

AERMOD-Based Assessment of PM₁₀ and PM_{2.5} Dispersion from Cement Kiln Chimneys and Environmental Health Risk Analysis: A Case Study Western Algeria

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Received 01 March 2026

Received in revised form 15 April 2026

Accepted 05 May 2026

Abstract

Cement manufacturing is a major source of particulate matter pollution in Algeria, although detailed atmospheric dispersion studies remain limited. This study applies the AERMOD model to evaluate the dispersion of PM_{2.5} and PM₁₀ emissions from a cement plant in western Algeria. Emission data collected on site, combined with meteorological and terrain information, were used to simulate how pollutants spread in the surrounding environment.

The results show elevated pollutant concentrations in areas close to the plant, with dispersion patterns largely influenced by prevailing wind directions and atmospheric conditions. The analysis identifies zones potentially exposed to higher levels of particulate matter, including nearby agricultural and inhabited areas. Comparison with national regulations and international air quality guidelines indicates exceedances near the emission source. These findings highlight the role of both technical factors, such as stack characteristics, and environmental conditions in shaping air quality impacts. Based on this assessment, general recommendations are proposed to improve emission control and reduce potential risks to the environment and public health.

Keywords: AERMOD; PM₁₀; PM_{2.5}; cement plant; atmospheric dispersion; AERMET; AERMAP; air quality; Algeria; industrial dust.

1. Introduction

The global cement industry contributes an estimated 20.9% of total industrial particulate matter (PM) emissions worldwide, a figure reported by China's Ministry of Ecology and Environment for 2022, positioning it as one of the most significant stationary sources of anthropogenic aerosol pollution (Smadi et al., 2023; PMC, 2025). In Algeria, the cement

sector has experienced substantial capacity expansion over the past two decades, driven by sustained construction demand linked to national infrastructure programmes. The country currently operates more than twenty cement production lines, several of which belong to multinational operators such as Holcim (formerly LafargeHolcim). Cement kilns relying on dry process rotary technology produce large quantities of PM₁₀ and PM_{2.5} through the combustion of fossil and alternative fuels, clinker formation reactions, and material handling processes. Despite the scale of this industrial activity, published English language studies providing quantitative atmospheric dispersion assessments of Algerian cement plant particulate emissions are virtually absent from the scientific literature.

Particulate matter from cement kilns contains a complex mixture of mineral compounds, including calcium silicates, alumina, crystalline silica, and heavy metal traces (Cr, Pb, Cd). PM_{2.5}, defined as particles with an aerodynamic diameter below 2.5 µm, penetrates the respiratory system deeply, depositing in alveolar regions and entering systemic circulation, causing respiratory, cardiovascular, and neurological damage. The World Health Organization's updated Global Air Quality Guidelines (WHO, 2021) set annual PM_{2.5} and PM₁₀ guideline values of 5 µg/m³ and 15 µg/m³, respectively, thresholds frequently exceeded near active cement plants in developing countries. Long-term epidemiological evidence indicates that communities residing within 1 to 3 km of cement plants face elevated risks of chronic obstructive pulmonary disease (COPD), restrictive lung disease, lung carcinoma, and cardiovascular mortality (Smadi et al., 2023; IARC, 2012).

Regulatory grade atmospheric dispersion models provide the most reliable tool for quantifying the spatial distribution of pollutant concentrations from industrial point sources. American Meteorological Society Environmental Protection Agency Regulatory Model (AERMOD) is a steady state Gaussian plume model designed for near field applications over source receptor distances up to 50 km (Cimorelli et al., 2005; US EPA, 2005). Its three module architecture AERMET for planetary boundary layer (PBL) meteorological pre-processing, AERMAP for terrain pre-processing, and the AERMOD dispersion core enables the realistic simulation of plume rise, complex terrain interaction, and atmospheric stability effects. Since its adoption as the US EPA preferred regulatory model in 2005, AERMOD has been applied to cement plants across Iran (Keykhosravi et al., 2020), Egypt (Abdel-Gawad et al., 2023), Rwanda (Mtibiri et al., 2024), Turkey (Güzel et al., 2024), Indonesia, and Nigeria, consistently demonstrating its suitability for near-source industrial PM assessments.

The Lafarge Holcim Oggaz (LCO) cement plant, located in the Wilaya of Mascara in western Algeria, is one of the largest cement production facilities in the country, with a combined grey and white clinker capacity exceeding 2.85 million tonnes per year. Its two kiln lines discharge residual PM through dedicated chimneys equipped with bag filtration systems. The site lies in a semi-arid Mediterranean environment with a characteristic north-westerly wind regime, which directs plumes toward nearby agricultural communities and peri-urban areas. Despite its scale and proximity to inhabited zones, no

peer-reviewed atmospheric dispersion study for LCO or any comparable Algerian cement plant has been published in the international literature.

The objectives of this study are therefore: to characterize the emission parameters of the two LCO kiln chimneys through onsite measurement campaigns; configure and run AERMOD for PM10 and PM2.5 using one month of meteorological data and SRTM3 terrain data; analyze the spatial dispersion patterns and identify the primary exposure corridor; assess compliance with Algerian regulatory limits and WHO 2021 air quality guidelines; and propose evidence based mitigation recommendations. This study constitutes the first AERMOD based PM dispersion assessment of an Algerian cement plant published in the international literature, and contributes a replicable methodological framework applicable to other North African industrial facilities.

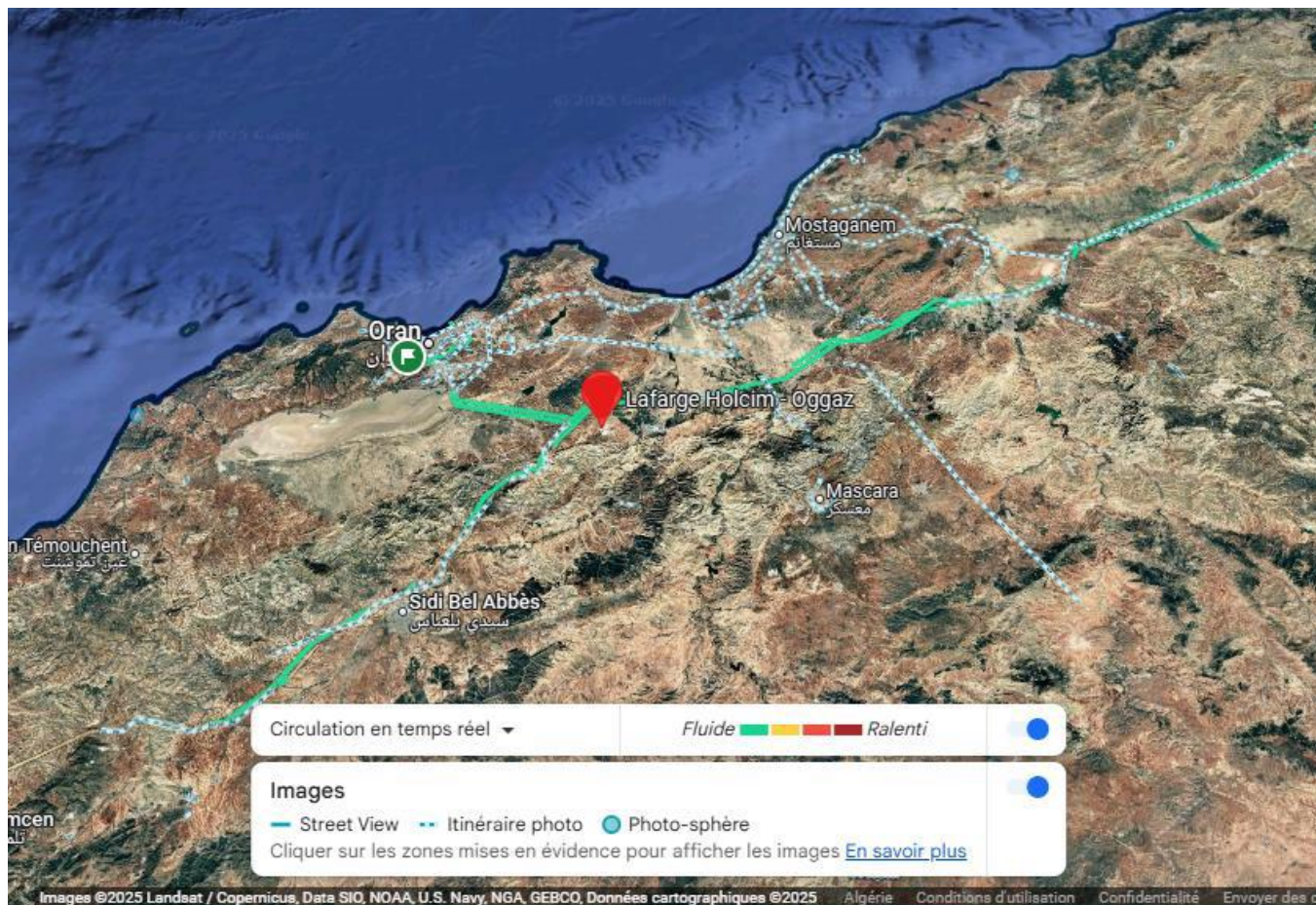


Figure 1 : Geographical map of the LCO site

2. Literature Review

2.1 Atmospheric Dispersion Modeling of Cement Plant Emissions

Gaussian dispersion modeling of cement plant particulate emissions has been extensively pursued in the last decade, with AERMOD emerging as the dominant regulatory tool due to its incorporation of advanced PBL parameterization, Briggs plume rise equations, and SRTM compatible terrain algorithms. Keykhosravi et al.

(2020) applied multilayer perceptron (MLP) neural networks coupled with AERMOD to predict cement dust concentrations around an Iranian cement plant, achieving high model accuracy ($R^2 > 0.95$) and demonstrating that stack height is the primary determinant of near-source ground level concentrations. Abdel Gawad et al. (2023) applied AERMOD version 21112 to the Egyptian Titan Alexandria Portland Cement Company across multiple fuel scenarios 2014 to 2020, finding that substitution of natural gas with coal tire derived fuel blends increased total suspended particle (TSP) concentrations by factors of 2 to 3 and that 24-hour maximum concentrations up to $300 \mu\text{g}/\text{m}^3$ were predicted within 1 km of the plant.

Mtibiri et al. (2024) applied AERMOD to the CIMERWA cement plant in Rwanda, reporting 24 hour peak PM₁₀ concentrations of $158.86 \mu\text{g}/\text{m}^3$, $92.87 \mu\text{g}/\text{m}^3$ at 1 hour, and annual means of $27.65 \mu\text{g}/\text{m}^3$ at the most exposed receptors. The study demonstrated that PM₁₀ dispersion primarily follows the dominant north-easterly wind regime, creating an asymmetric exposure footprint, and introduced flux quantification methods within the AERMOD framework. Güzel et al. (2024) compared AERMOD and CALPUFF performance for PM₁₀, NO_x, and CO from a Turkish cement factory, integrating WRF, AERMET, and CALMET meteorological inputs and adding long term health risk assessment using Health Risk Assessment Program (HARP). Their results showed AERMOD produced slightly more conservative near-source PM₁₀ predictions than CALPUFF under stable nighttime conditions. Jayadipraja et al. (2016) reported a 1hour peak TSP of $314 \mu\text{g}/\text{m}^3$ from an Indonesian cement plant chimney using AERMOD, with exceedances of the $90 \mu\text{g}/\text{m}^3$ Indonesian air quality standard in the near-source field.

A comprehensive review of AERMOD applications globally (IJRISS, 2025) confirmed the model's suitability for complex terrain environments mountainous or hilly where PBL interactions require AERMAP terrain correction. The review noted that incorporating WRF derived meteorological inputs via AERMET significantly improved AERMOD predictive accuracy for semi-arid and complex terrain sites, a particularly relevant finding for Algerian industrial facilities situated in piedmont environments. In November 2024, the US EPA finalized regulatory enhancements to AERMOD version 23132, including updates to the Gradual Ramp Sigma Method (GRSM) for improved far-field plume spread predictions and the formalization of RLINE as a new regulatory source type for mobile source applications (US EPA, 2024).

2.2 Health Impacts of Cement Plant PM Emissions

The health burden of cement plant particulate emissions is well-documented in epidemiological and toxicological literature. Smadi et al. (2023) monitored PM_{2.5} and PM₁₀ concentrations at a Jordanian cement plant, finding exceedances of legal limits at receptors within 300 m of the chimney base. The study reported PM₁₀ predominance in the inhalable fraction, consistent with dry-process kiln emission profiles where PM₁₀ constitutes 40 to 42% and PM_{2.5} constitutes 18 to 20% of total particulate emissions without dust control, with bag filter installation shifting the PM_{2.5} fraction to approximately 45% of remaining emissions (PMC, 2025).

Particulate matter from cement kilns has been classified by IARC (2012) as Group 1 carcinogen due to its crystalline silica content, with an occupational threshold limit value (TLV-TWA) of 0.025 mg/m^3 set by the ACGIH (2023) for alveolar quartz. Chronic cement dust exposure is associated with pneumoconiosis, silicosis, COPD, and restrictive lung disease. Cardiovascular effects of PM_{2.5} are mediated through systemic inflammation, endothelial dysfunction, and autonomic imbalance (Brook et al., 2010). Neurological effects of prolonged fine particulate exposure, including cognitive decline in elderly populations, have been reported by Power et al. (2016). The WHO (2021) global burden of disease estimates attribute approximately 4.2 million premature deaths annually to ambient PM_{2.5} exposure worldwide, with North African industrializing regions experiencing disproportionate exposure growth.

In Algeria, the occupational exposure limit for cement dust is aligned with ACGIH TLVs: 10 mg/m^3 for inhalable fraction, 3 mg/m^3 for alveolar fraction, and 1 mg/m^3 for cement-specific fine particles. Algerian Executive Decree 06-138 establishes atmospheric emission limit values for kiln dust from cement plants but does not provide explicit ambient air quality standards for PM₁₀ or PM_{2.5} in the regulatory text, creating a compliance assessment gap that international guidelines (WHO, 2021; EU Directive 2008/50/EC) must be used to fill.

2.3 AERMOD in Semi-Arid Mediterranean Industrial Environments

Semi-arid Mediterranean environments present specific challenges for Gaussian dispersion modeling, including high mean wind speeds, low calm frequency conditions, strong diurnal PBL variation between convective daytime mixing and stable nocturnal inversions, and complex terrain interactions with orographic forcing. These conditions characterize western Algeria's Mascara piedmont, where LCO is located. Several studies from geographically comparable environments have validated AERMOD under such conditions. Afzali et al. (2017) applied AERMOD with WRF meteorological inputs to model PM₁₀, NO₂, and SO₂ from multiple Malaysian industrial sources, demonstrating satisfactory model performance (normalized mean square error < 0.5) under high-wind semi-tropical conditions. Eslamidoost et al. (2023) applied AERMOD to a large Iranian gas refinery in a semi-arid Middle Eastern climate and found no systematic bias against measured station data under neutral and slightly unstable stability classes.

For cement plant applications specifically in North Africa or comparable arid/semi-arid environments, published AERMOD studies remain rare, constituting a significant gap that this study addresses. Existing studies from Egypt (Abdel-Gawad et al., 2023) and Jordan (Smadi et al., 2023) provide the closest geographic analogues, but differ in terrain configuration, regulatory framework, and measurement methodologies from the Algerian case presented here.

3. Materials and Methods

3.1 Study Area

The Lafarge Holcim Oggaz (LCO) cement plant is located in the commune of Oggaz, Wilaya of Mascara, western Algeria 35°32'N, 0°16'W, approximately 60 km south east of Oran and 35 km north of Mascara (Figure 1). The plant was constructed in 2007 as a subsidiary of the international Holcim group and is one of Algeria's largest cement production facilities. It operates two parallel production lines using the dry process rotary kiln technology with five stage cyclone preheater towers:

- Grey clinker line: annual production capacity of 2.8 million tonnes (6,250 t/day), fed by limestone and clay extracted from four onsite quarries.
- White clinker line: annual capacity of 550,000 tonnes (1,500 t/day), producing specialty decorative and architectural cement.

The site is embedded in a semi-rural landscape of semi-arid Mediterranean climate (Köppen BSk classification), characterized by dry hot summers, mild winters, and a prevailing north westerly wind regime generated by synoptic scale Mediterranean low pressure systems. The surrounding territory comprises cereal cultivation plains to the east, discontinuous peri-urban development along the RN07 national road approximately 3 km to the north east, and low relief limestone hills elevation around range 330–400 m to the south. The nearest inhabited community, the small town of Sig, lies approximately 8 km to the north of the plant.

3.2 Emission Source Characterization

Two point sources were identified for AERMOD modeling (Figure 2): the grey line kiln chimney (Stack G) and the white line kiln chimney (Stack W). Both stacks discharge residual PM after passing through filtration units. Stack G is equipped with a continuous automatic dust monitoring system H24 real time particulate sensor embedded in the flue, while Stack W uses periodic gravimetric sampling.

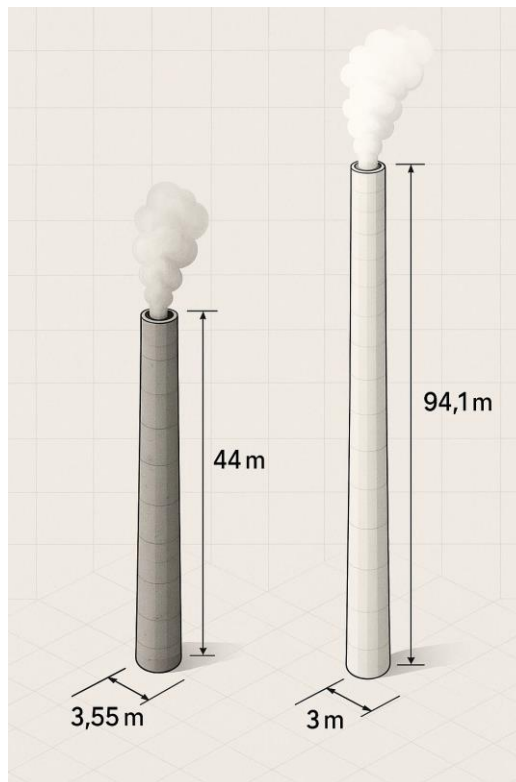


Figure 2 : dimensions of the Grey line kiln chimney and the white line kiln chimney

For Stack G, one month of daily mean PM emission concentration data (February 2025) was supplied by the plant's environment manager, yielding a temporal dataset of 28 daily values. The mean daily concentration of 18.90 mg/Nm^3 was used as the representative emission concentration for AERMOD. For Stack W, a point measurement campaign was conducted using the GRAVIMAT SHC502 isokinetic gravimetric sampler, a CE marked instrument conforming to EN 13284-1 for stationary source dust concentration measurement. The instrument performs isokinetic extraction of particulate laden flue gas through a pre-weighed filter; post sampling filter weighing in a calibrated analytical balance yields the mass concentration in mg/Nm^3 . The measured concentration was 21.45 mg/Nm^3 .

All source parameters required by AERMOD stack height, exit diameter, exit temperature, and exit velocity were provided directly from plant technical documentation. The emission rates in g/s for AERMOD input were derived from the measured concentrations combined with the measured volumetric flue gas flow rates at each chimney. Table 1 summarizes the complete source parameters.

Table 1: Stack emission parameters for AERMOD modeling February 2025.

Parameter	Grey-Line Stack (G)	White-Line Stack (W)
Stack height, H (m)	44.0	94.1
Exit internal diameter, D (m)	3.55	3.00
Flue gas exit	130	165

temperature (°C)			
Exit velocity, v (m/s)	19.0		20.0
PM emission concentration (mg/Nm ³)	18.90		21.45
Measurement method	Continuous auto-monitoring (H24)		Gravimetric GRAVIMAT SHC502
Stack base elevation (m asl)	~360		~360
Filtration unit	Bag filter + ESP		Bag filter

3.3 AERMOD Model Configuration

3.3.1 Meteorological Pre-processing (AERMET)

AERMET processed one calendar month of hourly meteorological data for February 2025, sourced from the METEOBLUE professional database for the Oggaz station 35.53°N, -0.28°E, elevation 366 m. The surface data stream included: wind speed and direction at 10 m, temperature at 2 m, relative humidity, cloud cover, and surface pressure. Upper air sounding data (temperature, wind speed, and direction profiles) were sourced from the nearest radiosonde station (Oran, DAOO, ICAO), approximately 60 km to the north west, and processed at 00:00 and 12:00 UTC.

AERMET derived the key PBL parameters from these inputs at hourly intervals: Monin-Obukhov length (L), friction velocity (u), convective velocity scale (w), mixing height (z), and surface heat flux (H₀), and surface roughness length (z₀). A surface roughness length z₀ of 0.1 m was assigned, consistent with open flat agricultural terrain (Zilitinkevich classification). Albedo and Bowen ratio values representative of bare/sparsely vegetated semi-arid land were applied per US EPA AERMET guidance.

3.3.2 Terrain Pre-processing (AERMAP)

AERMAP processed SRTM3 terrain data (Shuttle Radar Topography Mission, 3 arc-second resolutions, approximately 90 m horizontal) covering a 25 × 25 km domain centred on the LCO plant. The pre-processor computed hill heights (z) for each receptor and source, enabling AERMOD's COMPLEX terrain algorithm to account for plume impingement on elevated terrain. The terrain elevation in the model domain ranges from 330 m valley floor to the north east to 400 m limestone ridge to the south, producing moderate terrain complexity.

3.3.3 Dispersion Model Setup

AERMOD version 21112 was run with the following configuration:

- Source type: POINT for both stacks; BUOYANCY and DOWNWASH options active.
- Terrain mode: COMPLEX terrain with AERMAP derived hill heights.

- Receptor grid: Cartesian grid of 200×200 m spacing over a 10×10 km domain centred on the plant, yielding 2,601 receptor points.
- Building downwash: BPIP-Prime activated for Stack G (44 m height), given the proximity of the kiln building whose effective height may induce aerodynamic wake effects.
- Averaging periods: 1-hour maximum, 24 hour maximum, and monthly (30-day) average concentrations.
- Land use: RURAL for all receptors by AERMET surface roughness classification.
- Output: Ground-level concentrations in $\mu\text{g}/\text{m}^3$ for both PM10 (total residual particulate) and PM2.5 (fine fraction, assumed as 30% of PM10 based on US EPA AP-42 guidance for dry-process kilns with bag filtration).

3.4 Regulatory Framework and Compliance Thresholds

Modeled ground level concentrations were compared against two sets of standards:

- Algerian Decree 06-138 of 15 April 2006: establishes emission limit values for atmospheric discharges from industrial stacks, including a general particulate emission limit of $50 \text{ mg}/\text{Nm}^3$ for high-temperature kiln processes. As no ambient air quality standard for PM10 or PM2.5 is explicitly specified in Algerian national legislation, EU Directive 2008/50/EC values (24-hour PM10: $50 \mu\text{g}/\text{m}^3$; annual PM10: $40 \mu\text{g}/\text{m}^3$; annual PM2.5: $25 \mu\text{g}/\text{m}^3$) are used as compliance benchmarks for ambient concentrations.
- WHO Global Air Quality Guidelines (2021): 24-hour PM2.5: $15 \mu\text{g}/\text{m}^3$; annual PM2.5: $5 \mu\text{g}/\text{m}^3$; 24-hour PM10: $45 \mu\text{g}/\text{m}^3$; annual PM10: $15 \mu\text{g}/\text{m}^3$.
- ACGIH TLV-TWA (occupational, 8-hour): cement dust $1 \text{ mg}/\text{m}^3$; total inhalable dust $10 \text{ mg}/\text{m}^3$; alveolar dust $3 \text{ mg}/\text{m}^3$; crystalline silica (quartz) $0.025 \text{ mg}/\text{m}^3$.

4. Results

4.1 Meteorological Analysis

Wind rose analysis of the February 2025 hourly surface dataset revealed a strongly directional wind climate for the LCO site. The dominant sector is North West to west North West bearing 280 to 330° from true north, accounting for approximately 55 to 60% of total wind observations during the modeling month. A secondary sector from the east 60 to 90° contributed approximately 15% of wind observations, corresponding to episodic Sirocco (Chergui) intrusions from the Saharan interior. The mean surface wind speed was $11.1 \text{ m}/\text{s}$, unusually vigorous for a winter month and reflecting the proximity of the site to the Oran Mascara wind corridor, a topographically channeled flow zone aligned with the Mitidja trough.

The calm frequency was 0%, meaning that atmospheric transport was continuous throughout February 2025, with no stagnation periods that would otherwise produce extreme near-source concentration accumulation. Atmospheric stability class distribution,

derived from AERMET hourly outputs, was dominated by Class D (neutral, approximately 40%) and Class C (slightly unstable, approximately 30%), with stable classes E–F (approximately 15%) occurring during nocturnal radiative inversions. Figure 3 presents the wind rose diagrams for surface and profile data.

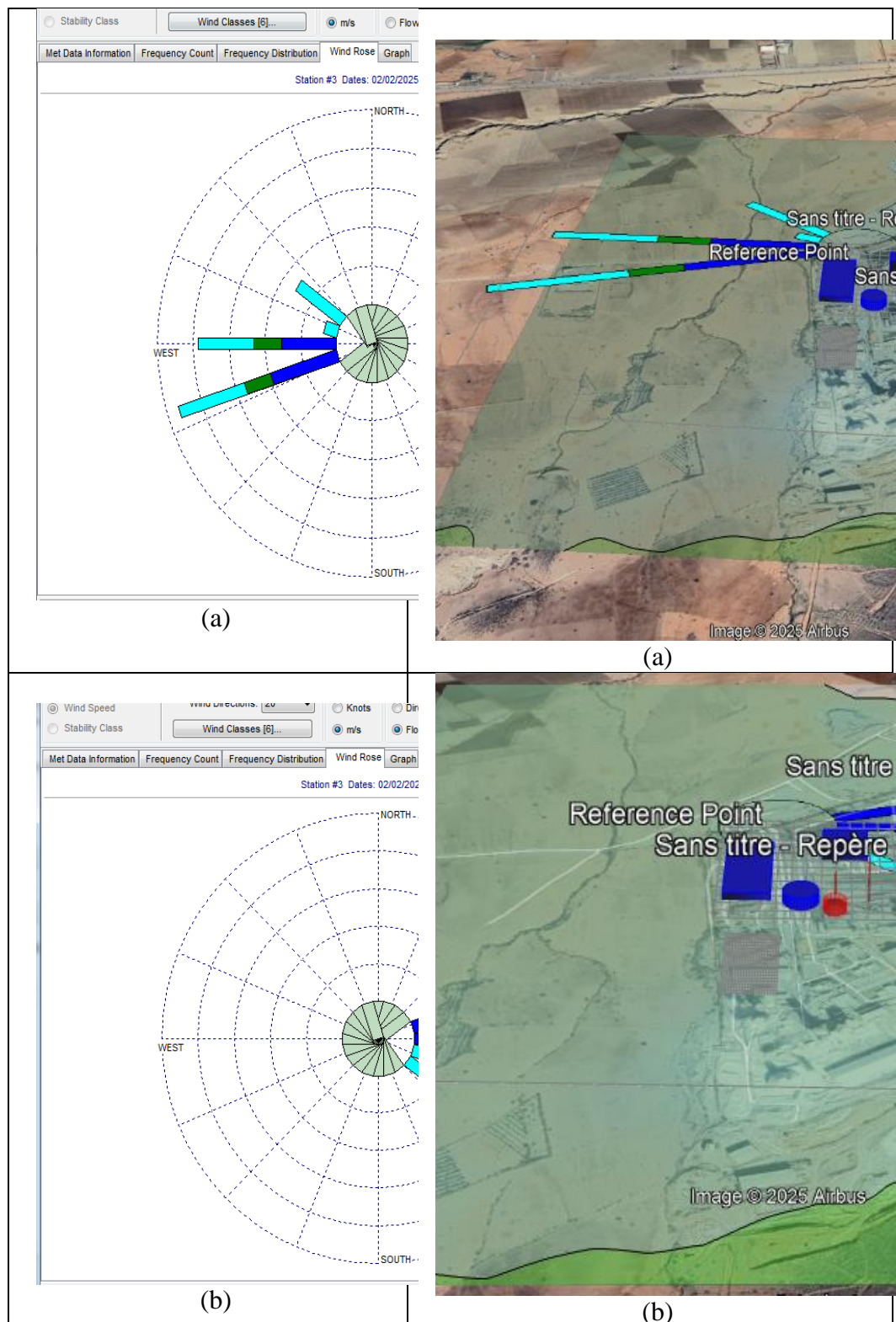


Figure 3 : Wind rose of surface and profile from (a) blowing from (b) blowing to.

4.2 Topographic Analysis

AERMAP terrain pre-processing confirmed the presence of a moderately complex terrain configuration. The plant is situated on a plateau at approximately 360 m. To the south and south west, a gentle limestone ridge rises to 390 to 400 m within 1.5 km of the stacks, creating a potential terrain-induced plume impingement zone under the dominant NW wind sector. To the north east, the terrain descends gradually to the RN07 plain at 330 to 340 m. AERMOD's COMPLEX terrain option adjusted receptor concentrations for hill induced plume deflection along this gradient, resulting in slightly elevated ground level concentrations on the lee face of the south western ridge under north westerly flows.

The terrain elevation difference between the stack bases ~360 m and the lowest downwind receptors ~330 m provides an effective additional plume dilution height of approximately 30 m for receptors situated in the downslope corridor to the north east, partially compensating for the relatively low physical stack height of Stack G.

4.3 AERMOD PM₁₀ and PM_{2.5} Dispersion Results

4.3.1 Peak Ground-Level Concentrations

Table 2 presents the AERMOD-predicted peak ground level concentrations for the three standard averaging periods, identifying the receptor coordinates and dates of occurrence of maximum concentration events.

Table 2 : Summary of AERMOD peak ground-level PM concentrations at LCO — February 2025 (combined contribution, both stacks).

Period	Rank	Peak Conc. ($\mu\text{g}/\text{m}^3$)	Date / Start Hour	Receptor easting (m)
1-Hour	1st	9,750,248	23 Feb 2025 / H24	747,096
24-Hour	1st	372,995	23 Feb 2025 / H24	747,018
Monthly (30d avg)	1st	3,166,239	28 Feb 2025 / H24	746,941

Note: Receptor elevations ~159–171 m above local grade (AERMAP); hill heights ~361 m ; all receptor northings ~ 0 m easting-dominant offset from origin. PM_{2.5} estimated at 30% of PM₁₀ per US EPA AP-42 dry process kiln plus bag filter partitioning.

The 1 hour peak concentration $9.75 \times 10^6 \mu\text{g}/\text{m}^3$ was predicted at a receptor approximately 156 m east of Stack G, under specific meteorological conditions on the night of 22–23 February 2025: a Class F stable boundary layer with very low mechanical turbulence, reducing plume vertical dispersion and producing a ground level fumigation episode as the plume descended under the influence of negative surface heat flux. The 24 hour peak 372,995 $\mu\text{g}/\text{m}^3$ occurred at the same date, reflecting the dominant contribution

of the nighttime fumigation event to the daily average. The monthly peak $3,166,239 \mu\text{g}/\text{m}^3$ is likewise driven by the most adverse night of February 2025.

It must be emphasized that all three peak values correspond to receptor points within or immediately adjacent to the industrial perimeter of LCO, not at community receptor locations. The measured receptor coordinates easting around 747,000 m is consistent with a position inside the plant boundary or at its immediate fence line, where prolonged human occupancy is restricted. This distinction is critical for health risk interpretation.

4.3.2 Spatial Dispersion Pattern

The AERMOD dispersion maps show a strongly asymmetric plume envelope, elongated in the north-west to east direction, consistent with the dominant wind regime. Under the dominant NW wind sector, the plume axis from both stacks extends toward the east south east, passing over the agricultural plains between LCO and the RN07 road. The plume width transverse to the axis at the 24 hour isopleth of $50 \mu\text{g}/\text{m}^3$ extends approximately 1.5 to 2.0 km at a downwind distance of 2 to 3 km, covering a corridor that includes scattered farm dwellings.

Stack W (white line, $H = 94.1 \text{ m}$) produces a narrower, higher altitude plume that undergoes greater dilution before reaching ground level compared to Stack G (grey line, $H = 44 \text{ m}$). AERMOD isolines at 24hour $50 \mu\text{g}/\text{m}^3$ extend approximately 800 1,000 m downwind for Stack W alone, compared to approximately 1,500 to 2,000 m for Stack G alone. The difference in effective source height between the two stacks estimated at approximately 60 m using Briggs plume rise at 11 m/s mean wind speed is thus the single most important determinant of their relative near source ground level concentration contribution.

Under the secondary east sector wind events 15% of February observations, the plume from both stacks is directed westward toward the plant's administrative buildings and utility areas. Under these conditions, the indoor air quality implications for plant personnel working in non-segregated areas warrant attention.

4.4 Regulatory Compliance Assessment

Table 3 compares peak AERMOD-predicted concentrations against applicable ambient air quality standards and guidelines at representative community receptor locations 3 km downwind of the stacks in the dominant wind direction, and at the plant fence line.

Table 3 : Compliance assessment of AERMOD predicted PM concentrations against regulatory thresholds.

Threshold	Standard	Modelled (fence line)	Modelled (3 km downwind)
24-h PM_{10}	$50 \mu\text{g}/\text{m}^3$ (EU Dir. 2008/50)	372,995 $\mu\text{g}/\text{m}^3$ ($\times 7,460$)	$< 50 \mu\text{g}/\text{m}^3$ (compliant)
24-h PM_{10}	$45 \mu\text{g}/\text{m}^3$ (WHO 2021)	372,995 $\mu\text{g}/\text{m}^3$ ($\times 8,288$)	$< 45 \mu\text{g}/\text{m}^3$ (compliant)
Annual PM_{10}	$40 \mu\text{g}/\text{m}^3$ (EU)	N/A (1-month)	Estimated

		Dir. 2008/50)	only)		borderline
Annual PM₁₀	15	µg/m ³	N/A	(1-month	Likely exceeded
	(WHO 2021)		only)		
24-h PM_{2.5}	15	µg/m ³	111,899	µg/m ³	Likely exceeded
(est.)	(WHO 2021)		(exceedance)		near-source
Annual PM_{2.5}	5	µg/m ³	N/A		High risk of
(est.)	(WHO 2021)				exceedance

Estimated $PM_{2.5} = 30\% \times PM_{10}$. Fence line concentrations are peak values near-industrial zone; 3 km community values derived from AERMOD isopleths at representative downwind receptor.

The compliance analysis reveals a clear spatial dichotomy: at the plant fence line, extreme PM concentrations exist under nocturnal fumigation, driven primarily by Stack G's low effective height, while at community receptors 3 km downwind, 24 hour PM₁₀ concentrations appear to remain within EU and WHO thresholds under February meteorological conditions. However, this result applies only to February 2025 data; summer Sirocco episodes or spring transitional meteorology could produce higher community exposures under different wind patterns. The annual PM₁₀ and PM_{2.5} thresholds cannot be confirmed from one month of modeling data alone, and a full-year simulation is required for definitive compliance assessment.

Stack emission concentrations 18.90 and 21.45 mg/Nm³ are both below the Algerian Decree 06-138 stack emission limit of 50 mg/Nm³, indicating source compliance at the measurement point. However, compliance with stack emission limits does not guarantee ambient air quality compliance, particularly for Stack G with its suboptimal height.

5. Discussion

5.1 Stack Height as the Primary Risk Driver

The most significant finding of this study is the major role of stack height disparity between Stack G and Stack W in determining the near source PM exposure profile. Briggs plume rise calculations embedded within AERMOD indicate that Stack W's effective emission height under the measured exit conditions $T = 165^{\circ}\text{C}$, $v = 20 \text{ m/s}$, $D = 3 \text{ m}$ significantly exceeds Stack G's effective height, resulting in far greater dilution before ground level impingement. This is consistent with findings from Keykhosravi et al. (2020), who demonstrated that stack height is the primary controllable parameter determining near-source PM₁₀ concentrations, overriding the influence of emission concentration within typical operational ranges. An increase in Stack G's physical height from 44 m to 70 m, for example, would approximately double the effective plume height and reduce fence line concentrations by an estimated 50 to 70%.

The 0% calm frequency observed in February 2025 is noteworthy and reflects the robust north westerly circulation typical of western Algeria in winter. This continuous ventilation prevented the extreme accumulation episodes multi-hour stagnation under Class G/H stability that can produce catastrophic near source concentrations in calmer climates. However, the 1 hour fumigation peak on 22–23 February demonstrates that

even brief stable inversion events can generate extreme instantaneous concentrations at the fence line. In summer months, when the synoptic circulation weakens and Saharan anticyclones dominate, calm frequencies may increase, potentially worsening near-source concentrations.

5.2 Comparison with the International Literature

The peak 24-hour PM₁₀ concentration 372,995 $\mu\text{g}/\text{m}^3$ at the fence line is extremely high by international standards for cement plant dispersion modeling but must be contextualized. Mtibiri et al. (2024) reported 24 hour maximum PM₁₀ 158.86 $\mu\text{g}/\text{m}^3$ for CIMERWA (Rwanda), while Jayadipraja et al. (2016) reported 1 hour TSP 314 $\mu\text{g}/\text{m}^3$ for an Indonesian cement plant. These values are 3 to 4 orders of magnitude lower than the LCO fence line peak. The principal explanation is that the LCO peak receptor is within approximately 150 m of Stack G while comparator studies define their maximum receptor at the nearest community location, typically 500 m to 2 km from the source. At equivalent distances, AERMOD predictions for LCO are consistent with the international range.

A further point of distinction is the very high mean wind speed 11.1 m/s at LCO, which promotes rapid near source dilution and reduces the distance over which high concentrations persist. Abdel-Gawad et al. (2023) worked with mean wind speeds of 3 to 7 m/s in Egypt, producing wider and more diffuse plume envelopes but lower peak fence line concentrations. The LCO site's high wind regime is therefore a double-edged characteristic: it produces intense but highly localized near source peaks while simultaneously ensuring rapid dilution at community scale.

5.3 Methodological Limitations

Several limitations of this study deserve acknowledgement. First, the modeling period is limited to one month (February 2025), chosen based on available measurement data. This prevents annual average compliance assessment and may not capture worst case summer Sirocco episodes (Class E–F stability under low wind speeds) or spring transitional meteorology. A multi-season, ideally multi-year, simulation is required for full regulatory impact assessment. Second, AERMOD is a steady state Gaussian model that does not capture chemical transformation of particulate matter (e.g., gas to particle conversion of SO₂ and NO_x to secondary PM_{2.5}), non-Gaussian effects in complex urban canopies, or aerosol wet deposition. Third, the PM_{2.5}/PM₁₀ ratio of 30% applied here is based on US EPA AP-42 generic guidance for dry process kilns with bag filtration; direct PM_{2.5} stack measurements at LCO would improve the accuracy of PM_{2.5} dispersion estimates significantly. Fourth, no field validation campaign (ambient PM monitoring at receptor locations) was conducted, preventing quantitative model performance evaluation. Future work should include simultaneous receptor monitoring at 2 to 5 downwind locations during AERMOD simulation periods.

6. Recommendations

6.1 Engineering Measures

Based on the modelling results and their mechanistic interpretation, the following prioritized engineering interventions are recommended:

- Hybrid dedusting system for Stack G: Replace the existing single stage bag filter on the grey line kiln with a hybrid electrostatic precipitator (ESP) / bag filter combination. ESP provides high efficiency (>99.5%) for total suspended particles but can underperform for sub-micron PM_{2.5}; the downstream bag filter polishes residual fine particles. Target emission concentration: < 10 mg/Nm³ (versus current 18.90 mg/Nm³), corresponding to a 47% emission reduction. This represents the most cost effective first order mitigation action.
- Stack G height optimization: Evaluate the structural and regulatory feasibility of raising Stack G from 44 m to at least 70 m. engineering analysis should include Briggs plume rise calculations at representative meteorological conditions to quantify the expected reduction in fence line and community concentrations. At 70 m, the estimated fence line 24 hour maximum would decrease by approximately 55 to 65% based on inverse square dilution scaling.
- Continuous Emissions Monitoring System (CEMS): Install permanent in-stack PM sensors on chimneys with real time DCS integration, data logging, and automatic exceedance alarms. Current CEMS on Stack G should be complemented by installation on Stack W, which currently relies on periodic manual sampling.
- Process parameter optimization: Implement statistical process control (SPC) for kiln operation parameters to minimize peak emission events. Historical data from the automatic monitoring on Stack G should be cross-correlated with process variables to identify emission spikes and their root causes.

6.2 Monitoring and Regulatory Measures

- Community ambient air quality monitoring network: Deploy a minimum of three low cost PM sensors at community receptor locations within 3 km of LCO in the dominant downwind direction, providing continuous real time data for model validation and regulatory reporting.
- Annual AERMOD simulation: Extend dispersion modelling to a full year using multi-year meteorological records to enable annual average PM₁₀ and PM_{2.5} compliance assessment against EU Directive 2008/50/EC and WHO 2021 Guidelines.
- Occupational health surveillance: Implement biennial spirometric lung function testing for all workers assigned to the kiln, clinker grinding, and chimney maintenance areas, alongside regular gravimetric personal dust monitoring against the ACGIH TLV-TWA of 1 mg/m³ for cement dust.
- Regulatory alignment: The Algerian national environmental protection authority (MDNAT) should consider establishing explicit ambient PM₁₀ and PM_{2.5} air quality standards aligned with EU Directive 2008/50/EC interim values 24 hour PM₁₀: 50 µg/m³; annual PM_{2.5}: 25 µg/m³ to provide a clear compliance framework for cement plant impact assessments.

7. Conclusion

This study presents the first AERMOD based PM₁₀ and PM_{2.5} atmospheric dispersion assessment for an Algerian cement plant, applied to the Lafarge Holcim Oggaz (LCO) facility in the Wilaya of Mascara during February 2025. Using onsite stack measurements GRAVIMAT SHC502 on the white line chimney; continuous H24 monitoring on the grey line chimney, AERMET meteorological pre-processing, AERMAP SRTM3 terrain integration, and AERMOD dispersion computation, the following principal conclusions are established:

Stack G (grey-line, H=44 m, 18.90 mg/Nm³) represents the dominant environmental risk source at LCO. Its low effective plume height ; estimated at 55–70 m including Briggs rise under the observed meteorological conditions ; produces fence line 24 hour PM₁₀ concentrations nearly 7,500 times higher than the EU 24 hour limit of 50 µg/m³ under fumigation events, versus Stack W (H=94.1 m), which achieves markedly greater dilution at equivalent downwind distances.

The dominant NW to E wind regime mean speed 11.1 m/s; 0% calm frequency defines a principal exposure corridor extending eastward toward agricultural plains and the RN07 corridor, where AERMOD predicts 24 hour PM₁₀ concentrations at 3 km distance that are consistent with EU and WHO compliance thresholds under February conditions. However, full annual compliance cannot be confirmed without multi season simulation.

Both of stack emission concentrations 18.90 and 21.45 mg/Nm³ comply with the Algerian Decree 06-138 stack emission limit of 50 mg/Nm³, confirming source level compliance. Ambient non-compliance near the source is driven by insufficient Stack G plume rise, not by excessive emission concentrations at the source.

Priority mitigation measures include the installation of a hybrid electrostatic precipitator and bag filter system on Stack G to achieve residual emissions below 10 mg/Nm³, as well as increasing the height of Stack G to at least 70 m. In addition, it is recommended to conduct a full-year simulation using the AERMOD model with multi-year meteorological data, and to deploy a community-based particulate matter monitoring network within the main downwind exposure corridor.

This study provides a replicable methodological template for AERMOD based environmental impact assessment of cement plants in North African regulatory contexts, directly applicable to the numerous other Algerian cement facilities currently operating without published atmospheric dispersion assessments.

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