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Environmental pollutants particulate matter ($PM_{2.5}$, PM_{10}), Carbon Monoxide (CO), Nitrogen dioxide (NO_2), Sulfur dioxide (SO_2), and Ozone (O_3) impact on lung functions

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ABSTRACT

Objectives: Environmental pollution has been an emerging global public health problem worldwide. This study aimed to investigate the impact of air pollutants particulate matter $PM_{2.5}$, PM_{10}, Carbon Monoxide (CO), Nitrogen Dioxide (NO_2), Sulfur Dioxide (SO_2), and Ozone (O_3) on lung functions.

Methods: In this matched case-control, cross-sectional study, two schools were selected located in two different areas, school # 1 was located near a traffic-polluted area, and school # 2 was in an area away from the traffic-polluted area. Of a total of 300 students, 150 (75 boys and 75 girls) students from school # 1 and 150 students (75 boys and 75 girls) were from school # 2 located away from a traffic-polluted area. The mean age of students was 13.53 ± 1.20 years. The students in both schools were enrolled in the study on their voluntary involvement, and health status, matched by age, height, weight, gender, nationality, regional, socioeconomic, and cultural background, and the admission criteria of their schools. The environmental pollutants particulate matter "$PM_{2.5}$, PM_{10}, CO, NO_2, SO_2, and O_3" were recorded. The level of air pollutants in school # 1 was 35.00 ± 0.65, significantly higher compared to school # 2 (29.95 ± 0.32). The pulmonary function test (PFT) parameters were performed on an electronic Spirometer. The parameters included "Forced Vital Capacity (FVC); Forced Expiratory Volume in the first second (FEV1); Forced Expiratory Ratio (FEV1/FVC %); Forced Expiratory Flow 25 % (FEF 25 %); Forced Expiratory Flow 50 % (FEF 50 %); Forced Expiratory Flow 75 % (FEF 75 %) and Peak Expiratory Flow Rate (PEFR) were recorded".

Results: The results revealed that the mean values for FEF-50 % (3.31 ± 1.18); FEF-75 % (1.66 ± 0.80) and PEFR (5.02 ± 1.79) were significantly decreased among students studying in school situated in a motor vehicle polluted area compared to those studying in school positioned away from the motor vehicle polluted area FEF-50 % (5.85 ± 6.21) ($p = 0.001$); and FEF-75 % (4.49 ± 6.87) ($p = 0.001$), and PEFR (8.14 ± 15.08) ($p = 0.012$). However, the groups had no significant difference between FVC, FEV1, FEV1/FVC Ratio (%), and FEF-25 %. The findings further demonstrated that the pattern of lung function impairment was peripheral airway lung involvement amongst the students in schools placed in environmentally contaminated areas.

Conclusions: Environmental pollution significantly impaired lung function parameters FEF-50%, FEF-75% and PEFR, with peripheral airway lung involvement among students who studied in a school situated in motor vehicle-polluted areas. The results highlight the importance of the implementation of effective mitigation strategies and promoting sustainable and environmentally friendly transportation options to combat environmental pollution.

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1. Introduction

Over the past three decades, air pollution has been a global public health problem worldwide. The swift urbanization and industrial revolution increased environmental pollution to a dangerous level. The numerous pollution sources change the environment's arrangement and composition, including air, water, and soil (Manisalidis et al., 2020).

The severity and composition of air pollution can vary based on the geographical location, weather conditions, population, and human activities in each area. The multiple sources of air pollution are natural and human-made, which contaminate the environment. Industrial emissions have been recognized as a substantial contributor to environmental degradation and climate change. Industrial emissions pose significant challenges to environmental and human well-being. Industrial activities including manufacturing, power generation, and chemical production release pollutants such as "particulate matter (PM), carbon monoxide (CO), nitrogen oxides (NOx), Ozone (O_3), sulfur dioxide (SO_2), and volatile organic compounds" (VOCs). These gases and chemical substances contaminate the environment (World Health Organization (WHO), 2023).

The WHO has declared that environmental pollution is a silent killer, killing about seven million people each year, or 15.5 people per minute, because of air pollution. Pollution affects both human health and global economies as 400 billion US Dollars are spent on subsidizing fossil fuel use [World Health Organization, 2023]. Environmental pollution developed a highly hazardous situation with considerable damage to the global human health and living organisms. It is a leading risk factor for several illnesses, mainly respiratory (Meo et al., 2019; Deng et al., 2023; Su et al., 2023), coronary artery diseases (Rajagopalan et al., 2018), endocrine (Zhang et al., 2020; Meo et al., 2015), nervous system disorders (Yuan et al., 2023), and cancer (Shehata et al., 2023).

The rapid economic development, population growth and migration of people from various countries resulted in an increase in metropolitan boundaries and the number of motor vehicles in the urban areas. The increase in motor vehicle fleet size has increased environmental pollution (Meo et al., 2019). Evidence suggests that motor vehicles generate enormous quantities of CO2, CO, NO_2, $PM_{2.5}$ and PM_{10}, which contaminate the environment and cause environmental pollution (Lin et al., 2019).

Worldwide, many schools are located near roadways with heavy traffic or traffic-related polluted areas. Exposure of children and adolescents to these environmental pollutants, particularly during their physiological developmental age period increases the risk of respiratory diseases with other health issues. In the current global situation of environmental pollution, this study is essential to understand the impact of traffic-related environmental pollution on adolescents' respiratory functions. Lung function tests hold significant clinical importance in various aspects of respiratory care. Lung function tests provide valuable information to health care professionals regarding the diagnosis and prognosis of respiratory disorders and also the impact of air pollution on the respiratory system. This study aimed to investigate the effect of environmental pollutants "particulate matter $PM_{2.5}$, PM_{10}, nitrogen dioxide (NO_2), carbon monoxide (CO), sulfur dioxide (SO_2), and ozone (O_3)" on lung functions of students studying in schools located in or away from motor vehicle air-polluted areas.

2. Subjects and Methods

This matched case-control, "cross-sectional study was conducted in the Department of Physiology, College of Medicine, King Saud University, Riyadh, Saudi Arabia.".

2.1. Selection of schools

In this study, two schools located in two separate areas of Riyadh, Saudi Arabia were selected. The first school was situated near a motor vehicle-polluted area, within 200 m of the main traffic road. This school was considered a motor vehicle pollutant-exposed school (exposed group, school-1). The second school was located about 1,500 m away from the main road. This school was considered a school less exposed to motor vehicle pollutants (control group, school 2).

2.2. Selection of students

This study selected 300 students, 150 (75 boys and 75 girls) from school # 1, and 150 (75 boys and 75 girls) from school # 2. The students were recruited by their voluntary involvement, same age, gender, height, weight, socioeconomic status, class level and health status. This matching was to ensure valid and reliable comparisons between the two groups.

2.3. Exclusion criteria

Students with known cases of respiratory, coronary, endocrine, renal, and nervous system disorders were excluded from the study. Moreover, students who smoke cigarettes or shisha and work or live near any industry were excluded as well (Meo and Aldeghaither et al., 2019). Students whose family members, such as father or mother were cigarette smokers were also excluded from the study to minimize the passive smoking effect on lung functions.

2.4. Measurements of air pollutants

The air pollutants were determined every hour over 24 h through the integrated sampling systems. $PM_{2.5}$, PM_{10}, CO, NO_2, SO_2, and O_3 were measured using the MP101M (2.5), MP101M (10), CO12e, AC32e, AF22e, O342e, Air Quality Monitors. The air pollutants data were also obtained from the National Center for Environmental Compliance (NCEC), Riyadh, Saudi Arabia. Moreover, daily air pollutants were recorded from the (Air Quality Index, AQI, 2022). All these methods and sources were used to obtain the air pollutant data.

2.5. Lung function test [spirometry]

The lung function tests were performed on an electronic Spirometer at a specific time of the day (10.00–13.00 h). The spirometer was calibrated daily and appropriately operated as per American Thoracic Society (ATS) guidelines. The clinical history and anthropometric parameters were recorded, and the students were briefed about the test procedure and students were encouraged to practice in the study. The test procedure was repeated three times after adequate rest. For the participants, a new disposable sterile mouthpiece was used to avoid cross-infection. These parameters recorded were: "Forced Vital Capacity (FVC); Forced Expiratory Volume in the first second (FEV_1); Forced Expiratory Ratio (FEV_1/FVC %); Peak Expiratory Flow (PEF); Forced Expiratory Flow 25 % (FEF 25 %); Forced Expiratory Flow 50 % (FEF 50 %); and Forced Expiratory Flow 75 % (FEF 75 %)".

2.6. Statistical analysis

The data were analyzed by using the "Statistical Package for Social Sciences (SPSS for Windows, version 21.0; IBM, Armonk, NY, USA). The descriptive statistics were presented as means and standard deviations (Mean $\pm$ SD); an unpaired student's *t*-test (parametric test) was applied to assess the difference in the means between the variables. The level of significance was considered at $p < 0.05$.".

3. Results

3.1. Environmental pollutants in school localities

In both schools, the air pollutants include "$PM_{2.5}$, PM_{10}, CO, NO_2, O_3,

SO_2, and total pollutants were recorded (Table 1). The mean level of environmental pollutants $PM_{2.5}$ in school # 1 was 110.64 ± 33.61 significantly higher compared to school # 2 (108.86 ± 25.04) (p = 0.004). Similarly, the mean concentration of PM 10 in school # 1 (60.22 ± 46.04) was significantly higher compared to school # 2 (27.38 ± 18.62) (p = 0.001). The concentration of Nitrogen dioxide (NO_2) was 11.32 ± 10.76, significantly higher in school #1 compared the school # 2 (6.39 ± 3.52) (p = 0.001). Moreover, the concentration of Carbon Monoxide (CO) 7.32 ± 3.20 and Sulfur dioxide (SO2) 2.36 ± 1.38 in school # 1 was high compared to school # 2 Carbon Monoxide 6.62 ± 4.15 and Sulfur dioxide 2.33 ± 1.15 but did not significantly high. However, the overall concentration of "$PM_{2.5}$, PM_{10}, CO, NO_2, O_3, SO_2," was 35.00 ± 0.65 significantly higher in school # 1 compared to school # 2 (29.95 ± 0.32) (p = 0.001) (Table 1).

3.2. Demographic variables of the students

In this study, 300 students were enrolled, 150 (75 males and 75 females) from school # 1 located in a traffic-polluted area, and 150 students (75 males and 75 females) from school # 2 located away from a traffic-polluted area. The study participants were recruited on the same age, gender, height, weight, BMI, ethnicity, health status, uniform educational and socioeconomic status.

Table 2 demonstrates the demographic variables of the students belonging to School # 1 and School # 2. The mean age of the participants was 13.53 ± 1.20 years. The average age of students from school # 1 was (n = 150, mean = 13.56; SD = 1.27), and mean age of students from school # 2 was (n = 150, mean = 13.50; SD = 1.17). A visual inspection of histograms for age (mean = 13.53; SD = 1.20) of students, normal Q-Q plots and the box plots showed the data of age in years were normally distributed for students at school # 1 and school # 2.

The average height of students at school #1 (n = 150, mean = 161.32; SD = 9.62), and school # 2 was (n = 150, mean = 162.09; SD = 9.17). While the mean weight of students at school # 1 was (n = 150, mean = 62.50; SD = 121.33; and school # 2 was (n = 150, mean = 62.91; SD = 17.71). Moreover, the BMI of students at school # 1 was (mean = 23.79; SD = 6.72 and school # 2 was (mean = 23.91; SD = 6.39. The age, height, weight, and BMI matching of the students in both schools was non-significant. It shows that the students in both schools were very well-matched for age, gender, height, weight, and BMI (Table 2).

3.3. Lung function test Parameters

In this study, the ventilatory lung function test parameters were recorded including "Forced Vital Capacity (FVC); Forced Expiratory Volume in the first second (FEV1); Forced Expiratory Ratio (FEV1/FVC %); Forced Expiratory Flow 25 % (FEF 25 %); Forced Expiratory Flow 50 % (FEF 50 %); Forced Expiratory Flow 75 % (FEF 75 %); and Peak Expiratory Flow Rate (PEFR)". The Spirometer was calibrated daily, and the tests were performed as per ATS Guidelines. The results revealed that the mean values for PEFR 5.02 ± 1.79; FEF-50 % 3.31 ± 1.18; FEF-75 % 1.66 ± 0.80 were significantly decreased among students studying in school # 1 compared to those studying in school # 2, PEFR 8.14 ± 15.08 (p = 0.012); FEF-50 % 5.85 ± 6.21 (p = 0.001); and FEF-75 % 4.49 ± 6.87 (p = 0.001). However, there was no significant difference between FVC, FEV1, FEV1/FVC Ratio (%), and FEF-25 % between the groups (Table 3).

Table 1
Environmental pollutant levels in a school situated in a motor vehicle polluted area compared to a school situated away from the motor vehicle polluted area.

Pollutants (24 hs/ average)	School # 1	School #2	Significance level
Particulate Matter $PM_{2.5}$ μg/m^3	110.64 ± 33.61	108.86 ± 25.04	0.004
Particulate Matter PM_{10} μg/m^3	60.22 ± 46.04	27.38 ± 18.62	0.001
Carbon Monoxide (CO) ppm	7.32 ± 3.20	6.62 ± 4.15	0.394
Nitrogen dioxide (NO_2) DU	11.32 ± 10.76	6.39 ± 3.52	0.001
Ozone O_3 (DU)	18.11 ± 6.84	28.09 ± 16.65	0.001
Sulfur dioxide (SO_2) DU	2.36 ± 1.38	2.33 ± 1.15	0.548
Total air pollutants	35.00 ± 0.65	29.95 ± 0.32	0.001

4. Discussion

Environmental pollution has been a global public health challenge of the 21st century. Rapid urbanization, industrialization and the rising number of motor vehicles are the leading causes of environmental pollution [Meo et al., 2019]. The various air pollutants produced by industries and motor vehicles contaminate the atmosphere and damage the lungs (Fig. 1). These pollutants include $PM_{2.5}$, PM_{10}, CO, NO_2, and VOCs. Among all the body systems the respiratory system is the most vulnerable body systems to environmental pollution. This study investigates the effect of $PM_{2.5}$, PM_{10}, CO, NO_2, SO_2, and O_3 on lung functions in students studying in schools located in motor vehicle-allied air-polluted areas. Lung function plays a major role in the diagnosis and management of respiratory diseases and serves as a vital indicator of overall well-being. The assessment of lung functions provides valuable information for diagnosing, monitoring, and managing a wide range of respiratory conditions.

(Meo et al., 2019) performed a pilot study and investigated the effect of motor vehicle pollution on lung function and found that FVC and FEV1 were decreased due to traffic-allied air pollution. (Zhang et al., 2023) determined the acute impact of exposure to polycyclic aromatic hydrocarbons (PAHs) on the respiratory system in fourteen healthy females working in an office. The authors found that PAH levels were more in winter weather than in the summer and autumn. These pollutant exposures showed a relationship with reduced lung functions.

(Zhou et al., 2022) examined the relationship between $PM_{2.5}$ and lung function among children in China. There was a significant negative relationship between $PM_{2.5}$ and lung functions, FVC, FEV1, and PEF in children with asthma. Another study (Yang et al., 2021) investigated the impact of prolonged exposure to $PM_{2.5}$ on lung functions in China. This study provides reasoning and confirms that prolonged exposure to ambient $PM_{2.5}$, organic matter, and nitrate were linked with decreased large and small airway function.

Similarly, (Suhaimi et al., 2022) determined the relationship between traffic-related air pollution (TRAP) and respiratory health among children in high and low-traffic areas. It was identified that children exposed to an elevated level of TRAP have an increased risk of impaired lung functions. In another study, (Suhaimi et al., 2023) conducted an interesting study in Malaysia and determined the association between exposure to TRAP and respiratory health effects. The air pollutant, PM2.5 is the leading air pollutant which influences respiratory features and lung function. It was also found that school children's exposure to high TRAP increases the risk of lung function reduction. The findings of these studies conducted by (Suhaimi et al., 2022; Suhaimi et al., 2022) are in agreement with the present study findings that environmental air pollutants negatively affect lung functions.

The present study investigated the impact of air pollution on lung function among school adolescents. It was identified that environmental pollutants $PM_{2.5,}$ $PM_{10,}$ $NO_{2,}$ and $O_{3,}$ were significantly higher in a school located near a motor vehicle area compared to a school situated away from a traffic-congested area. It was found that motor vehicle-allied environmental pollutants cause reduced lung function with peripheral airway lung impairment among the students studying in a school located in an air-polluted area compared to the students who study in a school situated away from the polluted areas. In short, the present study findings suggested that exposure to air pollution reduced

Table 2
The age, height, weight, and BMI of students (n = 300).

Variable	School (n = 150 in each school)	Mean	SD	Minimum	Maximum	Significance level
Age (years)	School # 1 students	13.56	1.27	11.0	17.0	NS
	School # 2 students	13.50	1.17	11.0	16.0	
Height (cm)	School # 1 students	161.32	9.62	143.0	183.0	NS
	School #2 students	162.09	9.17	143.50	182.0	
Weight (kg)	School #1 students	62.50	21.33	29.0	140.0	NS
	School # 2 students	62.91	17.71	31.0	130.0	
BMI kg/m)^2	School #1 students	23.79	6.72	12.00	46.40	NS
	School #2 students	23.91	6.39	12.90	46.12	

NS = non-significant.

Table 3
Lung function parameters comparison between students studying in a school located in polluted areas compared to students studying in a school located away from polluted areas.

Parameters	School	Descriptive Mean	SD	*t*-test of equality of Variances *T*	*Df*	Mean D	Sig.
FVC (L)	1	3.96	1.30	1.65	298	0.234	0.100
	2	3.72	1.15				
FEV1 (L/Sec)	1	3.05	0.81	0.964	298	0.094	0.336
	2	2.96	0.89				
FEV1/FVC Ratio (%)	1	77.24	13.91	0.478	298	0.914	0.633
	2	76.32	18.83				
PEFR (L/Sec)	1	5.02	1.79	2.51	298	3.11	0.012
	2	8.14	15.08				
FEF-25 % (L/Sec)	1	4.60	1.64	0.534	298	0.096	0.594
	2	4.70	1.47				
FEF-50 % (L/Sec)	1	3.31	1.18	4.90	298	2.53	0.001
	2	5.85	6.21				
FEF-75 % (L/Sec)	1	1.66	0.804	4.99	298	2.82	0.001
	2	4.49	6.87				

lung function with peripheral airway lung impairment, with the most probable mechanisms involved being airway inflammation and airway wall remodelling. This study provides an insight into the effects induced by exposure to air pollutants associated with underlying mechanisms in lung function impairment.

4.1. Potential Mechanism: How does particle pollution impair lung functions

The air pollutants particulate matter less than PM2.5 µg can enter the respiratory system, cross the conducting zone, deposit deep into the lungs and induce inflammation. Airway inflammation enhances airway responsiveness to air particle pollution and reduces lung function through bronchoconstriction. Moreover, air pollution allied with inflammation damages the alveolar-capillary barrier and disturbs the physiological balance between inflammatory conditions and the repair of anti-inflammatory defences. Environmental air pollution may affect the permanence or progression of these conditions through inflammatory effects in the respiratory tree and develop chronic respiratory conditions including chronic obstructive lung diseases (Zhao et al., 2019; Wang and Liu, 2023).

4.2. Study strengths and limitations

This study has some strengths and limitations. This study investigated the environmental pollution impact on lung functions among school adolescents studying in schools located near and away from motor vehicle air-polluted areas. The mean concentration of environmental pollutants $PM_{2.5}$, PM_{10}, CO, NO_2, SO_2, and O_3 were recorded during the study period. The study findings are based on these common air pollutants, the students were matched for age, height, weight, BMI, and socioeconomic levels as lung functions depend on these

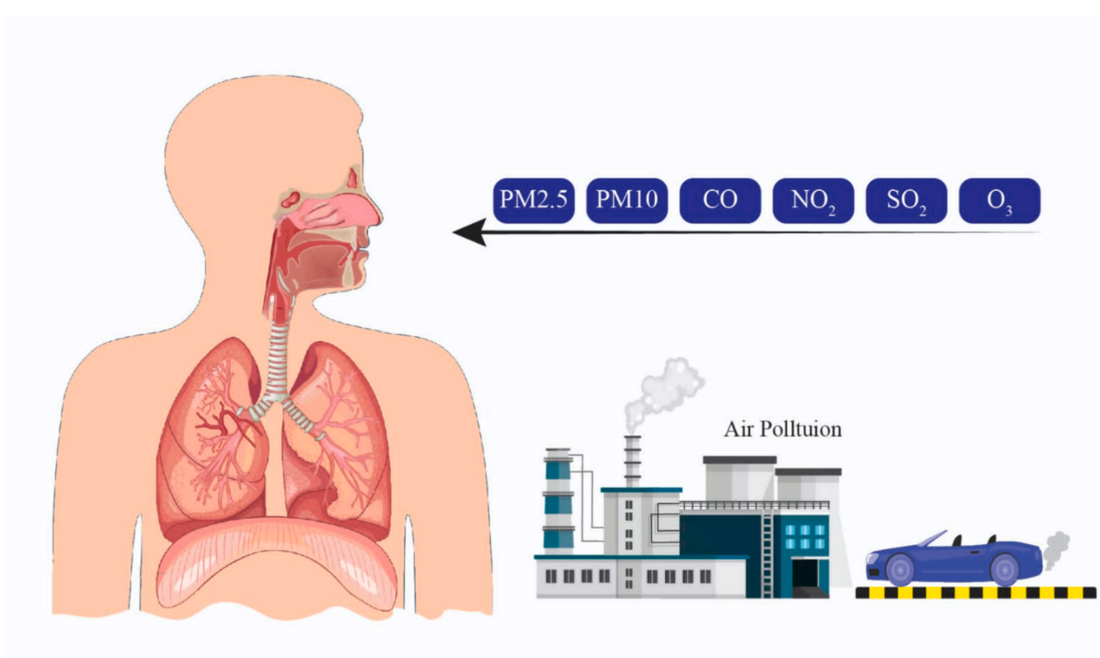

Fig. 1. Environmental pollutants entry into the lungs and pathophysiology.

physiological parameters. There is a rare matching in the studies and investigation of the main air pollutants. The limitation is that the due to COVID-19 pandemic and lockdown public activities were restricted there was a reduction in air pollution because of decreased industrial, economic activities, fewer vehicles on roads, and decreased energy consumption, reduced traffic emissions. These factors collectively led to improvement in air quality and a reduction in air pollution levels during the lockdown periods worldwide. This may hence be not an actual reflection of the magnitude of the impact of these pollutants as produced during normal traffic operations.

5. Conclusions

Environmental pollution concentration was significantly higher in motor vehicle-congested areas compared to areas away from motor vehicle-congested areas. The lung function parameters "Forced Expiratory Flow 50 % (FEF-50 %), Forced Expiratory Flow 75 % (FEF-75 %), and Peak Expiratory Flow Rate" (PEFR) were significantly reduced among students studying in schools located in motor vehicle-polluted areas compared to those students studying in schools located away from vehicle-congested areas. The results further revealed that air pollution causes a decline in lung function with most probably obstructive pattern and peripheral air lung involvement. To combat this issue, it is crucial to implement effective mitigation strategies, as well as promote sustainable and environmentally friendly transportation options. Continued research and collaboration between policymakers, researchers, and the automotive industry are essential for developing innovative solutions to reduce motor vehicle emissions.

Ethical Statement

"Ethical approval was obtained from the Institutional Review Board, College of Medicine, King Saud University, Riyadh," KSA (Ref # 21/01099/IRB).

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Sultan Ayoub Meo: Writing – review & editing, Project administration, Conceptualization. **Mustafa A Salih:** . **Joud Mohammed Alkhalifah:** Validation, Investigation, Formal analysis, Data curation. **Abdulaziz Hassan Alsomali:** Validation, Investigation, Formal analysis, Data curation. **Abdullah Abdulrahman Almushawah:** Visualization, Validation, Formal analysis, Data curation.

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