

A STUDY OF PERSONNEL HEALTH EFFECTS ASSOCIATED WITH EXPOSURE TO AIRCRAFT EXHAUST EMISSIONS

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ABSTRACT

Airport staff face potential occupational exposure to emissions from jet engines, which, akin to diesel exhaust emissions, contain nitrogen oxides, sulfur oxides, particulate matter, and volatile organic compounds, with carbon monoxide being the primary pollutant in aircraft exhaust that significantly influences the formation of Carboxyhemoglobin in the bloodstream. This study conducted an experimental investigation to assess the impact of aircraft engine exhaust on the health of ground handling personnel at Hurghada International Airport (HRG) during the year 2023. For this purpose, the air pollution measurements were carried out with two different methods. The total landing and takeoff cycle (LTO) emissions concentration were measured for 8-hours average during 2023 by using air pollution system. From our results, it was found that 32.98 $\mu\text{g}/\text{m}^3$ for NO, 21.2 $\mu\text{g}/\text{m}^3$ for NO₂, 54.2 $\mu\text{g}/\text{m}^3$ for NO_x, 39.2 $\mu\text{g}/\text{m}^3$ for SO₂, 4.94 mg/m³ for CO, 733782.94 $\mu\text{g}/\text{m}^3$ for CO₂, 82.9 $\mu\text{g}/\text{m}^3$ for O₃, 57 $\mu\text{g}/\text{m}^3$ for PM₁₀ and 17.9 $\mu\text{g}/\text{m}^3$ for PM_{2.5}. The recorded levels adhered to the air quality limit values established by law no. (4/2004) of Egypt and its amendment. The medical test was applied to 30 personnel who have direct contact with aircraft during 8 hour a day by using "RAPID Point 500" device that measure the gases in the blood. The results showed general low levels of Carboxyhemoglobin in personnel's blood, with maximum value was 0.8 % COHb (Carboxyhemoglobin), while the biological threshold for Carboxyhemoglobin tolerance is to 2 % COHb. Furthermore, increasing other familiar symptoms among ground handling personnel as general fatigue and headache. The air dispersion modelling showed that the concentration of CO would increase to 13 mg/m³ over the reference value 10 mg/m³ at 2050, which increase the percentage of Carboxyhemoglobin diseases among airport's personnel.

Keywords: health; aircraft; air quality; air pollution; airport, HRG: Hurghada International Airport

INTRODUCTION

Aircraft exhaust emissions represent a significant source of air pollution, particularly in airport environments where ground staff are exposed to high concentrations of toxic pollutants. These emissions contain a mixture of harmful substances, including particulate matter (PM), nitrogen oxides (NO_x), volatile organic compounds (VOCs), and carbon monoxide (CO) (Keuken et al., 2015; Burdon et al., 2023).

Vehicles such as aircraft, cars, and trucks operating at airports produce emissions as a result of fuel combustion. The emission of aircraft engines consisted of carbon dioxide (CO₂), which constitutes approximately 70% of the total exhaust, while water vapor (H₂O) makes up about 30%. The remaining less than 1% of the exhaust consists of pollutants, including nitrogen oxides (NO_x), sulfur oxides (SO_x), carbon monoxide (CO), partially combusted or unburned hydrocarbons (HC), particulate matter (PM), and various trace compounds (FAA, 2015). Typically, approximately 10% of aircraft emissions of pollutants occur at altitudes below 3,000 feet above ground level, while the remaining 90% are emitted at higher elevations. However, carbon monoxide (CO) and hydrocarbons (HCs) do not follow this trend, as they are released when aircraft engines operate at their lowest combustion efficiency, particularly during ground operations. Consequently, around 30% of these pollutants are emitted below 3,000 feet, with 70% occurring at higher altitudes (European Union & EFTA, 2013).

In addition to emissions from aircraft, other contributors to aviation-related emissions include ground support vehicles and airport access traffic, which primarily depend on fossil fuels. This group encompasses vehicles that transport passengers to and from the airport, shuttle buses, and ground support equipment (GSE) that services the aircraft. Additional sources of emissions at airports consist of auxiliary power units (APUs) that provide electricity and air conditioning to stationary aircraft, stationary power sources, and construction machinery operating on-site (ICAO Doc. 9889, 2020).

Among these pollutants, carbon monoxide is particularly concerning due to its ability to bind with hemoglobin, forming carboxyhemoglobin (COHb), which reduces the oxygen-carrying capacity of blood (Raub et al., 2000). As a result, chronic exposure to CO and other

pollutants can lead to severe health complications, including respiratory diseases, cardiovascular disorders, and neurological impairments (Wang et al., 2023; Chen et al., 2017). Despite increasing awareness of air pollution's impact on public health, research specifically focusing on the occupational hazards posed by aircraft emissions remains limited. There is a pressing need for further investigation, particularly regarding the long-term effects of CO exposure on neurological health and cognitive function. Additionally, gaps remain in understanding the cumulative impacts of mixed pollutant exposure and the effectiveness of mitigation strategies in high-risk environments (Barrett et al., 2010; Anderson et al., 2012).

One of the primary concerns related to aircraft emissions is the impact on respiratory health. Numerous studies have demonstrated that exposure to fine and ultrafine particulate matter (UFPs) emitted from aircraft engines contributes to lung inflammation and chronic respiratory diseases (Mazaheri et al., 2011; Int Panis et al., 2017). Fine particulate matter, particularly particles smaller than 2.5 micrometers (PM_{2.5}), can penetrate deep into the lungs, causing oxidative stress, inflammation, and exacerbation of conditions such as asthma and chronic obstructive pulmonary disease (COPD) (Keuken et al., 2015; Pope et al., 2009; Wang et al., 2023). Additionally, VOCs present in aircraft exhaust have been linked to airway irritation and long-term damage to lung tissues ((Bendtsen et al., 2021). Emerging research has also linked chronic exposure to aircraft pollutants with impaired lung function and increased susceptibility to respiratory infections (Schraufnagel et al., 2019). Given the continuous exposure of airport personnel to these pollutants, it is imperative to assess their long-term health risks and implement effective mitigation strategies.

Beyond respiratory issues, cardiovascular health is another area of concern for individuals exposed to aircraft emissions. Studies have shown that chronic exposure to NO_x and fine particulate matter is associated with an increased risk of cardiovascular diseases, including hypertension, atherosclerosis, and myocardial infarction (Pope et al., 2009; Mills et al., 2009; Brook et al., 2010). Carbon monoxide exposure further exacerbates these risks by reducing the oxygen supply to the heart and other vital organs, leading to ischemic events (Garcia et al., 2020). Elevated COHb levels have been documented among workers in high-exposure environments, correlating with symptoms such as dizziness, headaches, and cognitive

impairments (Cavallo et al., 2006). Recent studies also suggest a potential link between prolonged CO exposure and endothelial dysfunction, which may accelerate the progression of cardiovascular diseases (Garcia et al., 2020; Poursafa et al., 2011). Furthermore, COHb levels have been used as biomarkers in occupational health assessments to evaluate the severity of CO poisoning and its correlation with cardiovascular risk factors (Anderson et al., 2012). Another critical factor influencing cardiovascular health is the role of paraoxonase 1 (PON1), an enzyme involved in reducing oxidative stress and protecting against lipid peroxidation (Mackness et al., 1998; Liao et al., 2024; Costa et al., 2013). Research suggests that reduced PON1 activity due to chronic exposure to pollutants, including CO and fine particulate matter, may contribute to increased cardiovascular disease risk among exposed workers (Huen et al., 2018; Schraufnagel et al., 2019; Wang et al., 2023).

In addition to respiratory and cardiovascular impacts, emerging evidence suggests that chronic exposure to aircraft exhaust emissions may have genetic and neurotoxic effects. Occupational exposure studies have identified increased oxidative stress markers and DNA damage in workers frequently exposed to emissions from aircraft engines (Cavallo et al., 2006). Oxidative stress plays a crucial role in the pathogenesis of neurodegenerative diseases, as prolonged exposure to reactive oxygen species can lead to neuronal damage and cognitive decline (Costa et al., 2013). Furthermore, exposure to CO and other pollutants has been linked to delayed neurological deterioration, affecting memory, concentration, and motor functions. Studies have shown that CO exposure can disrupt mitochondrial function in brain cells, contributing to neuroinflammation and long-term cognitive impairments (Fu et al., 2022; Kalenik et al., 2025). Recent research has expanded on this by demonstrating CO's role in altering synaptic plasticity and neurotransmitter release, which could contribute to conditions such as Parkinson's disease and Alzheimer's (Poursafa et al., 2011; Anderson et al., 2012). Additionally, PON1 has been investigated for its neuroprotective role, as it mitigates oxidative damage and modulates inflammation in neural tissues (Huen et al., 2018; Mackness et al., 1998; Liao et al., 2024; Brook et al., 2010). Reduced PON1 activity, potentially induced by exposure to CO and other pollutants, has been linked to an increased susceptibility to neurodegenerative conditions (Schraufnagel et al., 2019).

The persistence of CO in tissues, even after COHb levels in the blood return to normal, underscores the potential for long-term health consequences among airport personnel, necessitating proactive monitoring and intervention. Carbon monoxide does not react very quickly with hemoglobin; red blood cells shaken within an atmosphere of 100% carbon monoxide take approximately 20 minutes to reach full saturation, with only about 25% of hemoglobin being converted to COHb after the first five minutes (Raub et al., 2000). As a result, inhaled carbon monoxide dissolves quickly in plasma, allowing it to reach susceptible organs before fully binding with hemoglobin, where it disrupts cellular enzyme function and contributes to toxicity (Rose et al., 2017). This highlights the importance of rapid medical intervention to minimize CO exposure effects.

Hurghada International Airport (IATA: HRG, ICAO: HEGN) is the international airport of Hurghada in Egypt. It is located inland, 5 km (3.1 mi) southwest of El Dahar, the city centre of Hurghada. It is the second busiest airport in Egypt after Cairo International Airport, one of the busiest airports in the Middle East.

The airport currently has two passenger terminals: Terminal 1 and Terminal 2.

The airport currently has three aprons (Ministry of Civil Aviation ,2022).

Apron Surface and Strength:

Apron1 Dimensions: 700 x 300M

Capacity: 23 different sizes of aircraft

Apron2

Capacity: 28 different sizes of aircraft

Apron3

Capacity: 3 different sizes of aircraft

There are 33 taxiways

There are two Runways:

34R-16L with dimensions 4000 M X 45 M

34L-16R with dimensions 4000 M X 60 M (Ministry of Civil Aviation ,2022).

This research seeks to examine the impact of aircraft engine exhaust specially carbon monoxide (co) on the health and safety of personnel working at the airfield of Hurghada International Airport.

The aim of this study is to determine the impact of aircraft engines exhaust on the public health and safety of personnel at the airfield of Hurghada International Airport by studying the emissions from aircraft engines in the movement area at airside. In addition, to assess the impact of these pollutants on the health of workers and the effects of their impact on safety level at the airport. Proposals, corrective and preventive actions to reduce those risks to health were also suggested.

MATERIALS AND METHODS

1. Duration of the study

This study conducted by determining the concentration of pollutants in the air at Hurghada International Airport and studying the numbers and types of aircraft during the period from 2020 to 2023, the concentration of these pollutants, and their impact on the health of aviation workers at Hurghada airport airfield.

2. Methodology for measurements of air pollution at HRG, as the following:

The parameters of Nitrogen Dioxide (NO₂), Nitric Oxide (NO), Nitrogen Oxides (NO_x), Sulphur Dioxide (SO₂), Carbon Monoxide (CO), Suspended Particulate Matter (PM₁₀) and Ozone (O₃), have been measured by air quality monitoring station that located at the HRG's airside.



Figure (1): the air quality monitoring station at HRG

- 2.1 Study the future concentration of pollutants by air dispersion modelling, as the following:
- 2.1.1 Calculation of the number of Air traffic density at Hurghada international airport during the period from 2020 to 2023.
 - 2.1.2 Determining different types of aircraft during the year to know the most models at the airport.
 - 2.1.3 Local weather data such as wind speed, direction, and temperature are entered by metrological department at HRG, which affect how pollutants spread in the air.
 - 2.1.4 Air dispersion modelled using AEDT (Aviation Environmental Design Tool), which perform modelling studies ranging from studying a single flight scenario to multiple scenarios at the regional and international levels.
 - 2.1.5 Air is modeled using AEDT, a comprehensive, multi-level air dispersion modeling system that simulates fundamental physical processes in the atmosphere and produces contour maps for air emission estimates using a wide range of meteorological and modeling scenarios to study the environmental impact of aircraft, such as estimating fuel consumption, emissions, noise, and the negative effects of emissions.
 - 2.1.6 AEDT calculates air emissions based on the AERMOD computational engine, which integrates the US Environmental Protection Agency (EPA) ISCST, ISC-PRIME, and AERMOD models into a single interface.
 - 2.1.7 A comprehensive multi-level air dispersion modelling system that simulates the basic physical processes in the atmosphere and produces contour maps for air emissions estimates A comprehensive array of meteorological and modeling scenarios is utilized to examine the environmental effects of aircraft, including the assessment of fuel consumption, emissions, and the adverse consequences associated with those emissions.
 - 2.1.8 The data and information used in the model inputs were obtained from the environmental department at Hurghada international airport, and the operations were entered during 24 hours to model the daily operation of the airport and study its impact on the surrounding areas.

3 Methodology for Measuring Carboxyhemoglobin Levels in the Blood of Airport Personnel

3.1 Selection of Exposed Samples for Medical Testing

The exposed group was selected based on the following criteria:

- 3.1.1:** Employment at the airport for more than 10 years.
- 3.1.2:** Age range between 30 and 45 years.
- 3.1.3:** Daily exposure to pollutants for a minimum of 8 hours.
- 3.1.4:** Non-smoking status.
- 3.1.6:** Absence of chronic respiratory diseases.
- 3.1.7:** Similar living conditions among participants.

3.2 Selection of Control Samples (Non-Exposed Group)

The control group was selected based on the following criteria:

- 3.2.1:** Age range between 30 and 45 years.
- 3.2.2:** Non-smoking status.
- 3.2.4:** Absence of chronic respiratory diseases.
- 3.2.5:** Similar living conditions among participants.

3.3 Sample Size

A total of 30 ground-handling personnel with direct exposure to aircraft operations and 20 non-exposed persons were selected for the study.

3.4 Sample Collection

Blood samples were collected by a specialized medical laboratory under standardized conditions.

3.5 Measurement of Carboxyhemoglobin (COHb) Levels

Carboxyhemoglobin levels in the blood of exposed personnel were measured using the "**RAPID Point 500**" blood gas analyzer.

3.6 Measurement of Oxygen Saturation (s O₂) Levels

Blood oxygen saturation levels were assessed using the same "**RAPID Point 500**" device.

3.7 Data Analysis and Comparison

The obtained results were analyzed and compared with reference values to assess the impact of pollutant exposure on carboxyhemoglobin and oxygen saturation levels.

4 Questionnaires are conducted for exposure to aircraft engines exhaust to determine the symptoms the worker may suffer after the end of the working periods on airside.

5 Statistical analysis

The Pearson Chi-Square Test & Fisher's Exact Test was used. Data was analyzed using SPSS version 21. Data was considered significant at $p \leq 0.05$.

RESULTS

1- Air traffic density:

The annually aircraft count data from 2010 to 2023 reveal several notable trends and potential underlying drivers:

Early- Decade Decline (2010–2013):

Following a peak of 56 512 aircraft in 2010, the fleet size fell steadily to 39 145 by 2013. This contraction may reflect post- recession airline retirements, deferred aircraft deliveries, and fuel price pressures that prompted operators to ground older, less efficient airframes.

Mid- Decade Recovery and Trough (2014–2016):

A modest rebound to 45 484 in 2014 and 44 619 in 2015 suggests improving economic conditions and resumed deliveries. However, 2016 saw an abrupt trough at 24 085—a 46% drop from 2015—which is likely an artefact of reporting changes or fleet accounting (e.g., reclassification of stored versus active aircraft) rather than an actual halving of global capacity.

Pre- Pandemic Expansion (2017–2019):

From 2017 onward, the data show a robust expansion: 35 441 → 46 540 → 51 530. This growth phase corresponds with record- low fuel prices, favorable financing for new aircraft, and the introduction of high- efficiency models (e.g., the Boeing 737 MAX and Airbus A320neo families).

Pandemic Impact (2020):

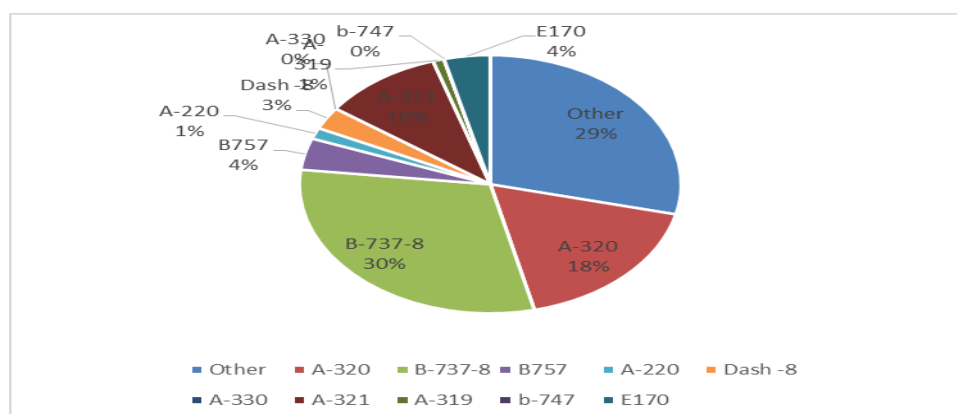
The COVID- 19 crisis precipitated an unprecedented collapse to 16 224 active aircraft—a 68% reduction from 2019—driven by global travel bans, airline bankruptcies, and the mass storage of fleets. This represents the largest single- year contraction in the period.

Post- Pandemic Recovery (2021–2023):

As restrictions eased, the fleet rebounded to 35 400 in 2021, then 48 732 in 2022, and 49 686 in 2023. While approaching pre- pandemic levels by 2023, the slower pace of recovery likely reflects ongoing supply- chain constraints for new deliveries, residual route suspensions, and strategic retirements of older jets.

In 2020, the Boeing 737- 800 and Airbus A320 accounted for 30 % and 18 % of total movements, respectively. Although the B737- 800 share held steady at 30 % in 2021, the A320 proportion dipped slightly to 15 %. By 2022, however, the A320 regained momentum—rising to 21 %—and the B737- 800 climbed modestly to 34 %. A more dramatic realignment emerged in 2023, when the A320 share surged to 31 %, overtaking the B737- 800, which declined to 25 %.

Both the A320 and B737- 800 families are classified as medium- size, single- aisle airliners powered by medium- thrust turbofan engines. Their similar engine characteristics and sortie profiles imply that, despite shifts in relative frequency, the aggregate exhaust emission profile at HRG Airport has remained within a moderate band over the four year period.



There are many different types of aircrafts used HRG, the top 5 aircraft operating at Hurghada international airport for each year starting from 2020 until 2023, as shown below in figure (2), (3), (4), and (5):

Figure (2): shows the number of flights for the top 5 aircraft operating during 2020 at HRG

The top 5 aircraft are Boeing B737-800, Airbus A320, Airbus A321, Boeing B757 and Embraer E170

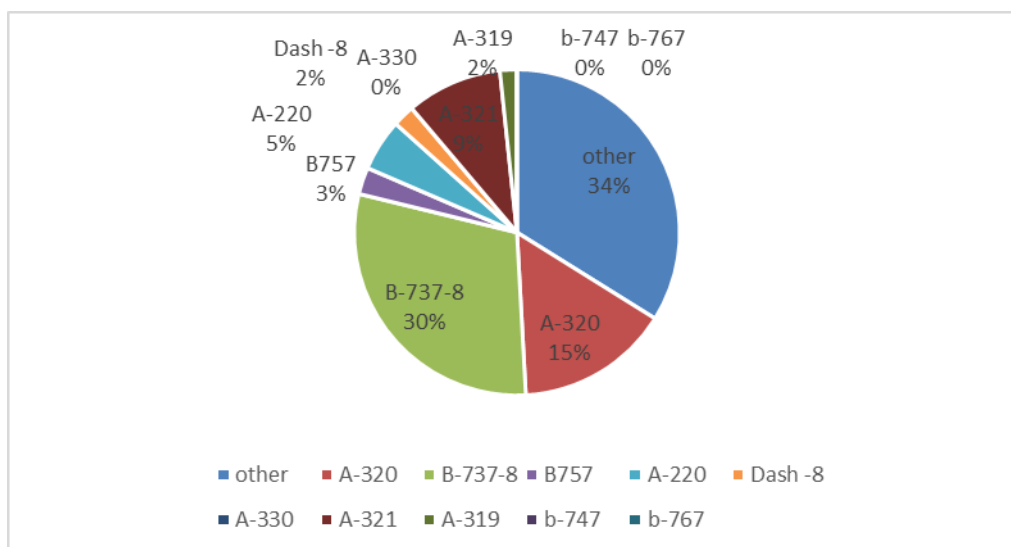


Figure (3): the number of flights for the top 5 aircraft operating during 2021 at HRG

The top 5 aircraft are Boeing B737-800, Airbus A320, Airbus A321, Boeing B757 and Airbus A220

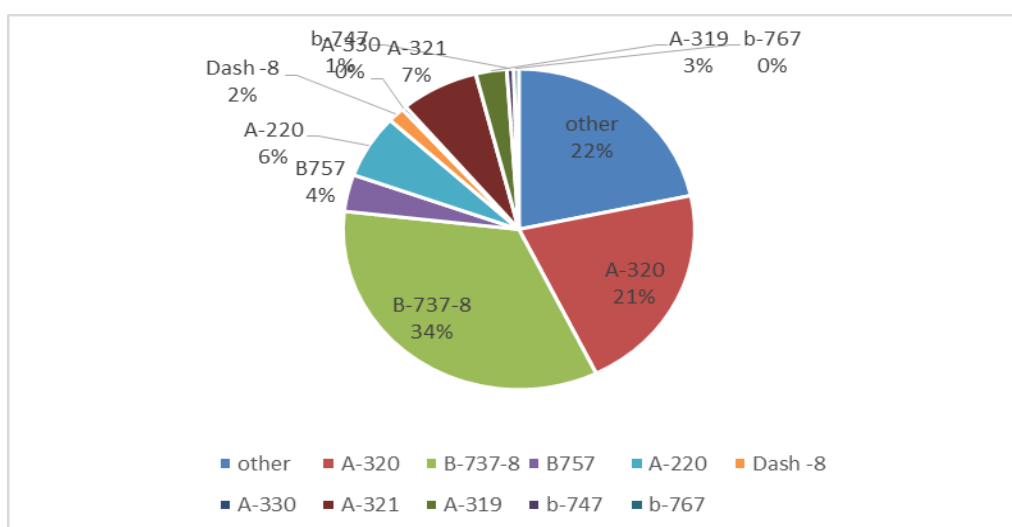


Figure (4): the number of flights for the top 5 aircraft operating during 2022 at HRG

The top 5 aircraft are Boeing B737-800, Airbus A320, Airbus A321, Airbus A220 and Boeing B757

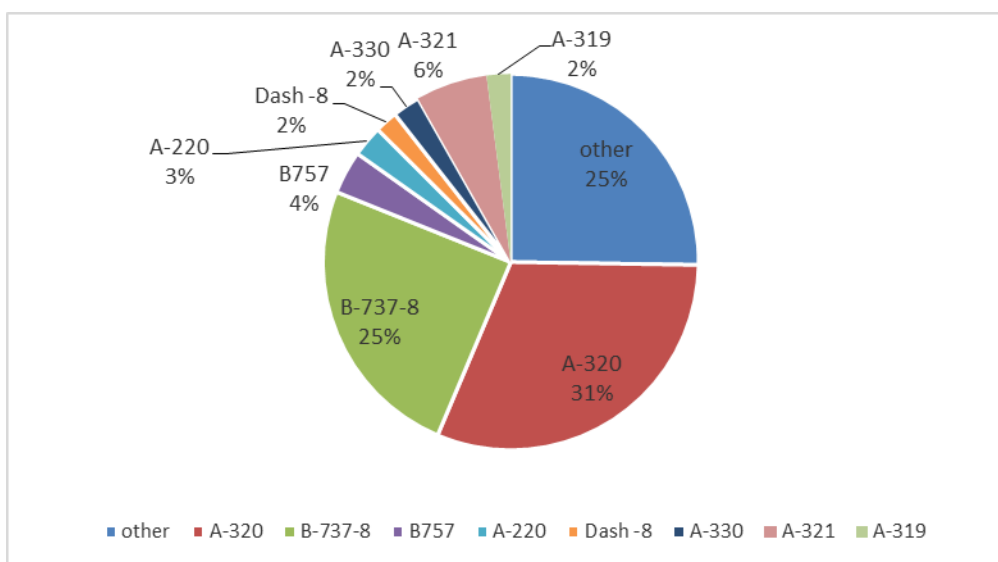


Figure (5) the number of flights for the top 5 aircraft operating during 2023 at HRG

The top 5 aircraft are Airbus A320, Boeing B737-800, Airbus A321, Boeing B757 and Airbus A220

2. Concentrations of atmospheric air pollutant downwind from the runways

2.1 Average concentrations

The air quality monitoring station at HRG were erected and commissioned. The following data has been obtained by this monitoring station, as shown in figure (1). The measurements undertaken by the air quality monitoring station at the airside of HRG during the period from 2020 to 2023, the concentrations shown below in table (1):

Table (2): the concentrations of atmospheric air pollutant measured at HRG

YEARS	CONCENTRATION OF ATMOSPHERIC AIR POLLUTANTS								
	NO ($\mu\text{g}/\text{m}^3$)	NO ₂ ($\mu\text{g}/\text{m}^3$)	NO _x ($\mu\text{g}/\text{m}^3$)	SO ₂ ($\mu\text{g}/\text{m}^3$)	CO (mg/m^3)	CO ₂ ($\mu\text{g}/\text{m}^3$)	O ₃ ($\mu\text{g}/\text{m}^3$)	PM ₁₀ ($\mu\text{g}/\text{m}^3$)	PM _{2.5} ($\mu\text{g}/\text{m}^3$)
2020	1.69	0.69	2.38	1.41	0.73	209298.99	72.14	66.54	21.39
2021	16.67	22.37	39.05	23.09	1.94	705517.91	67.49	43.37	27.91
2022	25.62	19.55	45.18	17.63	0.72	739146.03	75.73	47.76	24.82
2023	32.98	21.24	54.23	39.23	4.94	733782.94	82.99	57	17.9
Average ($\mu\text{g}/\text{m}^3$)	19.24	15.96	35.21	20.34	2.08	596936.5	74.58	53.67	23.00

- NO, NO₂ , NO_x: There has been a gradual increase in the concentrations of these pollutants over the years, especially NO_x (from 2.38 to 54.23).
- SO₂ : Clear fluctuations and a significant increase in 2023 (reaching 39.23 µg/m³).
- CO: Noticeable fluctuations, with a significant increase in 2023 (from 0.72 in 2022 to 4.94).
- CO₂ : A dramatic increase from 2020 (209,000) to over 730,000 µg/m³ over the past three years.
- O₃ (ozone): Gradually rising, to 82.99 µg/m³ at 2023
- PM10 and PM2.5: PM10 increased in 2023 compared to 2021–2022, while PM2.5 decreased in 2023.

3. The air dispersion modelling results

3.1 Meteorology and Climate

The meteorological values in the vicinity of the site as well as upper atmospheric values recorded during the year 2023 for the designated study area.

The surface dataset comprises parameters such as wind speed and direction, temperature, cloud cover, and ceiling height, while the upper atmospheric data includes wind speed, dew point, atmospheric pressure, and measurement level height. The accompanying figure illustrates the prevailing wind direction, derived from the meteorological data from 1: 28 /02/ 2023, indicating a southeast orientation.

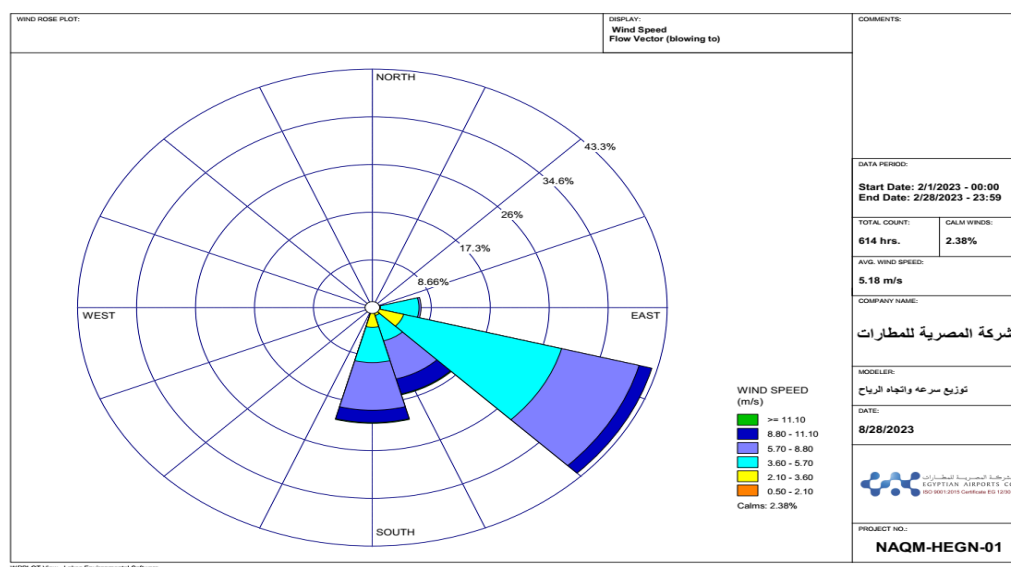


Figure (6): Prevailing wind direction during modelling period from 1: 28 /02/ 2023

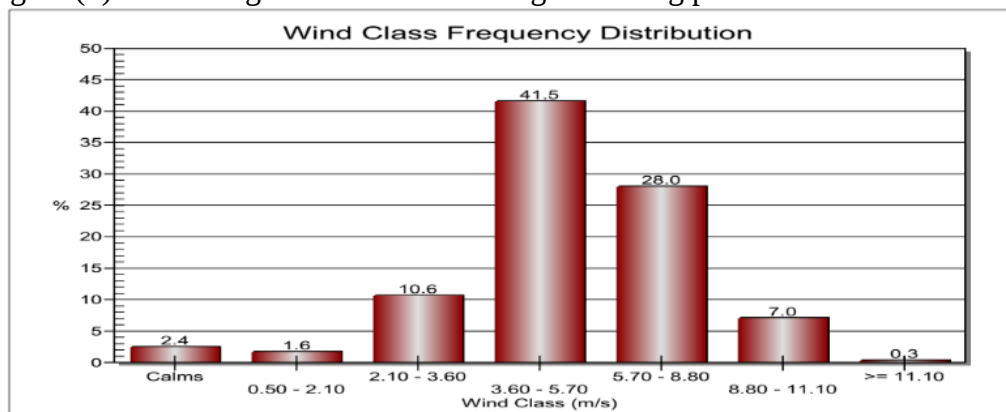


Figure (7): Distribution of wind frequency classes during the dispersion-modelling period from 1: 28 /02/ 2023

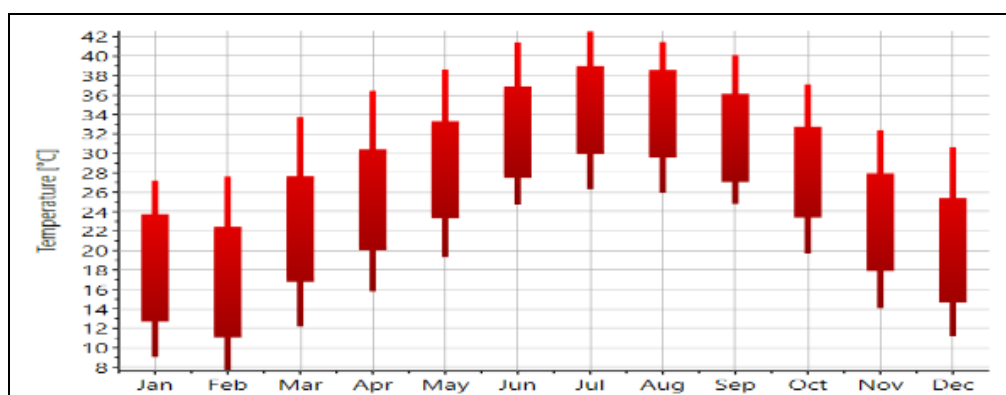


Figure (8): Maximum, minimum and average temperatures at Hurghada international airport at year 2023

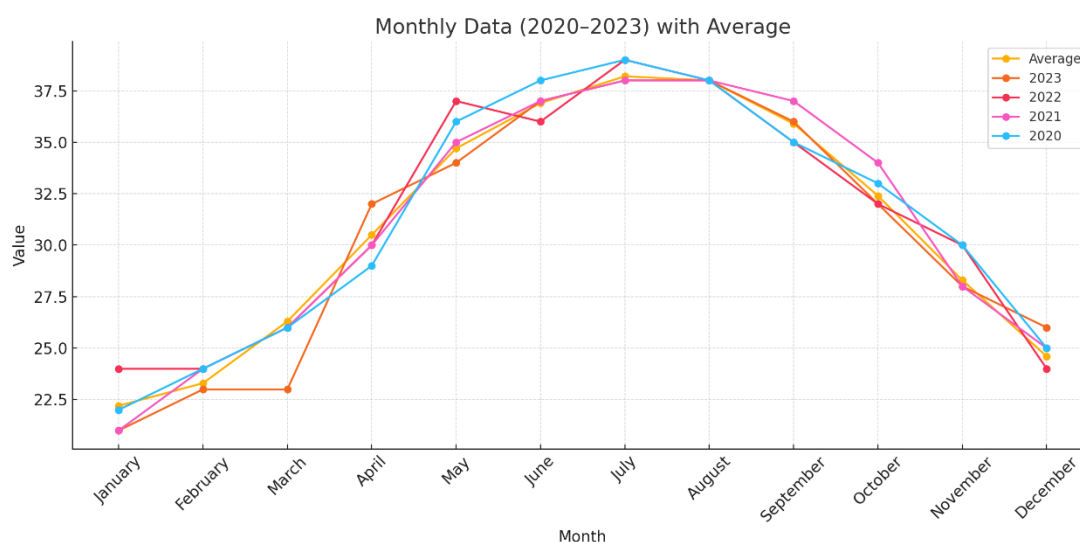


Figure (9): Average monthly maximum temperatures (years 2020:2023)

3.2 Forecasting the concentrations of pollutants

The data was studied to determine the expected concentrations of pollutants in specific areas in the airport.

This section discusses the maximum concentration values that were studied within the dispersion model in the AEDT program and their impact on personnel at Hurghada international airport, which are as follows:

The air dispersion calculations were completed using AEDT to estimate the concentrations of pollutants that will be emitted during normal operations at Hurghada international airport. Table (2) and (3), show the highest concentrations of the following emissions: NO_x , CO, SO_2 , and PM_{10} that were recorded during the specified modelling period, and comparing these results with national and international air quality standards.

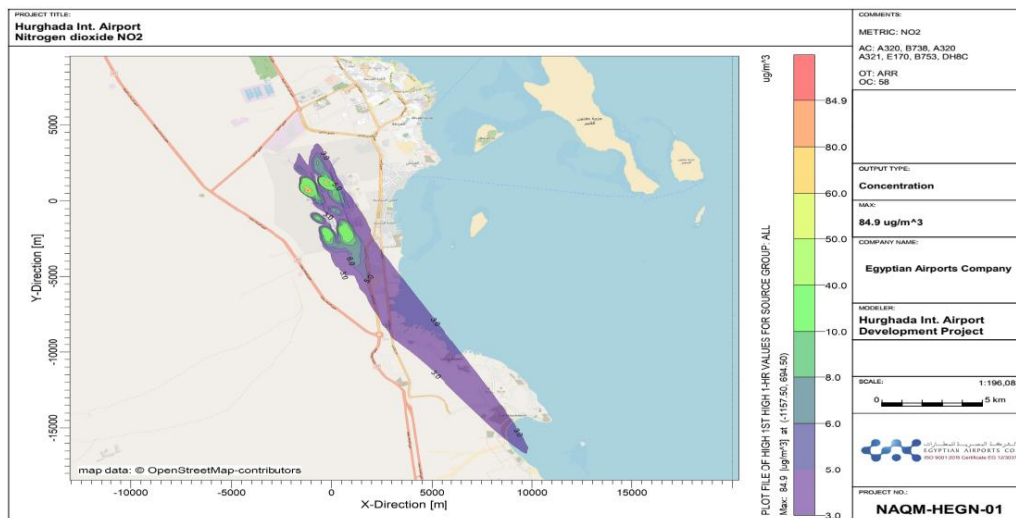
Table (2): Maximum predicted concentrations resulting from daily operation at Hurghada international airport, take-off phase

POLLUTANT	AVERAGE TIME	THE MAXIMUM VALUE THAT WAS PREDICTED	MEASUREMENT'S $\mu\text{G}/\text{M}^3$			PERMITTED EXCESSES
			European Directive	World Health Organization	Egyptian Environmental Law	
			EC/50/2008	WHO-2005	165/ Decree	
Carbon monoxide CO	1 hour	13.89	--	30000	30000	Once a Year Twice a Month
	8 hours	1.98	10000	10000	10000	
Nitrogen dioxide NO ₂	1 hour	502.8	200	200	300	24 Times a Year -- --
	24 hours	27.93	--	--	150	
	Annual	--	40	40	60	
Sulphur dioxide SO ₂	1 hour	22.3	350	--	300	24 Times a Year 3 Times a Year --
	24 hours	1.238	125	125	125	
	Annual	--	--	--	50	
Particulate matter PM ₁₀	24 hours	0.115	50	150	150	12 Times a Year
	Annual	--	40	70	100	

Table (3): Maximum predicted concentrations resulting from daily operation at Hurghada international airport, landing phase

POLLUTANT	AVERAGE TIME	THE MAXIMUM VALUE THAT WAS PREDICTED	MEASUREMENT'S $\mu\text{G}/\text{M}^3$			PERMITTED EXCESSES
			European Directive	World Health Organization	Egyptian Environmental Law	
			EC/50/2008	WHO-2005	165/ Decree	
Carbon monoxide CO	1 hour	13.89	--	30000	30000	Once a Year Twice a Month
	8 hours	110.7	10000	10000	10000	
Nitrogen dioxide NO ₂	1 hour	84.68	200	200	300	24 Times a Year -- --
	24 hours	4.71	--	--	150	
	Annual	--	40	40	60	
Sulphur dioxide SO ₂	1 hour	9.6	350	--	300	24 Times a Year 3 Times a Year --
	24 hours	0.55	125	125	125	
	Annual	--	--	--	50	
Particulate matter PM ₁₀	24 hours	0.115	50	150	150	12 Times a Year
	Annual	--	40	70	100	

3.2.1 Dispersion modelling of nitrogen dioxide



Figures 10 and 11 are contour maps showing the dispersion of nitrogen dioxide gas resulting from airport operations during 24 hours according to the proposed scenario. The maps include the average concentrations of 1 hour, which are the highest concentrations.

Figure (10) is a contour map showing the distribution of nitrogen dioxide with an average of 1 hour during the landing phase, created by AEDT (Aviation Environmental Design Tool)

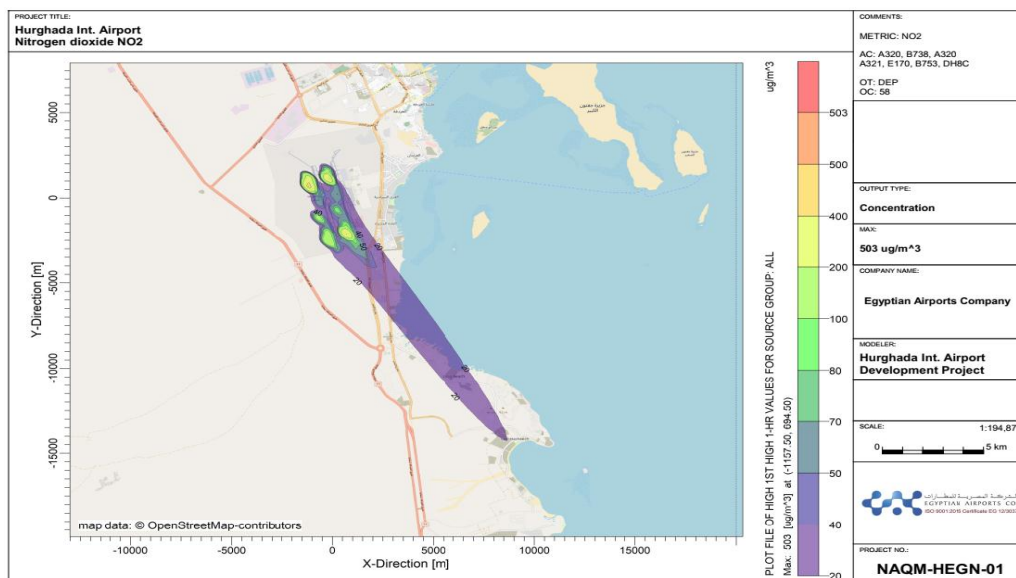


Figure (11): the distribution of nitrogen dioxide with an average of 1 hour during the take-off phase , created by AEDT (Aviation Environmental Design Tool)

3.2.2 Dispersion modelling of Sulphur Dioxide

Figures 12 and 13 are contour maps showing the dispersion of Sulphur dioxide gas resulting from airport operations during 24 hours according to the proposed scenario. The maps include 1-hour average concentrations, which are the highest concentrations.

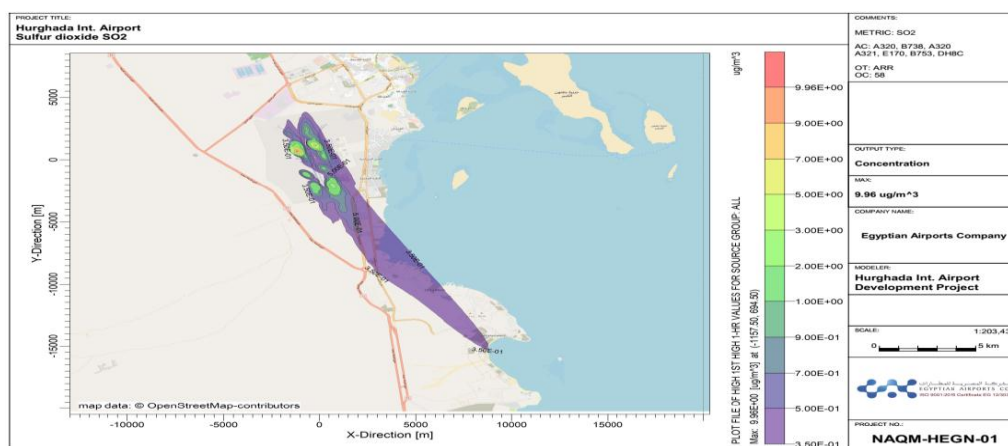


Figure (12): is a contour map showing the distribution of Sulphur dioxide at an average of 1 hour during the landing phase , created by AEDT (Aviation Environmental Design Tool)

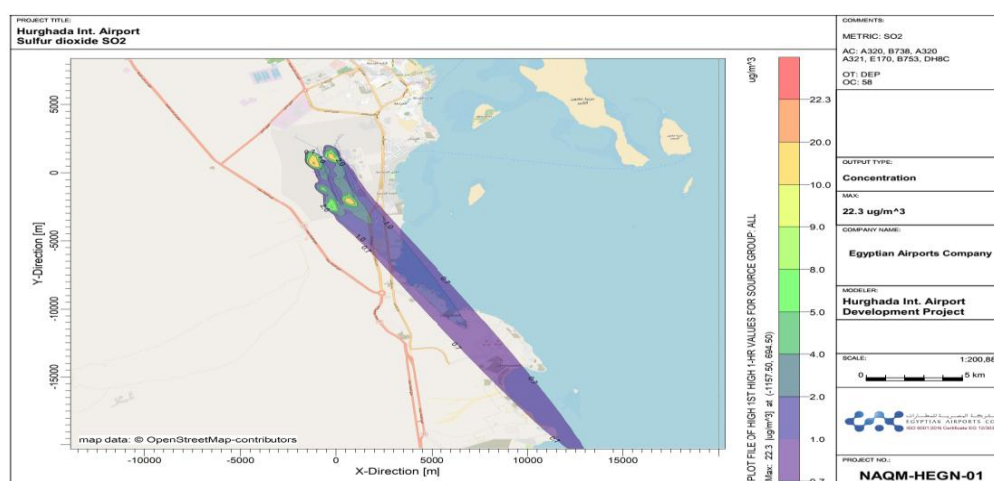


Figure (13): is a contour map showing the distribution of Sulphur dioxide at an average of 1 hour during the take-off phase, created by AEDT (Aviation Environmental Design Tool)

3.2.3 Dispersion modelling of Carbon Monoxide

Figures 14 and 15 show contour maps showing the dispersion of carbon monoxide (CO) resulting from airport operations over 24 hours according to the proposed scenario. The maps include 1-hour average concentrations, which are the highest concentrations.

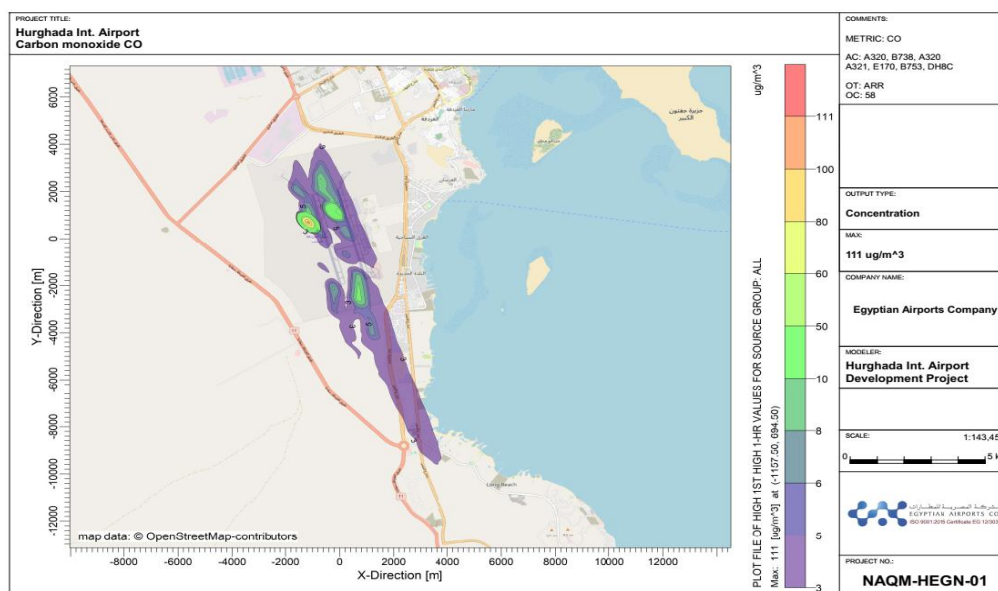


Figure (14): Contour map showing the distribution of carbon monoxide over an average of 1 hour during the landing phase, created by AEDT (Aviation Environmental Design Tool)

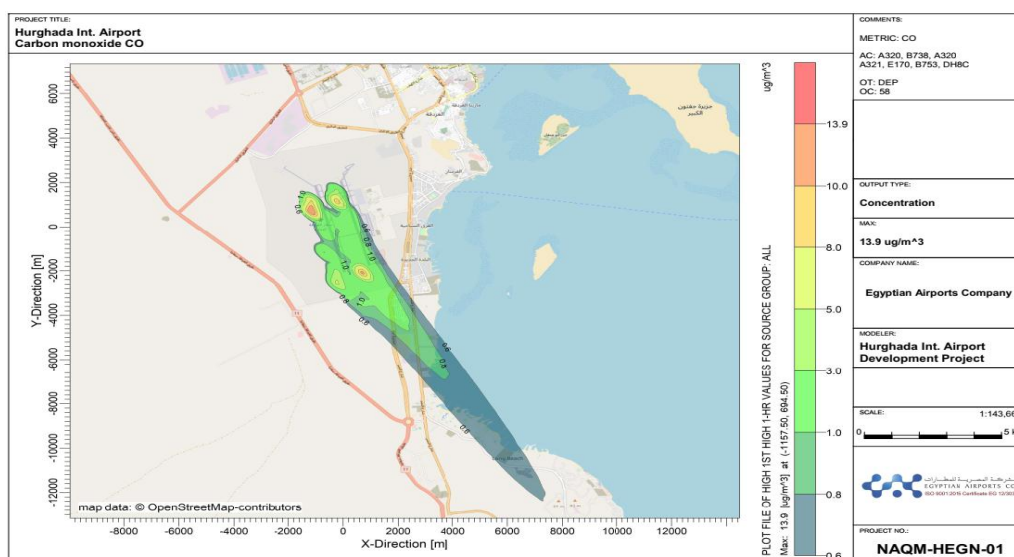


Figure (15): Contour map showing the distribution of carbon monoxide over an average of 1 hour during the take-off phase, created by AEDT (Aviation Environmental Design Tool)

3.2.4 Dispersion modelling of Suspended particles less than 10 micrometers

Figures 16 and 17 are contour maps showing the dispersion of suspended particles less than 10 micrometers resulting from airport operations during 24 hours according to the proposed scenario. The maps include average concentrations for 1 hour, which are the highest concentrations.

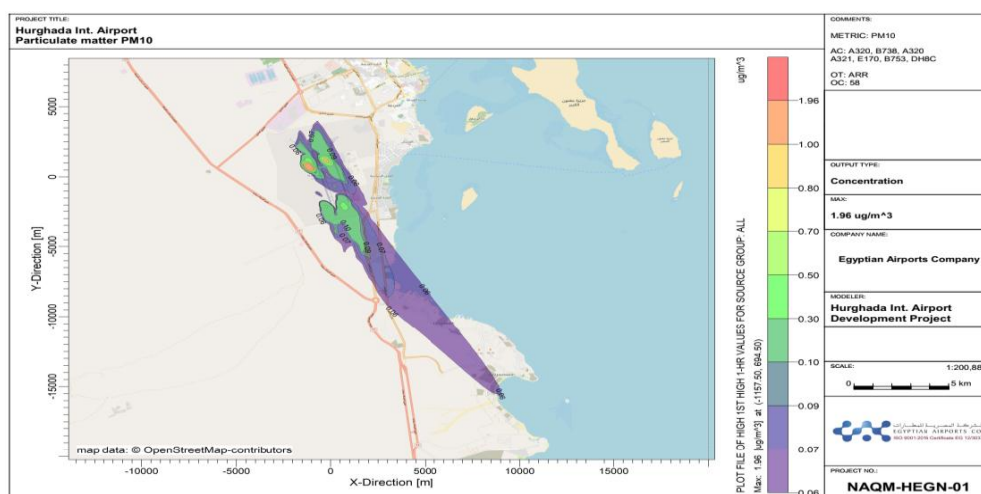


Figure (16): Contour map showing the distribution of suspended particles with an average of 1 hour during the landing phase, created by AEDT (Aviation Environmental Design Tool)

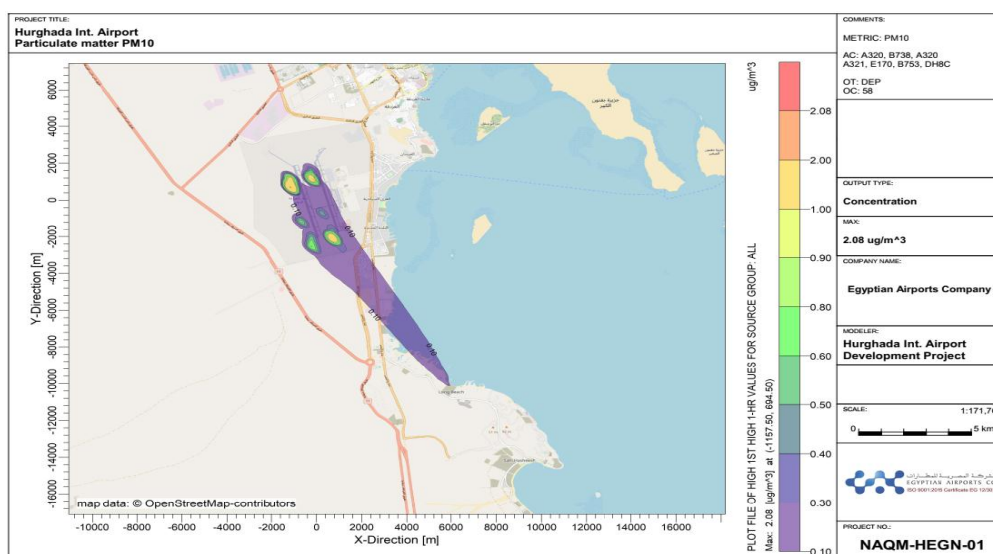


Figure (17): Contour map showing the distribution of suspended particles with an average of 1 hour during the take-off phase, created by AEDT (Aviation Environmental Design Tool)

3.3 Bio-medical parameter test results

3.3.1 carboxyhemoglobin (COHb medical analysis)

COHb medical analysis is done for sample of the most exposure to aircraft engines exhaust and the results as the following:

The Average of COHb for the most exposure to aircraft engines exhaust is 0.553333 g/dL. The average of Oxygen saturation (sO₂) for the most exposure to aircraft engines exhaust is 96.3 %.

COHb medical test is made for sample of non-exposure to aircraft engines exhaust (control) and the results as the following:

The average of COHb for the non-exposure to aircraft engines exhaust is 0.52 g/dL. The average of Oxygen saturation (sO₂) for the non-exposure to aircraft engines exhaust is 97.5 %. All the results were compliance with reference value of carboxyhemoglobin (maximum 2 g/dL), which is due to the low percentage of carbon monoxide into the air around aircraft. Aircraft engines nowadays are highly efficient with highly completed combustion so, emitted low CO into their exhaust.

3.3.2 Quantitative Overview

Table (4): “Levels of COHB and Oxygen saturation in the studied groups

study group		COHB g/dL		Oxygen saturation (sO ₂)	
control 20 persons	Mean± SD	0.52500±0.125132		97.51000 ±1.314654	
	Median	0.50000		97.70000	
	Maximum	0.800		99.100	
	Minimum	0.300		95.200	
Case 20 persons	Mean± SD	0.55333±0.130604		96.30000±2.126191	
	Median	0.50000		96.75000	
	Maximum	0.800		99.200	
	Minimum	0.300		90.000	
Independent t test		t	P	t	P
		-0.764	0.449	2.268	0.028

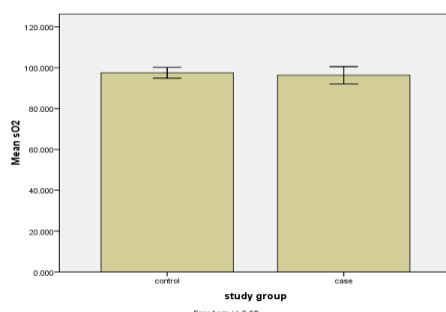


Figure (18): Mean Oxygen saturation (sO₂)

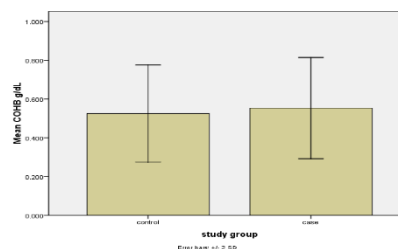


Figure (19): Mean COHB

3.4 Results of the incidence rates of different symptoms among airport workers due to exposure pollutants by using survey that most exposure to aircraft engines exhaust:

3.4.1 The survey results revealed a range of symptoms experienced by airport personnel exposed to aircraft engine exhaust. The most common symptom reported was general fatigue, affecting 76% of respondents. This was followed by headache (52%), difficulty walking (36%), and shortness of breath (24%). Other symptoms included vision problems (16%), mental confusion (16%), and dizziness (8%). Less frequently reported symptoms were chest pain, rapid breathing, and loss of consciousness, each affecting 4% of respondents. Notably, nausea, vomiting, and rapid or irregular heartbeat were not reported by any of the workers.

A comparative analysis of 50 airport personnel—20 unexposed controls and 30 individuals exposed to aircraft engine exhaust—revealed a non-significant trend toward increased shortness of breath among the exposed group (83.3% vs. 16.7%; $p = 0.091$), with no other symptom showing statistically significant differences (all $p > 0.05$). Despite the lack of formal significance in this small cohort, extensive literature demonstrates that chronic exposure to jet engine emissions—rich in ultrafine particles, volatile organics, and combustion by-products—is associated with a spectrum of respiratory and neurological complaints.

Using **Fisher's Exact Test** for eight binary symptoms and **Pearson Chi-Square Test** for two symptoms with larger counts:

- **Shortness of Breath:**
 - Control: 2/20 (16.7%) reported SOB; Case: 10/30 (83.3%) reported SOB
 - $p = 0.091$ (Fisher's Exact Test)
- **General Fatigue:**
 - Control: 15/20 (39.5%); Case: 23/30 (60.5%)
 - $p = 1.000$ (Fisher's Exact Test)
- **Dizziness:**
 - Control: 2/20 (10%); Case: 2/30 (6.7%)
 - $p = 1.000$ (Fisher's Exact Test)
- **Vision Problems:**
 - Control: 4/20 (20%); Case: 4/30 (13.3%)
 - $p = 0.697$ (Fisher's Exact Test)
- **Rapid Breathing:**
 - Control: 1/20 (5%); Case: 1/30 (3.3%)
 - $p = 1.000$ (Fisher's Exact Test)
- **Chest Pain:**
 - Control: 1/20 (5%); Case: 1/30 (3.3%)
 - $p = 1.000$ (Fisher's Exact Test)
- **Mental Confusion:**
 - Control: 4/20 (20%); Case: 4/30 (13.3%)
 - $p = 0.697$ (Fisher's Exact Test)

- **Loss of Consciousness:**
 - Control: 1/20 (5%); Case: 1/30 (3.3%)
 - $p = 1.000$ (Fisher's Exact Test)
- **Headache:**
 - Control: 13/20 (65%); Case: 13/30 (43.3%)
 - $X^2 = 2.257$, $p = 0.133$ (Pearson Chi-Square)
- **Difficulty Walking:**
 - Control: 5/20 (25%); Case: 13/30 (43.3%)
 - $X^2 = 1.751$, $p = 0.186$ (Pearson Chi-Square)

DISCUSSION

1. Air traffic density

The annually aircraft count data from 2010 to 2023 reveal several notable trends and potential underlying drivers:

Early- Decade Decline (2010–2013):

Following a peak of 56 512 aircraft in 2010, the fleet size fell steadily to 39 145 by 2013. This contraction may reflect post- recession airline retirements, deferred aircraft deliveries, and fuel- price pressures that prompted operators to ground older, less efficient airframes.

Mid- Decade Recovery and Trough (2014–2016):

A modest rebound to 45 484 in 2014 and 44 619 in 2015 suggests improving economic conditions and resumed deliveries. However, 2016 saw an abrupt trough at 24 085—a 46% drop from 2015—which is likely an artefact of reporting changes or fleet accounting (e.g., reclassification of stored versus active aircraft) rather than an actual halving of global capacity.

Pre- Pandemic Expansion (2017–2019):

From 2017 onward, the data show a robust expansion: 35 441 → 46 540 → 51 530. This growth phase corresponds with record- low fuel prices, favorable financing for new aircraft, and the introduction of high- efficiency models (e.g., the Boeing 737 MAX and Airbus A320neo families).

Pandemic Impact (2020):

The COVID-19 crisis precipitated an unprecedented collapse to 16 224 active aircraft—a 68% reduction from 2019—driven by global travel bans, airline bankruptcies, and the mass storage of fleets. This represents the largest single-year contraction in the period.

Post-Pandemic Recovery (2021–2023):

As restrictions eased, the fleet rebounded to 35 400 in 2021, then 48 732 in 2022, and 49 686 in 2023. While approaching pre-pandemic levels by 2023, the slower pace of recovery likely reflects ongoing supply-chain constraints for new deliveries, residual route suspensions, and strategic retirements of older jets.

In 2020, the Boeing 737-800 and Airbus A320 accounted for 30 % and 18 % of total movements, respectively. Although the B737-800 share held steady at 30 % in 2021, the A320 proportion dipped slightly to 15 %. By 2022, however, the A320 regained momentum—rising to 21 %—and the B737-800 climbed modestly to 34 %. A more dramatic realignment emerged in 2023, when the A320 share surged to 31 %, overtaking the B737-800, which declined to 25 %.

Both the A320 and B737-800 families are classified as medium-size, single-aisle airliners powered by medium-thrust turbofan engines. Their similar engine characteristics and sortie profiles imply that, despite shifts in relative frequency, the aggregate exhaust emission profile at HRG Airport has remained within a moderate band over the four-year period.

These findings align with broader industry observations. Post-COVID recovery spurred airlines to deploy their most versatile narrow-bodies on restored routes, with fleet availability and lease considerations dictating type mix more than optimal emission performance alone. The growing A320 share likely reflects both the influx of newer, lower-emission variants into regional fleets and the retirement of older B737-800 aircraft.

Implications for Airport Management and Sustainability

Given that medium-size turbofans dominate HRG operations, environmental mitigation efforts should focus on incremental improvements—such as incentivizing the deployment of “neo” and MAX series with higher bypass ratios and introducing sustainable aviation fuels. Ground-handling and taxi-in/taxi-out procedures can further reduce engine-on times, yielding immediate emissions benefits regardless of aircraft type mix.

2. Concentrations of atmospheric air pollutant downwind from the runways:

The findings of this study align with previous research indicating that air pollution levels are highest near areas of intense aircraft activity, such as runways and taxiways. Several studies have demonstrated that **ground-level emissions** are predominantly concentrated around these zones, with pollutants dispersing as the distance from the source increases (Carslaw et al., 2006; Schäfer et al., 2009).

Furthermore, research highlights that airport personnel are at risk of **occupational exposure** to jet engine emissions, which include **volatile organic compounds (VOCs)** and **particulate matter (PM)**. These emissions have been linked to various **adverse health effects**, including respiratory and cardiovascular diseases, emphasizing the importance of continuous air quality monitoring (Hudda et al., 2014).

Additionally, studies have shown that optimizing **airport surface movements**, such as implementing **end-around taxiways**, can significantly reduce emissions and enhance efficiency. These operational improvements contribute to **decreased surface congestion** and a **lower environmental impact** (Fala et al., 2014).

While the recorded pollutant concentrations in this study remain **within the permissible limits** set by **Environmental Law No. 4 of 1994**, long-term exposure to even moderate levels of aviation-related pollutants may pose **health risks** to both airport workers and nearby residents (Schäfer et al., 2009). Prior studies have demonstrated that emissions from **aircraft engines** contribute to elevated levels of **NO_x, CO, and PM**, which can have cumulative effects on public health and local air quality (Schäfer et al., 2009; Hudda et al., 2014).

To mitigate these risks, continuous **air quality monitoring** and the implementation of **emission reduction strategies** are essential. These strategies may include **improving aircraft taxiing procedures**, optimizing flight schedules to reduce idle time, and adopting **sustainable aviation fuels** to lower emissions and environmental impact (Hudda et al., 2020).

3. The air dispersion modeling results

3.2 Forecasting the concentrations of pollutants

The analysis of **contour maps** illustrating emissions during the **takeoff phase** indicates that pollutant concentrations remained **within the permissible limits** set by **ambient air**

quality standards for primary pollutants. As shown in **Tables (2) and 3)**, emission levels across **airport buildings and surrounding residential areas** did not exceed the regulatory thresholds established in the **executive regulations for air quality under Environmental Law No. 4 of 1994** (Egyptian Environmental Affairs Agency [EEAA], 1994).

Similarly, emissions generated during the **landing phase** were analyzed, and the results confirmed that **pollutant concentrations remained below** the limits stipulated in the **environmental regulations** (EEAA, 1994). These findings suggest that, under normal airport operations, pollutant dispersion does not significantly impact **local air quality beyond permissible levels**. However, continuous monitoring and predictive modeling are essential to assess potential **long-term environmental impacts** and ensure compliance with regulatory standards (Schäfer et al., 2009; Hudda et al., 2020).

3.2.1 Dispersion modelling of nitrogen dioxide

Nitrogen Dioxide (NO₂) Exposure and Its Implications

Nitrogen dioxide (NO₂) is a significant air pollutant primarily produced from combustion processes, with vehicular emissions being a major source. Exposure to elevated levels of NO₂ can lead to various health issues, particularly affecting the respiratory system. Short-term exposure may cause airway inflammation and exacerbate respiratory diseases such as asthma, while prolonged exposure has been linked to the development of respiratory infections and reduced lung function ([US EPA](#)).

In the context of airport operations, dispersion modeling of NO₂ emissions during aircraft landing and takeoff phases provides critical insights into potential environmental impacts. Analysis of dispersion maps, as depicted in Figures 10 and 11, reveals that:

Landing Phase: The maximum predicted NO₂ concentration reaches 85 micrograms per cubic meter (µg/m³) within the runway area. This value exceeds the permissible limits established by Egypt's Environmental Law No. 4 of 1994. However, it's important to note that these elevated concentrations are confined to areas with restricted human activity, such as the runway itself. At the airport's terminal buildings, NO₂ levels decrease to approximately 20 µg/m³, and in surrounding residential areas, concentrations are below 3 µg/m³, aligning with acceptable air quality standards.

Takeoff Phase: The dispersion model indicates a peak NO₂ concentration of 503 µg/m³ in the immediate vicinity of the runway during takeoff. While this concentration significantly surpasses the environmental law's thresholds, the affected zone is primarily limited to the runway area, where access is restricted to authorized personnel during specific operations. At the terminal buildings, concentrations are around 80 µg/m³, and in nearby residential zones, levels do not exceed 30 µg/m³, remaining within permissible limits.

These findings underscore the importance of continuous air quality monitoring and the implementation of mitigation strategies to minimize NO₂ emissions from airport activities. Adherence to environmental regulations, such as those outlined in Law No. 4 of 1994, is essential to safeguard public health and ensure compliance with air quality standards.

3.2.2 Dispersion modelling of Sulphur Dioxide

Sulphur Dioxide (SO₂) Emissions and Environmental Impact

Sulphur dioxide (SO₂) is primarily produced during the combustion of fuels containing Sulphur compounds. Major sources include power plants and industrial facilities utilizing petroleum-based fuels, particularly diesel (International Civil Aviation Organization, 2016). While gasoline-powered vehicles emit negligible SO₂, diesel engines contribute significantly to ambient concentrations. Additionally, open burning of organic waste releases SO₂, which plays a pivotal role in the formation of acid rain. This phenomenon adversely affects ecosystems, damages structures, and poses health risks, such as respiratory irritation upon inhalation (Rådet for Grøn Omstilling, 2010). Consequently, many governments have implemented regulations to limit SO₂ emissions from industrial activities. Industrially, SO₂ is utilized in producing sulfurous acid for applications like fabric bleaching and food preservation, and it serves as a precursor in synthesizing sulfates and sulfuric acid.

Under pressure and at temperatures below -10°C, SO₂ transitions into a liquid state, enabling its use as a refrigerant (International Civil Aviation Organization, 2016).

Dispersion Analysis of SO₂ Emissions at Hurghada International Airport

Dispersion modeling of SO₂ emissions from airport operations provides insights into potential environmental impacts:

Landing Phase: As depicted in Figure 12, the maximum predicted SO₂ concentration during aircraft landing reaches 9 micrograms per cubic meter (µg/m³) within the runway vicinity. At the terminal buildings, concentrations decrease to approximately 1 µg/m³. In surrounding residential areas, levels are below 0.05 µg/m³, aligning with the permissible limits set by Egypt's Environmental Law No. 4 of 1994 (International Civil Aviation Organization, 2016).

Takeoff Phase: Figure 13 illustrates that during takeoff, SO₂ concentrations peak at 22.3 µg/m³ near the runway. At the terminal buildings, levels are around 2 µg/m³, and in adjacent residential zones, concentrations remain under 0.3 µg/m³, complying with environmental standards (Rådet for Grøn Omstilling, 2010).

These findings indicate that, while SO₂ concentrations are elevated in immediate operational areas, they diminish significantly with distance, ensuring that residential zones remain within safe exposure levels. Continuous monitoring and adherence to environmental regulations are essential to mitigate potential health and ecological impacts associated with SO₂ emissions from airport activities (International Civil Aviation Organization, 2016; Rådet for Grøn Omstilling, 2010).

3.2.3 Dispersion modelling of Carbon Monoxide

Carbon Monoxide (CO) Emissions and Environmental Impact

Carbon monoxide (CO) is an odorless, colorless, and tasteless gas produced through the incomplete combustion of carbon-based fuels, particularly under oxygen-limited conditions or at high combustion temperatures (International Civil Aviation Organization [ICAO], 2016). This toxic gas is commonly emitted from industrial activities, vehicular exhaust, and airport operations. CO is classified as a heterogeneous diatomic molecule, consisting of carbon and oxygen. When combusted completely, it produces a blue flame, indicating the completion of the oxidation process (Rådet for Grøn Omstilling, 2010).

Exposure to CO can have significant health effects. At lower concentrations, it may cause fatigue in healthy individuals and chest pain in those with pre-existing cardiovascular conditions. Higher concentrations can result in dizziness, headaches, nausea, confusion, and impaired motor coordination, symptoms that resemble the flu but dissipate upon exiting the contaminated environment. Severe exposure can lead to the formation of carboxyhemoglobin in

the bloodstream, which inhibits oxygen transport and can cause hypoxia, cognitive impairment, and, in extreme cases, death (World Health Organization [WHO], 2005). Prolonged exposure, especially in enclosed or poorly ventilated areas, increases health risks for ground handling personnel at airports.

Dispersion Analysis of CO Emissions at Hurghada International Airport

Dispersion modeling was conducted to assess CO concentrations resulting from airport operations, including takeoff and landing activities:

Landing Phase: As illustrated in Figure 14, the maximum predicted CO concentration during aircraft landing reached 111 micrograms per cubic meter ($\mu\text{g}/\text{m}^3$) near the runway. At the airport's travel connection areas, concentrations declined to 30 $\mu\text{g}/\text{m}^3$. In surrounding residential areas, CO levels did not exceed 11 $\mu\text{g}/\text{m}^3$, which is within the permissible limits established by Egyptian Environmental Law No. 4 of 1994 (ICAO, 2016).

Takeoff Phase: Figure 15 shows that during takeoff, CO concentrations peaked at 13.9 $\mu\text{g}/\text{m}^3$ near the runway. This value exceeds acceptable exposure limits for ground handling personnel, who may be exposed to such concentrations for extended periods. At the airport's travel connection buildings, levels dropped to 6 $\mu\text{g}/\text{m}^3$, while in nearby residential areas, concentrations remained below 1.5 $\mu\text{g}/\text{m}^3$, complying with environmental regulations (Rådet for Grøn Omstilling, 2010).

Wind speed and direction significantly influence pollutant dispersion patterns, often reducing CO concentrations in residential zones and tourist accommodations. Continuous monitoring and mitigation strategies, such as improving airport ventilation and optimizing aircraft taxiing procedures, can help reduce exposure risks (WHO, 2005).

3.2.4 Dispersion modelling of Suspended particles less than 10 micrometers

Suspended Particulate Matter and Its Environmental Impact

Suspended particulate matter (PM), commonly referred to as fine particles, consists of solid or liquid particles dispersed in the air, originating from both natural and anthropogenic sources. These particles vary in size, shape, color, and chemical composition, influencing their environmental and health impacts (World Health Organization [WHO], 2005). The chemical composition of airborne pollutants plays a crucial role in determining their behavior in the

atmosphere, while particle size directly affects their dispersion patterns and interactions with living organisms and infrastructure (International Civil Aviation Organization [ICAO], 2016). The size of particulate matter ranges from 0.0001 to 500 micrometers (μm), with atmospheric residence times varying from seconds to several years, depending on environmental conditions. In recent years, greater attention has been given to particles smaller than $10\ \mu\text{m}$ (PM_{10}) due to their increased potential health risks. These particles are more readily inhaled, allowing them to penetrate deep into the respiratory system, where they can accumulate and cause adverse health effects, such as respiratory illnesses and cardiovascular complications (Rådet for Grøn Omstilling, 2010).

Major sources of PM emissions include vehicular traffic, industrial processes, and open waste burning. Additionally, arid and semi-arid environments, such as those found in Egypt, contribute to increased dust levels through natural wind activity. However, compared to emissions from human activities, natural dust is generally considered less harmful due to differences in chemical composition and particle characteristics (WHO, 2005).

Dispersion Analysis of PM Emissions at Hurghada International Airport

To evaluate the impact of PM emissions from airport operations, dispersion modeling was conducted for both landing and takeoff activities:

Landing Phase: As illustrated in Figure 16, the highest predicted PM_{10} concentration from aircraft landing operations reached $1.96\ \mu\text{g}/\text{m}^3$ near the runway. At the airport's travel connection buildings, this value dropped to $0.1\ \mu\text{g}/\text{m}^3$. In residential areas surrounding the airport, concentrations did not exceed $0.06\ \mu\text{g}/\text{m}^3$, remaining within the permissible limits outlined by Egyptian Environmental Law No. 4 of 1994 (ICAO, 2016).

Takeoff Phase: Figure 17 shows that during aircraft takeoff, the maximum predicted PM_{10} concentration reached $2.08\ \mu\text{g}/\text{m}^3$. At the airport's travel connection buildings, levels declined to $1\ \mu\text{g}/\text{m}^3$, while in surrounding residential areas, concentrations remained below $0.1\ \mu\text{g}/\text{m}^3$, meeting the regulatory standards set by Egyptian environmental authorities (Rådet for Grøn Omstilling, 2010).

The dispersion of suspended particles is heavily influenced by meteorological conditions such as wind speed and direction. Effective mitigation measures, such as improving ground handling procedures and reducing emissions from auxiliary power units, can help minimize particulate pollution from airport operations (WHO, 2005).

3.3 Bio-Medical Parameter Test Results

3.3.1 Carboxyhemoglobin (COHb) Medical Analysis

The analysis of carboxyhemoglobin (COHb) levels among airport personnel revealed that the recorded concentrations were consistently low, with the highest value being 0.8% COHb. This level remains well below the occupational exposure threshold of 2% COHb typically considered safe for non-smokers. At these levels, no clinical symptoms are generally expected, as COHb levels between 0–2% are classified as normal in non-smoking individuals.

However, an increase in the reporting of symptoms such as headache and fatigue among ground handling staff suggests a potential early indication of cumulative low-level exposure. Although these symptoms are usually associated with higher COHb levels (10–20%), it is plausible that repeated or prolonged exposure in semi-enclosed airport environments may produce mild subclinical effects even below established toxicity thresholds.

This observation highlights the need for continuous occupational health surveillance, particularly in high-risk zones such as aircraft taxiways and maintenance areas, where exposure to exhaust emissions is more concentrated. Preventive measures, including improved ventilation and periodic COHb monitoring, may be warranted to ensure long-term safety and wellbeing of airport personnel.

Air dispersion modeling results indicate that pollutant concentrations during airport operations—whether during the landing or take-off phase—remain within permissible limits in areas where workers are present, minimizing exposure risks. However, long-term projections suggest that **carbon monoxide (CO) concentrations could rise to 13 mg/m³ by 2050**, surpassing the reference threshold of **10 mg/m³** established by environmental regulations. Such an increase in CO levels could lead to a higher prevalence of hemoglobin disorders among airport workers due to extended exposure to elevated pollutant concentrations (International Civil Aviation Organization, 2016; Rådet for Grøn Omstilling, 2010).

The high prevalence of fatigue and headache among workers exposed to air pollution is consistent with findings from previous research on occupational health impacts. Lawin et al. (2018) conducted a systematic review highlighting that workers exposed to traffic-related air pollutants commonly report symptoms such as fatigue and headaches, which can significantly affect their well-being and productivity. In aviation environments, the contribution of aircraft engine emissions and other airport-related pollutants to ambient air quality has been well documented. Masiol and Harrison (2014) reviewed the sources and health impacts of these emissions, linking them to respiratory symptoms including shortness of breath among exposed personnel. These findings emphasize the importance of monitoring and mitigating air pollution exposure to protect the health of workers in high-risk occupational settings.

These findings suggest that airport workers may be at increased risk of developing health issues related to prolonged exposure to aircraft engine exhaust.

CONCLUSIONS

This research examines the effects of aircraft engine exhaust gases on public health and the safety of personnel at the HRG airfield. The concentration of emissions from the total landing and takeoff (LTO) cycles was recorded as an 8-hour average throughout the year 2023 by using air pollution system. From our results, it was found that 32.98 $\mu\text{g}/\text{m}^3$ for NO, 21.2 $\mu\text{g}/\text{m}^3$ for NO₂, 54.2 $\mu\text{g}/\text{m}^3$ for NO_x, 39.2 $\mu\text{g}/\text{m}^3$ for SO₂, 4.94 mg/m³ for CO, 733782.94 $\mu\text{g}/\text{m}^3$ for CO₂, 82.9 $\mu\text{g}/\text{m}^3$ for O₃, 57 $\mu\text{g}/\text{m}^3$ for PM₁₀ and 17.9 $\mu\text{g}/\text{m}^3$ for PM_{2.5}. These measured levels comply with the air quality limit values established by Egyptian Environmental Law No. 4/2004 and its amendments.

Biomedical analysis of carboxyhemoglobin (COHb) levels among airport personnel indicated generally low concentrations, with a maximum recorded value of 0.8% COHb, well below the occupational exposure threshold of 2% COHb. However, an increase in other common symptoms experienced by ground handling staff, such as headaches and fatigue.

RECOMMENDATIONS

To mitigate the health risks associated with exposure to aircraft exhaust emissions, the following measures are recommended:

1. Transition to Cleaner Fuels:

- Encouraging the use of **low-emission aviation fuels**, such as **biofuels**, to reduce the production of harmful pollutants.

2. Minimizing Direct Exposure:

- Implementing structured **work schedules** to limit the time personnel spend near active aircraft engines.
- Rotating shifts to prevent extended exposure to **highly polluted zones** near runways.

3. Personal Protective Equipment (PPE):

- Requiring airport ground staff to wear **protective masks with specialized filters** to reduce inhalation of fine particulate matter and toxic gases.

4. Routine Health Monitoring:

- Conducting **regular medical check-ups** for airport personnel, including testing for elevated levels of **carboxyhemoglobin (COHb)** and monitoring **oxygen saturation levels** in the blood.

By implementing these recommendations, the long-term health risks associated with aircraft emissions can be mitigated, ensuring a safer working environment for airport personnel.

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دراسة التأثيرات الصحية على الأفراد المرتبطة بالتعرض لانبعاثات عوادم الطائرات

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المستخلص

يتعرض العاملون بالمطار لخطر التعرض المهني لانبعاثات محركات الطائرات النفاثة، والتي تشمل على غرار انبعاثات عوادم الديزل أكاسيد النيتروجين وأكاسيد الكبريت والجسيمات والمركبات العضوية المتطايرة، وخاصة أول أكسيد الكربون الذي يعتبر الملوث الرئيسي في عوادم الطائرات والذي يؤثر بشكل مباشر على تكوين الكربوكسي هيموجلوبين في الدم. في هذه الدراسة، تم إجراء تحقيق تجريبي لتحديد آثار عوادم محركات الطائرات على صحة العاملين في المناولة الأرضية في مطار الغردقة الدولي (HRG) خلال عام 2023. ولهذا الغرض، أجريت قياسات تلوث الهواء بطريقتين مختلفتين. تم قياس تركيز انبعاثات دورة الهبوط والإقلاع الكلية (LTO) لمدة 8 ساعات في المتوسط خلال عام 2023 باستخدام نظام تلوث الهواء. ومن خلال نتائجنا، وجدنا أن تركيزات NO تبلغ 32.98 ميكروجرام/م³، و NO₂ 21.2 ميكروجرام/م³، و NO_x 54.2 ميكروجرام/م³، و SO₂ 39.2 ميكروجرام/م³، و CO₂ 4.94 ميكروجرام/م³، و CO₂ 733782.94 ميكروجرام/م³، و O₃ 82.9 ميكروجرام/م³، و PM₁₀ 57 ميكروجرام/م³، و PM_{2.5} 17.9 ميكروجرام/م³. وكانت هذه المستويات المقاسة متوافقة مع قيم حدود جودة الهواء الواردة في القانون رقم (2004/4) المصري وتعديلاته. وقد تم تطبيق الاختبار الطبي على 30 فرداً على اتصال مباشر بالطائرات خلال 8 ساعة يومياً باستخدام جهاز "RAPID Point 500" الذي يقيس الغازات في الدم. وأظهرت النتائج انخفاضاً عاماً في مستويات الكربوكسي هيموجلوبين في دم الأفراد، حيث بلغت القيمة القصوى 0.8% COHb، في حين أن العتبة البيولوجية لتحمل الكربوكسي هيموجلوبين هي 2% COHb. علاوة على ذلك، زيادة الأعراض الأخرى المألوفة بين العاملين في المناولة الأرضية مثل التعب العام والصداع. وقد أظهرت نمذجة انتشار الهواء أن تركيز

أول أكسيد الكربون سيرتفع إلى 13 ملجم/م³ عن القيمة المرجعية 10 ملجم/م³ في عام 2050، مما يزيد من نسبة أمراض الكربوكسي هيموجلوبين بين العاملين في المطار.

الكلمات المفتاحية: الصحة؛ الطائرات؛ جودة الهواء؛ تلوث الهواء؛ المطار، HRG: مطار الغردقة الدولي