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Assessment of NOx Levels in an Underground Hospital Car Park: Implications for Occupational and Environmental Health

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Abstract: Environmental air pollution poses a significant threat to human health, with nitrogen oxides (NOx) identified as contributors to respiratory and cardiovascular diseases. This study evaluates NOx levels in an underground car park of a hospital complex, where vulnerable patients frequently visit. NOx levels were assessed using direct-reading devices with high-resolution electrochemical sensors measuring NO and NO_2 concentrations. Measurements consistently remained below the legal occupational exposure limit values for car park employees, averaging around 10% of the limit. However, approximately 75% of days recorded NO_2 concentrations exceeding 70% of the World Health Organization's (WHO) recommendations, with about 20% surpassing the 0.1 ppm limit set by the WHO. The highest recorded one-hour NO_2 level reached 0.165 ppm, typically around 11:00 h. The study recommends that vulnerable patients, especially asthmatics, utilize outdoor parking, while all users should avoid using the car park as a waiting area. Employees are advised to spend more time in enclosed spaces with fresh air. Although occupational levels are generally within limits, environmental levels during peak hours could pose risks to vulnerable populations. Mitigation measures, such as increased ventilation during peak hours and restricted access based on emission levels, are suggested to minimize exposure and protect public health.

Keywords: nitrogen dioxide; nitric oxide; gases; underground car park; hospital

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1. Introduction

The escalating concerns surrounding nitrogen oxide (NOx) exposure have become increasingly pronounced since the early 1990s, propelled by a compelling linkage between heightened nitrogen dioxide (NO_2) levels and a corresponding surge in hospital admissions [1,2]. Notably, areas with diminished NO_2 levels in California witnessed significant health benefits, particularly regarding reduced emergency room visits [3]. This nexus gains added gravity when considering that NOx concentrations below established standards are implicated in a rise in respiratory diseases, culminating in fatalities [4]. Furthermore, NOx serves as a precursor for ozone formation. The release of oxides of nitrogen (NOx) and volatile organic compounds (VOCs) into the atmosphere initiates a complex reaction in the presence of solar irradiation, forming ozone in the troposphere. Emerging evidence underscores that short-term and long-term exposure to ozone, even at concentrations below the current regulatory standards, are associated with heightened mortality rates attributed to respiratory and cardiovascular diseases [5]. Ozone, recognized for its detrimental effects on human health, possesses the potential to induce inflammation in the respiratory tract, eyes, nose, and throat and can exacerbate asthma attacks.

Asthma, a chronic disease impacting 262 million people globally and causing 455,000 deaths [6], worsens with exposure to NO_2. Asthma management aims to control symptoms and prevent exacerbations marked by worsened symptoms necessitating systemic steroid treatment. This involves avoiding patient-specific triggers and using medications. Despite these efforts, exacerbations persist due to a complex interplay of biological and social factors, significantly contributing to asthma-related morbidity and mortality [7]. In 2019, an estimated 1.85 million new cases of pediatric asthma globally were attributed to NO_2 exposure, with urban areas accounting for two-thirds of this burden [8].

In the extensive examination of the short-term exposure effects of nitrogen dioxide (NO_2), a wealth of compelling evidence has surfaced, revealing its adverse impact on individuals with asthma and other respiratory diseases. Studies demonstrate that NO_2 exposure is linked to decreased lung function indices, particularly in cases of chronic obstructive pulmonary disease (COPD). At the same time, among asthmatics, it correlates with a reduction in Forced Expiratory Volume in one second (FEV1) [9]. Notably, heightened NO_2 exposure before a respiratory viral infection is associated with an increased severity of ensuing asthma exacerbations, even within current air quality standards [10]. Additionally, research indicates that indoor exposure to NO_2, even below the Environmental Protection Agency outdoor standard, is linked to respiratory symptoms among children with asthma in multifamily housing [11]. Intriguingly, short-term fluctuations in NO_2 and asthma visits seem more pronounced in areas with NO_2 levels below 10 $\mu g/m^3$ (0.005 ppm), suggesting that even low levels of NO_2 may contribute to asthma exacerbations [12].

Expanding the scope, investigating the relationship between the inhalation of nitrogen oxides (NOx) and asthma has yielded crucial insights. Noteworthy associations include the correlation between exposure to traffic-related air pollution, including NOx, during the first year of life and an increased risk of persistent wheezing and sensitization to inhaled allergens in preschool children [13]. Studies further indicate that exposure to NOx and other traffic-related pollutants may influence the effect of specific genes in the development of childhood allergic diseases [14]. Daily exposure to air pollution, including NOx, is linked to acute pediatric asthma exacerbations, reduced lung function, increased rescue medication usage, and heightened symptoms [15].

In alignment with these findings, a study conducted by J. Gillespie-Bennett et al. [16] revealed that geometric mean indoor NO_2 levels of 11.4 $\mu g/m^3$ (0.006 ppm) were associated with more frequent coughing and wheezing, as well as increased use of reliever medication during the day. This adds to the growing body of evidence emphasizing the adverse respiratory effects of indoor NO_2 exposure, highlighting the imperative for comprehensive air quality management both outdoors and within indoor spaces. Addressing indoor air pollution is increasingly crucial for public health initiatives, particularly in safeguarding vulnerable populations, including those with respiratory conditions such as asthma.

Additionally, ozone poses environmental risks by causing oxidative damage to vegetation, including crops. The primary sources generally emit NO and NO_2, which we refer to as primary pollutants. Over time, NO oxidizes, producing secondary NO_2. Thus, in the vicinity of the source, the NO/NO_2 ratio is much higher than in regional background areas. Parking garages, often overlooked as critical microenvironments, play a pivotal role in exposing both drivers and workers to deleterious air emissions, contributing to the enduring adverse impacts of motor vehicle-related air pollution on human health and the environment [17–19]. A noteworthy global trend sees cities transitioning from conventional street parking to embracing biodiverse green spaces, with a marked preference for subterranean parking structures [20,21].

The recently promulgated World Health Organization (WHO) guidelines underscore the paramount significance of air quality, estimating its toll at seven million premature deaths annually, with an additional loss of countless healthy life-years. Europe grapples with the grim reality that high NOx emissions from light-duty diesel vehicles (LDDVs) may be responsible for up to 10,000 premature deaths, particularly linked to PM2.5 and ozone formation [22]. Air pollution was responsible for 300.000 premature deaths in the EU27 in 2019 [23]. The primary provenance of atmospheric NOx lies in fossil fuels utilized for motor vehicles, power generation, and heating [24], augmented by natural sources such as forest fires and volcanic activity [25]. The combustion of gasoline and diesel engines within parking lots further contributes to the generation of nitrogen oxides through intricate chemical reactions between nitrogen (N_2) and oxygen (O_2) [26].

Recent findings have provided indications that suboptimal air quality could be linked to heightened severity and mortality in COVID-19 cases. However, the precise contribution of potential confounding factors at both individual and area levels to these observed variations remains uncertain. This underscores the need for comprehensive investigations to better understand the complex interplay between air quality and COVID-19 outcomes, considering various influencing variables that may impact the association [27].

Globally, endeavors to curtail NOx levels have given rise to initiatives ranging from the conception of car-free cities to reducing vehicular traffic for diverse reasons [28,29]. In recent years, there has been a notable decline in NO (nitric oxide) and NO_2 (nitrogen dioxide) emissions from car exhaust, marking a positive trend in addressing air quality concerns. This reduction is attributed to the implementation of various techniques aimed at curbing nitrogen oxide emissions, particularly from diesel engines. Among these strategies is the utilization of Exhaust Gas Recirculation (EGR), a method that lowers combustion temperature by reintroducing cooled exhaust gas into the combustion chamber, thereby limiting the available oxygen for combustion. Additionally, after-treatment devices such as Selective Catalytic Reduction (SCR) and Lean NOx Traps (LNT) play a crucial role in causing chemical reactions to reduce NOx emissions. Catalytic converters, tailored to engine size and aftertreatment type, also influence the NO_2 to NOX ratio, thereby contributing to the overall decrease in emissions. By adopting and combining these innovative approaches, the automotive industry has successfully diminished the levels of NO and NO_2 emissions in car exhaust, mitigating environmental impact and promoting enhanced air quality and public health [30,31]. In the contemporary landscape, a real-time on-road air quality monitoring network has been established, revolutionizing our ability to assess and manage environmental conditions continuously [32].

While cities have witnessed a reduction in NOx levels over the past few decades, persistent challenges endure, especially in areas identified as hotspots, such as traffic jams [32]. The pronounced mortality burden attributed to NO_2 was predominantly observed in expansive cities and capital cities across western and southern Europe. Sensitivity analyses underscored the significance of the exposure-response function in determining outcomes while demonstrating comparatively lesser sensitivity to variations in baseline mortality values and exposure assessment methodologies [33]. The Hospital Universitario Central de Asturias (HUCA) car park stands out as a specific microenvironment characterized by frequent vehicular agglomerations during peak hours, further complicated by pollutants like nanoparticles and diesel fumes [34]. A startling statistic reveals that diesel-powered vehicles contribute significantly, accounting for roughly 80% of the overall NOx emissions emanating from vehicular traffic [35]. Additionally, NO_2, frequently serving as an indicator of diesel emissions, doubles as a marker for the presence of other anthropogenic pollutants [36]. In a bid to curtail NOx emissions, certain vehicles are now equipped with Selective Catalytic Reduction (SCR) systems employing urea as an effective reducing agent [37].

Among nitrogen oxides, nitrogen dioxide (NO_2) takes center stage and holds profound implications for human health [24]. Exposure to NO_2 has been unequivocally associated with irritations, coughing, dyspnea, and clinical manifestations such as chest pain and pulmonary edema [38,39]. Beyond immediate symptoms, NO_2 triggers an inflammatory response in the respiratory system, augmenting susceptibility to lung infections and fostering the formation of potentially carcinogenic nitrosamines [40]. Notably, in the asthmatic population, even low-level exposure at 0.5 ppm for a mere 2 h elicits reported symptoms, including coughing, sputum production, irritation of mucous membranes, and chest discomfort [41]. Recognizing the health risks, international literature has set forth health-protective levels, recommending a short-term exposure guideline range of 0.2 to 0.6 ppm, catering to susceptible individuals and the general population [25]. Additionally, concentrations as minimal as below 10 μg/m^3 (0.005 ppm) have been found to potentially trigger asthma exacerbation [12].

The genesis of this study lies in the comprehensive analysis of gases within the outpatient parking lot of HUCA in Asturias, Spain. Our primary objective is to meticulously assess the levels of NOx in the subterranean hospital parking facility and derive meaningful recommendations tailored to both the workforce and patients utilizing this integral facility. In doing so, our research aims to contribute nuanced insights to the broader discourse on environmental pollution and healthcare infrastructure, underscoring the salient implications for public health and the evolving landscape of urban living.

2. Materials and Methods

2.1. Parking Description

The subject of our investigation is a strategically located parking facility adjacent to the hospital, seamlessly integrated into the consultation area through an underpass. This versatile structure doubles as a pedestrian plaza on its roof, offering direct access to the broader hospital complex known as Plaza del Monasterio de Valdediós. Spanning two underground levels, each covering 9643 m^2, the parking facility boasts 722 spaces, including 20 designated for handicapped wheelchair access and an additional 22 for motorcycles. Four staircases and two elevators facilitate pedestrian access to the parking area. Primarily catering to hospital workers and patients, including vulnerable individuals attending medical consultations, the parking is equipped with a CO monitoring system. This system triggers mechanical ventilation when CO levels reach specific thresholds: one extraction system activates at 50 ppm, another at 100 ppm, and emergency mode engages at 150 ppm. All measurements were meticulously conducted on level -2 (Figure 1), aligning with safety criteria for a worst-case scenario [42].

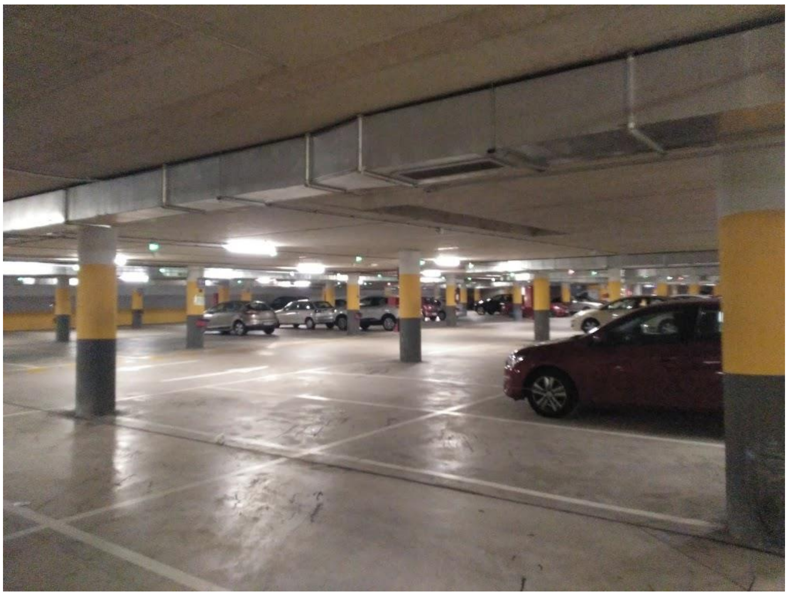

Figure 1. Parking garage level -2.

The car park is used by around 1500 cars daily from Monday to Friday. During the weekends or bank holidays, the number of vehicles is meagre because the hospital activity is reduced. On average, the car park was used by approximately 20,000 cars per month. Usually, on average, the cars arrive at about half past seven in the morning, and in a few hours, the car park will be full. During the day, there is a continuous movement of cars, mainly belonging to patients, until approximately half past two, when the employees start to leave the car park. During the evening and night, the car park has a very low level of activity, as it is mainly used by some night shift workers.

Importantly, it should be noted that, due to height clearance limitations in the parking facility, with an actual maximum height of 2.20 m, vans or other vehicles exceeding this height are not permitted to enter. Access is restricted exclusively to passenger cars and motorcycles. This measure contributes to ensuring safety and the suitability of space for authorized vehicles, thereby optimizing the functionality of the parking facility; it is noteworthy that larger vehicles, typically excluded from access due to height limitations in the parking facility, tend to exhibit higher pollution levels. This restriction contributes to safety and space optimization and aligns with environmental considerations, acknowledging the generally elevated emissions associated with larger vehicles.

In the context of this study, it is essential to highlight that hospital parking lots, especially those catering to patients attending medical consultations, experience high turnover rates. Unlike typical city parking facilities, hospital parking sees a substantial influx of patients who primarily utilize the space for their scheduled appointments, leading to frequent rotations. Additional point measurements were conducted in other hospital underground parking facilities in Salamanca and Aviles to provide a comprehensive dataset, allowing for a broader perspective on the atmospheric conditions and pollutant levels in diverse urban settings.

2.2. Sample Design

The Dräger X-am® 5600 (Dragerwerk AG & Co KGaA, Luebeck, Schleswig-Holstein, Germay) is part of a new generation of gas detectors designed specifically for personal monitoring. It can also accurately measure the concentration of 1 to 5 gases, combustible gases and vapors, as well as oxygen and toxic gas concentrations. Its compact size, audio and visual alarms, data logging and full-color display make these devices easy to handle, robust and accurate. In this case, the Dräger X-am 5600, a portable gas detector, was outfitted with low-sensitivity sensors for NO and NO_2 (Figure 2). This compact instrument, designed for measuring up to six gases, features NO and NO_2 sensors with low cross-interference (sensor numbers 6811545 and 6812600). The NO sensor boasts a range of 0 to 200 ppm, a resolution of 0.1 ppm, and ±3% sensitivity to the measured value, while the NO_2 sensor covers a range of 0 to 50 ppm, with a resolution of 0.02 ppm and ±3% sensitivity to the measured value. This equipment records NO and NO_2 levels at intervals of 10 s, generating a comprehensive dataset of real-time measurements. Subsequently, these recorded levels are downloaded and meticulously analyzed in an Excel file, allowing for a detailed examination of temporal variations and concentration trends over the monitoring period. This robust data analysis process contributes to precision and reliability. The analysis of air pollutant samples involved the application of a time series model, which constitutes a sequential arrangement of data points measured at uniform intervals over successive points in time. This approach allows for the discernment of the temporal trends in NO and NO_2 concentrations at the site, providing valuable insights into how these concentrations vary over time. Maintaining adherence to recommended standards for both environmental and occupational measurements [43,44], all measurements were consistently taken at a height of 1.5 m above ground level [45].

In strict compliance with UNE–EN 689 standards [46], it is required to conduct 3 to 6 representative exposure measurements for workers within each SEG (similar exposure group). In the event that a sample surpasses 20% of the OELV, a statistical test is necessary to assess whether less than 5% of exposures in the SEG exceeded compliance levels. The results also guided the recommended time intervals, ranging from 1 to 3 years for conducting subsequent measurements, contingent on exposure levels.

Figure 2. Multigas detector Dräger X-am 5600 (Dragerwerk AG & Co KGaA, Luebeck, Schleswig-Holstein, Germany).

2.3. Limits

Our exploration considered occupational exposure limit values (OELVs) and short-term OELV. OELV reflects average exposure based on an 8 h workday and a 40 h workweek. Simultaneously, short-term OELV, a 15 min exposure limit, should not be surpassed at any time during a workday, even if the 8 h OELV is compliant. As stipulated by Spanish and European legislation, recommended OELVs for NO and NO_2 stand at 2 ppm and 0.5 ppm, respectively, with a short-term OELV of 1 ppm for NO_2 [47]. Table 1 presents the occupational exposure limit values (OELVs) for NO and NO2 in various countries, as compiled by the IFA [48]. These limits apply to occupational exposure for parking workers, while environmental values are designated for users.

Table 1. NO and NO_2 OELVs in different countries [48].

	NO_2				NO			
	Limit Value—8 h		Limit Value—Short Term		Limit Value—8 h		Limit Value—Short Term	
	ppm	mg/m³	ppm	mg/m³	ppm	mg/m³	ppm	mg/m³
Australia	3	5.6	5	9.4	25	31		
Austria	0.5	0.96	1	1.91	2	2.5		
Belgium	0.5	0.96	1	1.91	2	2.5		
Canada-Ontario	3		5		25			
Canada-Québec	3	5.6	5	9.4	25	31		
Denmark	0.5	0.96	2	4	2	2.5	4	5
European Union	0.5	0.96	1	1.91	2	2.5		
Finland	0.5	0.96	1	1.9	2	2.5		
France	0.5	0.96	1	1.91	2	2.5		
Germany (AGS)	0.5	0.95	1	1.9	2	2.5	4	5
Germany (DFG)	0.5	0.95	0.5	0.95	0.5	0.63	1.0	1.26
Hungary		0.96		1.91		2.5		
Ireland	3	5	5	9	25	30	35	45
Italy	0.5	0.96	1	1.91	2	2.5		
Latvia	0.5	0.96	1	1.91	2	2.5		
New Zealand	3	5.6	5	9.4	25	31		
Norway	0.5	0.96	1	1.91	2	2.5		
China		5		10		15		

Table 1. *Cont.*

	NO_2				NO			
	Limit Value—8 h		Limit Value—Short Term		Limit Value—8 h		Limit Value—Short Term	
	ppm	mg/m³	ppm	mg/m³	ppm	mg/m³	ppm	mg/m³
Poland		0.7		1.5		2.5		
Romania	0.5	0.96	1	1.91	2	2.5		
Singapore	3	5.6	5	9.4	25	31		
South Africa	0.4				50			
South Africa Mining	3	5	5	9	25	30	35	45
South Korea	3		5		25			
Spain	0.5	0.96	1	1.91	2	2.5		
Sweden	0.5	0.96	1	1.9	2	2.5		
Switzerland	1.5	3	3	6	5	6		
The Netherlands	0.5	0.96	1	1.91	2	2.5		
USA-NIOSH			1	1.8	25	30		
USA-OSHA			5	9	25	30		
United Kingdom	0.5	0.9	1	1.91	25	30		

European Environment Agency standards prescribe a maximum of 200 μg/m^3 (0.1 ppm) for nitrogen dioxide in one hour and 40 μg/m^3 (0.02 ppm) as an annual average [32,49]. In compliance with Directive 2008/50/EC and RD 102/2011, the limit value for NOx to safeguard ecosystems is set at 30 μg/m^3 as an annual average, representing a new critical level for vegetation protection. This standard reflects a commitment to maintaining environmental quality and mitigating the impact of nitrogen oxides on ecosystems, aligning with established regulatory frameworks.

Notably, certain countries, such as Japan, enforce even lower NO_2 environmental levels, with a limit of 113 μg/m^3 (0.06 ppm) in one hour. The World Health Organization (WHO) strongly advocates for an annual average of 10 μg/m^3 (0.01 ppm) and a short-term (24 h) value of 25 μg/m^3 for NO_2 [50] and a 1 h maximum of 200 μg/m^3 (0.1 ppm) [51].

3. Results

Table 2 presents a comprehensive summary of NO and NO_2 concentration levels in Oviedo car park level -2, offering valuable insights into the temporal variations and potential exposure risks associated with vehicular emissions in the underground facility. The dataset covers diverse dates, capturing variations in traffic and sampling times. Additionally, it is important to note that the table also provides data on NO and NO_2 levels outside the parking facility, collected at an air quality station proximal to the parking area [52]. This inclusion allows for a more holistic understanding of the air quality dynamics, comparing indoor and outdoor pollutant levels to assess the overall impact on environmental and public health in the vicinity.

Figure 3 illustrates the percentage of working days during which, for at least one hour, the NO_2 levels exceed 70% of the proposed limits set by the World Health Organization (WHO) and the European Environment Agency.

To contextualize the Oviedo parking facility levels, spot measurements were conducted in two other hospital parking facilities in different cities. The results of these measurements are presented in Table 3.

Table 2. Indoor and outdoor NO and NO_2 levels in Oviedo car park.

						Underground Car Park							Outdoor	
						NO			NO_2				NO	NO_2
nº	Date	Nº Vehicles	Start	Finish	Hours	Average (ppm)	Max (ppm)	Standard Deviation (σ)	Average (ppm)	Max (ppm)	Max (1 h Average) (ppm)	Standard Deviation (σ)	Max (1 h Average) (ppm)	
1	18/07/2019	1614	8:32	19:08	10:36	0.045	0.60	0.113	0.039	0.58	0.095	0.050	0.022	0.016
2	19/07/2019	1481	7:46	13:46	6:00	0.201	1.00	0.194	0.097	0.62	0.165	0.060	0.014	0.019
3	15/02/2021	1552	7:49	15:36	7:47	0.354	1.30	0.194	0.047	0.45	0.083	0.043	0.123	0.041
4	16/02/2021	1590	8:00	16:24	8:24	0.087	0.80	0.155	0.033	0.25	0.083	0.037	0.053	0.038
5	17/02/2021	1618	7:51	16:48	8:57	0.117	1.10	0.201	0.037	0.14	0.072	0.033	0.069	0.036
6	08/04/2021	1640	7:36	17:59	10:23	0.124	1.50	0.203	0.009	0.31	0.033	0.022	0.056	0.030
7	09/04/2021	1600	7:34	16:50	9:16	0.246	3.50	0.244	0.0167	0.14	0.075	0.029	0.080	0.038
8	15/04/2021	1605	7:51	15:42	7:51	0.023	1.00	0.091	0.03	0.18	0.064	0.032	0.052	0.040
9	07/09/2021	1484	8:52	13:01	4:09	0.196	7.3	0.326	0.026	1.17	0.074	0.076	0.054	0.038
10	15/09/2021	1679	7:49	18:22	10:33	0.0811	1.6	0.172	0.032	0.51	0.100	0.048	0.026	0.028
11	16/09/2021	1662	8:07	17:48	9:41	0.1268	0.8	0.190	0.022	0.36	0.087	0.042	0.018	0.022
12	17/09/2021	1618	7:54	14:48	6:54	0.13	1	0.170	0.042	0.24	0.072	0.034	0.027	0.023
13	28/09/2021	1654	8:03	17:56	10:53	0.182	0.8	0.202	0.052	0.26	0.107	0.036	0.037	0.029
14	30/09/2021	1642	8:03	14:32	6:29	0.176	1.7	0.211	0.046	0.32	0.098	0.048	0.066	0.030

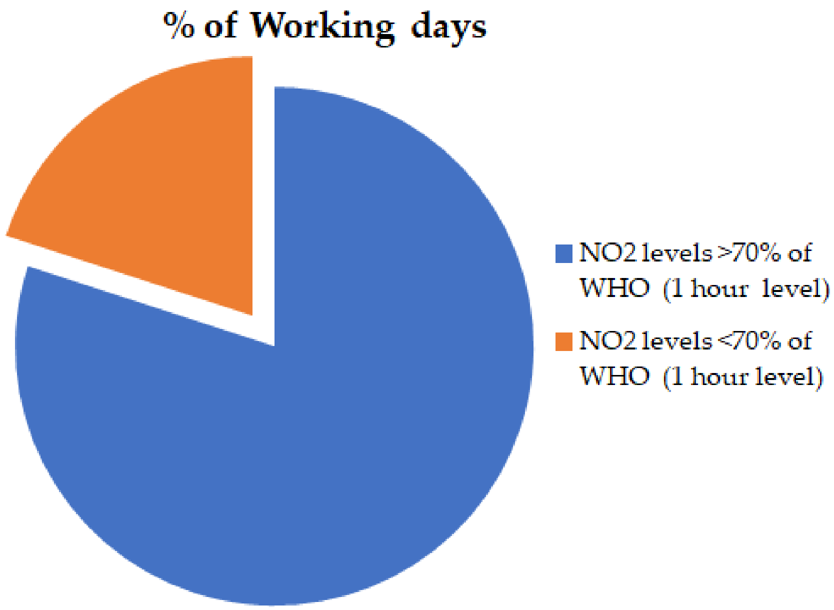

Figure 3. Percentage of working days and NO_2 levels (for at least one hour).

Table 3. NO and NO_2 measurement summary of other hospitals' underground car parks.

						NO		NO_2		
nº	**Date**	**City**	**Start**	**Finish**	**h**	**Average (ppm)**	**Max (ppm)**	**Average (ppm)**	**Max (ppm)**	**Max (1 h Average) (ppm)**
1	21/11/2023	Salamanca P-2	7:30	16:20	8:50	0.03	0.7	0.02	0.18	0.039
2	21/11/2023	Salamanca P-1	7:56	16:41	8:45	0.08	0.8	0.06	0.2	0.085
3	27/04/2023	Aviles P-2	7:36	14:27	6:51	0.47	1.8	0	0.11	0.001
4	27/04/2023	Aviles P-3	7:48	14:21	6:33	0.6	1.8	0.01	0.1	0.03

4. Discussion

The results indicate that all measured values fall below established occupational exposure levels for both NO and NO_2, with average levels generally remaining at or below 10% of the occupational exposure limit values (OELVs), except for specific instances (e.g., NO_2 on 19 July 2019 and NO on 15 February 2021), where values approached 20% OELV. While punctual measurements recorded maximum levels of 7.3 ppm for NO and 1.17 ppm for NO_2, these instances were of a short duration, lasting less than one minute.

However, it is essential to note that these exposure limit values are primarily designed for occupational use, and the HUCA parking facility caters to a diverse user base, including vulnerable patients and children attending for medical needs. In light of this, there is a critical need to revisit the current exposure limit standards, considering the unique characteristics of parking facilities associated with healthcare institutions.

Despite overall compliance with occupational standards, environmental values raise concerns. Approximately 75% of the sampled days witnessed maximum one-hour NO_2 concentrations surpassing 70% of the World Health Organization (WHO) recommended value, with around 20% of the sampled days exceeding the 0.1 ppm NO_2 level in one hour as per WHO guidelines.

The environmental assessment of NO_2 levels revealed a concerning pattern, with a maximum reported level of 0.165 ppm for a one-hour average, exceeding the World Health Organization (WHO) recommendations. Notably, around 20% of the sampled days exhibited at least one hour of NO_2 concentrations surpassing WHO guidelines, particularly prevalent around 11:00 am. The dynamic nature of NO_2 levels during peak hours raises concerns about potential health risks, especially for the vulnerable population. Given that asthma and other respiratory conditions worsen with exposure to NO_2, individuals with sensitivities should avoid underground environments in such conditions.

Despite compliance with legal requirements for NOx levels in a new parking facility (established in 2014), the study underscores the need for heightened awareness and precautionary measures, especially during peak hours. Vulnerable patients are strongly advised to utilize outdoor parking spaces whenever possible, with indoor parking discouraged during traffic peaks, especially in level -2. Visitors are encouraged not to linger in the parking area while waiting for consultations, and workers are advised to minimize their time spent in vehicles, opting instead for enclosed spaces with a fresh supply of outside air.

The temporal patterns in the maximum one-hour average NO_2 concentration indicate that peak levels typically manifest around 11:00 am, aligning with increased vehicular activity within the parking facility. A continuous traffic flow is observed until approximately 4:00 pm, after which concentrations experience a significant decline. Typically, there is heightened activity during the morning shift, primarily driven by patients attending consultations, and there is also a larger number of workers during this time.

Histogram analysis reveals that while most measurements hover close to zero, implying predominantly low concentrations of NO and NO_2, there are intermittent periods marked by potentially hazardous levels. The association between NO and NO_2 levels, evident in similar temporal patterns of peaks and valleys, is nuanced, varying across specific time series segments. This variability can be attributed to individual vehicle emissions characteristics, with newer Euro 6 vehicles emitting approximately 30% of NOx in NO_2.

Figure 4 illustrates NO and NO_2 levels throughout a typical working day, highlighting concentration peaks during vehicular entry and exit times and a significant reduction around 15:40.

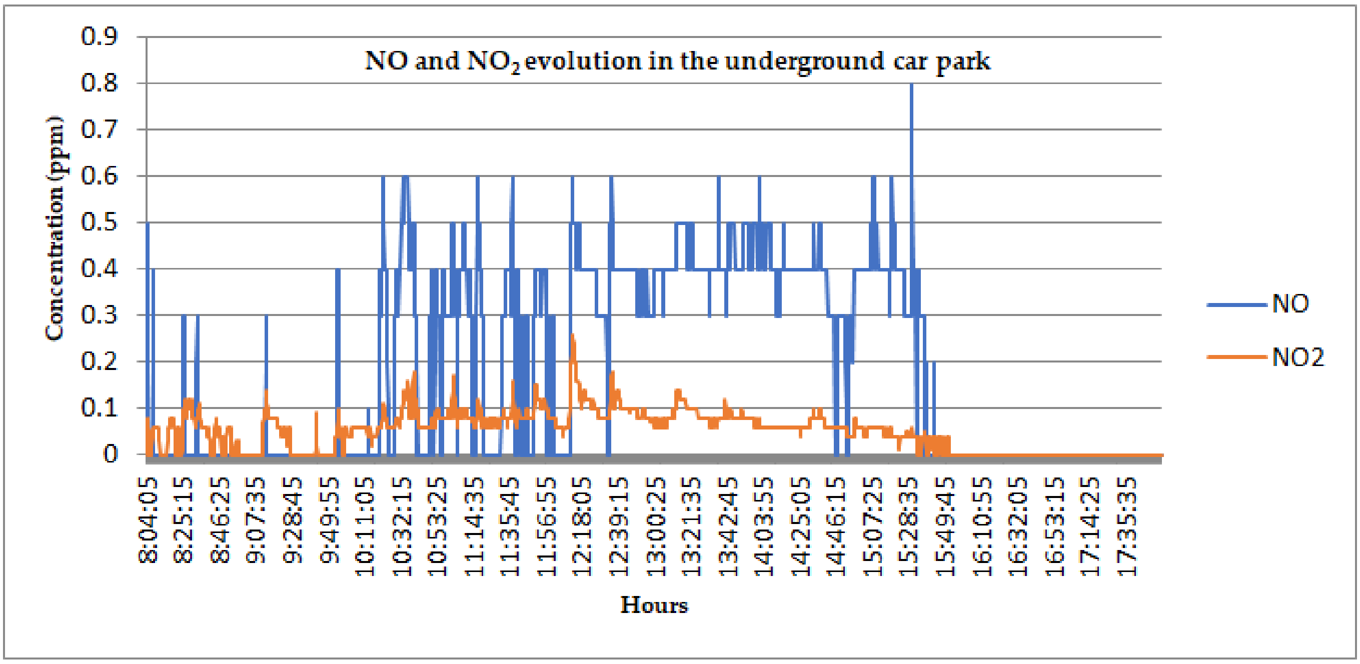

Figure 4. Representative working day NO and NO_2 levels.

This graph exemplifies the concentration trends of NO and NO_2 on an average working day, showcasing heightened levels during vehicle entry and exit times and a substantial decrease around mid-afternoon. Elevated concentrations align with vehicular movements, emphasizing the dynamic nature of gas levels within the parking facility.

Recommendations encompass the implementation of an Enhanced Ventilation System specifically designed for peak hours, aiming to swiftly decrease pollutant concentrations and prioritize safety, particularly for vulnerable individuals. It is imperative to advocate for using outdoor parking facilities, especially among groups susceptible to respiratory issues, to minimize their exposure to harmful emissions effectively. The introduction of an Emission-Based Access Control policy, which restricts vehicle access during peak hours based on emission levels and includes access restrictions to the underground parking based on vehicles' eco-stickers (O, Eco, B, and C), can emerge as a proactive strategy to limit emissions from vehicles with higher environmental impacts. This measure is crucial for minimizing NOx accumulation. Strategic placement of clear signage and the execution of targeted awareness campaigns are vital components of informing users about potential health risks associated with NOx actively discouraging using the underground parking area as a waiting space. Establishing a routine monitoring system for NOx levels and periodic publication of findings is essential for sustained compliance with health and safety standards. This collective approach contributes to developing a comprehensive and sustainable air quality management strategy within the discussed context.

The data from other hospitals exhibiting similar patterns with a significant influx of vehicles during the morning shift, particularly from patients attending consultations, suggest the potential for comparable situations. With a limited number of samplings, we have obtained a sample that is at 85% of the levels recommended by the WHO for a one-hour duration. These findings underscore the relevance of addressing air quality concerns in hospital parking facilities, especially during peak hours of vehicular activity.

5. Conclusions

The outcomes of this investigation illuminate the atmospheric conditions within the Hospital Universitario Central de Asturias (HUCA) underground parking, specifically in parking level -2. They offer crucial insights into the potential health risks associated with exposure to NO and NO_2. The conclusions from data analysis collected across various dates and times are pivotal in shaping targeted recommendations for occupational and general user groups.

The study reveals a general adherence to occupational exposure limits for NO and NO_2 in the hospital parking facility. However, occasional instances approached 20% of the occupational exposure limit values (OELVs), signaling the need for nuanced considerations. Environmental assessments uncovered significant concerns, with around 75% of sampled days surpassing 70% of the World Health Organization's (WHO) recommended values for maximum one-hour NO_2 concentrations. These environmental challenges emphasize addressing air quality concerns within healthcare parking facilities.

The unique characteristics of healthcare parking facilities, catering to a diverse user base that includes vulnerable patients and children, prompt a reconsideration of current exposure limit standards designed for occupational settings. The study underscores the need for standards that better align with the varied composition of users in healthcare parking facilities.

Temporal patterns in NO_2 concentrations, especially during peak hours, raise health concerns, particularly for individuals with respiratory conditions. The dynamic nature of NO_2 levels during peak hours suggests potential health risks for vulnerable populations. This underscores the importance of tailored mitigation strategies to protect users' health.

Recommendations for mitigation include implementing an Enhanced Ventilation System during peak hours to reduce pollutant concentrations rapidly. Encouraging outdoor parking for vulnerable groups, especially those with respiratory issues, is crucial to mitigate exposure to harmful emissions. Introducing an Emission-Based Access Control policy during peak hours can minimize NOx accumulation. Strategic signage and awareness campaigns are proposed to inform users about health risks and discourage the use of underground parking as a waiting space. Routine monitoring and publication of findings are essential for compliance with continuous health and safety standards. Using environmental NOx values to design underground car park ventilation systems, at least in hospital facilities, is highly recommended.

The study's relevance extends beyond the specific parking facility studied, as data from other hospitals with similar traffic patterns underline the importance of addressing air quality concerns, especially during heightened vehicular activity. This broader perspective emphasizes the need for comprehensive strategies to manage air quality in hospital parking facilities, contributing to the ongoing discourse on indoor air quality in healthcare settings.

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