a medium Canyon Street corresponds to L/H=5, and a short Canyon Street corresponds to L/H<3, where L is the length of the canyon and H is the height of the Canyon (He et al., 2019; Muniz-Gäal et al., 2020). These ratios significantly impact airflow and pollutant concentrations inside Canyon Streets (da Silva et al., 2022; He et al., 2019; Li et al., 2020; Voordeckers, Meysman et al., 2021).

It should be noted that the two street cases chosen for this study have two common characteristics: both are short canyons, with an L/H ratio of less than 3, and their immediate environment is dense. Therefore, in the interpretation of the results, the elements to be discussed are the direction of the wind entering the street, the aspect ratio (AR), vegetation, and their impacts on the pollutant concentrations.

PM10 is generally considered a primary indicator of fine particle pollution from road traffic at the local level (Ladji et al., 2009; Talbi et al., 2018; Belarbi et al., 2020). Considering this pollutant, Figures 8, 9, and 10 show the variation in average normalized concentrations (C+) of pollutants on both sides of Larbi Ben M'Hidi and Mohamed Azzouzi canyons Streets. By analyzing the pollutant concentration values displayed in the graphs above, we observe that the peak pollutant concentration values in Larbi Ben M'Hidi Canyon Street are higher than those in Mohamed Azzouzi Canyon Street. Indeed, the maximum normalized average concentration values of pollutants (C+) for Larbi Ben M'Hidi Canyon Street reached 41.95 and 7.27 for walls A and B, respectively (see graphs 8 and 9), whereas in Mohamed Azzouzi Canyon Street, this concentration value (C+) reached 31.33 for both walls A and B (see graphs 10). Moreover, when comparing the peak (C+) values of the two canyons with the PM10 values recommended by the World Health Organization (WHO, 2021), we notice that these values exceed the admissible annual standards of 15ug/m3, contrary to the daily standard of 45ug/m3, in most walls of both canyons, except for wall B of Larbi Ben M'Hidi (See Figures 8, 9, 10). However, it can be said that the population frequenting Larbi Ben M'Hidi Canyon Street, especially near wall A, is more vulnerable to the effects of daily PM10 concentration values than those frequenting Mohammed Azzouzi Canyon Street near both walls A and B (See graph b in Figure 8 and graph b in Figure 10). These higher pollutant levels related to road traffic are likely due to the higher aspect ratio of Larbi Ben M'Hidi Street (H/W=2; deep street canyon), which is greater than that of Mohammed Azzouzi Street (H/W=1; shallow street canyon). This is consistent with the results of previous studies, which have shown that a deeper aspect ratio (AR) plays a key role in increasing pollutant concentration levels (Gromke & Ruck, 2012; Di Bernardino et al., 2018; Voordeckers, Meysman et al., 2021). Furthermore, (Baik & Kim, 1999; Tan et al., 2019; Zhang et al., 2020) demonstrated in their studies that deep canyons largely favor the trapping of pollutants near the walls due to the greater buildings height and the narrow width of the street. This creates a very confined space that prevents air circulation and favors the accumulation of pollutants. In contrast, shallow canyons allow pollutants to be more freely distributed, through the availability of space for air circulation, which provides better ventilation conditions due to the lower building height and the wider width of the canyon. This ultimately leads to a reduction in the concentration levels of pollutants near the ground.

3.3.2. Prevailing Wind Direction in the Canyon Street

When Larbi Ben M'Hidi street is subjected to an oblique wind direction (α = 45°), the normalized average pollutant concentrations (C+) are higher on wall A than on wall B (see Figures 8 and 9). This is due to wall A being on the leeward side, while wall B is on the windward side, where concentrations are lower (Gromke & Ruck, 2008). Consequently, a flow regime is established in this context, specifically a corkscrew flow regime that promotes the accumulation of pollutants in the leeward parts of the canyon (Gromke & Ruck, 2012; He et al., 2019). Additionally, the wind flow inclined towards the canyon, may first impact wall B and then move towards wall A, influenced by obstacles in the middle of the street, such as vehicles and vegetation, which affect the wind direction within the canyon (Buccolieri et al., 2011; Makar et al., 2021). As a result, under these conditions, particularly when vegetation density is very high, traffic is dense, and buildings are closely spaced, vortices are generated. These vortices can alter the wind direction and contribute to the accumulation of pollutants near the ground in the canyon street. This is especially evident on wall A, located on the leeward side, where pollutant concentrations are much higher compared to wall B, located on the windward side, which experiences lower concentrations (see Figure 9) (Zhang et al., 2020).

In the case where Mohammed Azzouzi Street is subjected to a parallel wind direction ($\alpha = 0°$), the normalized average pollutant concentrations (C+) are the same and parallel for both walls A and B (See Figure 10). As shown in Figure 10, due to the channeling flow formed inside the canyon, pollutants accumulate in the final part of the canyon (Gromke & Ruck, 2012; He et al., 2019; Voordeckers, Meysman et al., 2021). This type of airflow creates a direct relationship with the concentration of pollutants. Specifically, when the wind blows straight down the street, it indicates that there are no obstacles, such as trees and cars, which would otherwise reduce the vertical exchange of air with the atmosphere above. As a result, pollutants tend to accumulate towards the end of the street, where the wind direction concludes. On the other hand, ventilation in the part of the canyon exposed to the wind, particularly at the beginning of the street, remains more effective, and pollutant concentrations are lower, as shown in Figure 10 (Huang et al., 2019).

3.3.3. Tree Planting in Canyon Street

Larbi Ben M'Hidi canyon street is characterized by the presence of trees along both sides of the street, which are associated with low stand density ($\rho ts = 0.5$) and low crown porosity ($PVol = 96.0\%$; $\lambda = 200m^{-1}$), where λ is the pressure loss coefficient of the tree crown. In contrast, Mohammed Azzouzi Street has no trees, i.e. zero stand density ($\rho ts = 0$) and ($PVol = 100\%$). Previous studies have shown that the presence of trees in a street affects wind behavior, including its direction and speed, as well as pollutant concentration levels (Buccolieri et al., 2011; Gromke & Ruck, 2012; Karttunen et al., 2020). Higher pollutant concentration values were observed in Larbi Ben M'Hidi Street, unlike those in Mohammed Azzouzi Street (see Figures 8, 9, 10). This can be explained by the presence of trees, even at low stand density ($\rho ts = 0.5$) and low crown porosity ($PVol = 96.0\%$; $\lambda = 200m^{-1}$). The low stand density means that pollutants are captured by direct deposition to a limited extent in Larbi Ben M'Hidi Street. At the same time, the low crown porosity means that the trees are dense, with little space for air to pass through. This prevents air from circulating beneath the trees, reducing both vertical and lateral dispersion of air, and thus increasing the accumulation of pollutants at the street level (Gromke et al., 2008; Salmond et al., 2013; Vos et al., 2013; Abhijith et al., 2017).

4. Conclusion and Recommendation

This study aims to explore the theoretical use of the CODASC database to interpret the heterogeneity of air pollutant concentration patterns in two types of urban canyons.

We propose a methodology for this work, which is primarily based on selecting canyon streets from different urban fabrics in Algiers, specifically the medieval organic fabric and the colonial fabric. These canyons were chosen because they share similarities with those in the CODASC database in terms of aspect ratio (H/W), direction of the prevailing wind (α), and tree planting (ρts and PVol). Consequently, the selected canyons are Larbi Ben M'Hidi Canyon Street in the colonial fabric and Mohammed Azzouzi Canyon Street in the medieval organic fabric.

The typologies and normalized average air pollutant concentration profiles (C+) representing the canyon models studied demonstrate that the highest pollutant concentration levels are clearly associated with canyon depth, which is strongly influenced by the aspect ratio (H/W), determining whether the canyon is deep or shallow. In addition, the perpendicular wind (α=45°) results in higher pollutant concentrations on the leeward wall compared to the windward wall, while the parallel wind (α=0°) shows lower concentrations along both sides of the walls, except at the extreme ends of the canyon. Furthermore, the presence of trees negatively affects pollutant concentration levels due to their unsuitable morphology on Larbi Ben M'Hidi Street, in contrast to Mohammed Azzouzi Street, which has no trees, leading to lower pollutant concentrations.

The statistical model developed in this study allows for simulations and scenario studies aimed at mitigating particulate pollution in canyon-type streets by adjusting appropriate parameters. However, to gain a better understanding of the methodology developed, it is necessary to analyze additional streets and rely on continuous air quality measurements. This will increase the data volume and allow it to be processed and analyzed by machine learning algorithms to develop even more powerful models.

The study of the impact of geometric and microclimatic parameters of canyons on air quality using CFD numerical simulations should be considered during the design phase of future sustainable urban development projects in Algiers. This could include, for example, the grouping of morpho-climatic parameters that favor the prevention of pollutant accumulation as a mitigation strategy for urban pollution. Key factors include: an aspect ratio that is either shallow or wide; surrounding areas of canyon streets that should be permeable to facilitate air exchange; wind direction, which should preferably be parallel to the canyon axis; and trees, which should be planted on the walls and roofs of buildings bordering the urban canyon to avoid disrupting air flow in the street. For future research, the use of the CODASC database should evolve from theoretical to practical by incorporating new configurations of canyon streets. Furthermore, urban planners and policymakers should take advantage of the presence of dilapidated buildings to carry out urban restructuring that involves creating openings parallel to prevailing winds, removing obstacles to winds, reinforcing vegetation cover, and reducing aspect ratios in new urban fabrics or through heightening in preserved fabrics.

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Resume

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