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The Association Between Particulate Matter Air Pollution and Cardiopulmonary Health Around the Kriel Coal-Powered Station of Mpumalanga, South Africa

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Abstract: Air pollution, particularly from particulate matter (PM), has emerged as a critical public health concern globally, with significant implications for respiratory and cardiovascular health. This study investigates the relationship between particulate matter (PM) air pollution and the incidence of cardiopulmonary conditions in the Kriel community near the Eskom Kriel coal-power station in Mpumalanga, South Africa. A quantitative, cross-sectional, and descriptive design was employed, analysing health records from 62 patients at the Kriel Community Health Centre (CHC) from January 1 to June 30, 2017. Data on ambient PM levels, specifically PM_{10} and $PM_{2.5}$, were collected from the Kriel village air monitoring station during the same period. The findings revealed a significant association between elevated PM levels and the prevalence of respiratory conditions, with asthma being the most common diagnosis, particularly among individuals aged 30–34 and 50–54. The study noted higher incidences of asthma in females compared to males and indicated that meteorological factors, such as low rainfall and temperature inversions, may exacerbate pollution effects. Despite limitations, including a small sample size and challenges in diagnosing respiratory conditions in children, the study underscores the urgent need for enhanced air quality management and public health interventions to mitigate the health risks associated with PM exposure. The findings contribute to the understanding of air pollution's health impacts in under-resourced settings and provide evidence for policy recommendations aimed at improving air quality and protecting community health.

Keywords: air pollution; particulate matter (PM_{10} and $PM_{2.5}$); cardiopulmonary conditions; Kriel -Mpumalanga; environmental health

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Introduction

Air pollution, particularly from particulate matter (PM), is a critical public health issue globally, with significant implications for respiratory and cardiovascular health (Miller et al., 2024; Wafula et al., 2023). The WHO (World Health Organisation) 2024 has identified PM as one of the most harmful air pollutants, linking it to millions of premature deaths annually worldwide. PM comprises a mixture of tiny particles and liquid droplets, including chemicals, metals, and organic materials, which can be classified into two main categories based on size: PM_{10} (particles with a diameter of 10 micrometres or less) and $PM_{2.5}$ (particles with a diameter of 2.5 micrometres or less). The smaller particles ($PM_{2.5}$) are particularly harmful because they can penetrate deep into the lungs and even enter the bloodstream, causing systemic inflammation and various adverse health effects (Hamanaka & Mutlu, 2018; Araujo, 2011). In developing countries, air pollution-related health issues are exacerbated by rapid industrialisation and inadequate pollution control measures. Mpumalanga, South Africa, is a prominent example where industrial activities, including coal-based power generation and mining, significantly contribute to ambient air pollution. The region is home to several coal-power stations, which are major sources of PM pollution. A study by Ngcoliso et al. (2025) identified Mpumalanga as one of the world's most polluted areas, with PM levels frequently exceeding international air quality standards. The health risks associated with exposure to such high levels of PM are profound, particularly for vulnerable populations such as children, the elderly, and those with pre-existing health conditions (McDuffie et al., 2021; Amegah & Agyei-Mensah, 2017).

Epidemiological studies conducted worldwide have provided strong evidence that PM exposure is linked to increased incidence of respiratory and cardiovascular diseases. For instance, Monoson et al. (2023) found that exposure to ambient air pollution in urban areas of China was associated with higher risks of asthma attacks, hospital admissions for cardiovascular conditions, and mortality from respiratory diseases. Similarly, research in Europe by Gross et al. (2025) indicated that long-term exposure to $PM_{2.5}$ was correlated with increased hospital admissions for respiratory ailments and cardiovascular events, as well as elevated mortality rates. These studies underscore the urgent need for preventive actions to reduce PM exposure and its health impacts. South Africa's air quality challenges are compounded by socioeconomic factors that increase vulnerability to air pollution. Many residents of Mpumalanga – a province in South Africa – live in low-income communities near industrial zones, such as Kriel, where the prevalence of respiratory conditions has raised significant public health concerns (Kamolane-Kgadima & Kathi, 2024). The health impact of residing near coal-power stations in this community is particularly alarming, as PM exposure is known to worsen existing respiratory conditions and contribute to the onset of new cases of cardiopulmonary diseases (Millar et al., 2022). This is supported by studies showing that populations living close to industrial sources of air pollution are at higher risk of respiratory and cardiovascular morbidity and mortality (Hagemeyer et al., 2019).

The present study was conducted to assess the relationship between PM exposure and the incidence of cardiopulmonary conditions in Kriel, located in the Mpumalanga province of South Africa. This town is situated near the Eskom Kriel coal-power station, a significant source of PM pollution. By analysing the levels of PM_{10} and $PM_{2.5}$ emissions and comparing them to the incidence of respiratory and cardiovascular conditions among residents, this research aims to determine whether proximity to the power station correlates with adverse health outcomes. The study also seeks to provide insights into the role of meteorological factors, such as wind speed and temperature inversions, in influencing pollutant dispersion and health impacts (Chen et al., 2020). Previous research in similar industrial regions provides a context for understanding the findings from Kriel. For example, Heinrich et al. (1999) conducted a study in Germany that showed increased rates of respiratory disorders and allergic sensitisation among children living near industrial sites with high air pollution levels. In another study, Kiser et al. (2020) found a significant relationship between fine PM exposure and emergency room visits for asthma in Nevada, USA, highlighting the acute health effects associated with $PM_{2.5}$. The health impacts of air pollution are not confined to short-term exposure; long-term exposure has been associated with chronic conditions such as chronic obstructive pulmonary disease (COPD), lung cancer, and cardiovascular diseases (Alemayehu et al., 2020; Aithal et al., 2023).

The present study also considers the complex interactions between individual susceptibility and environmental exposure. Factors such as age, gender, socioeconomic status, and pre-existing health conditions can influence the severity of health effects experienced by individuals exposed to PM pollution. Children and the elderly are particularly vulnerable due to their physiological characteristics and immune system status, making them more likely to suffer from the effects of air pollutants (Brook et al., 2010). The differential impact of air pollution on these subpopulations is an important consideration in designing effective public health interventions. Thus, this study addresses a critical gap in the literature on air pollution and health in South Africa by evaluating the cardiopulmonary risks associated with PM exposure in Kriel. Given the ongoing industrial activities in Mpumalanga, there is a pressing need for comprehensive air quality management strategies to protect the health of residents. The results of this research may serve as a basis for revising environmental regulations and implementing measures to reduce PM emissions from coal-power stations, thereby mitigating the health impacts on vulnerable communities.

Methodology

The study employed a quantitative, cross-sectional, and descriptive design to investigate particulate matter (PM) air pollution and the incidence of cardiopulmonary conditions in Kriel, located in the Mpumalanga province of South Africa. This design is suitable for assessing both exposure and health outcomes concurrently within a representative sample of the population, enabling the identification of associations between air quality and disease prevalence. According to the World Health Organisation (2001) and studies by Aldous et al. (2012), cross-sectional studies are valuable for measuring exposure and health conditions at a single point in time, providing a snapshot of the population's health status in relation to environmental risk factors. This approach facilitates the evaluation of the potential impact of PM exposure on respiratory and cardiovascular health within the community. The study focused on the community of Kriel, located approximately 7 kilometres from the Eskom Kriel coal-power station. It included a total of 62 patient records from the Kriel Community Health Centre (CHC), covering the period from January 1, 2017, to June 30, 2017. The patient demographic was characterised by a higher proportion of females (77%, n = 48) compared to males (23%, n = 14), and more Black (68%, n = 42) than White participants (32%, n = 20). The largest age group represented was 55–60 years, accounting for 27% (n = 17) of the study population. Data were compiled using the "Recording Cardiopulmonary Conditions Form," which documented health records, and the "Recording of Ambient Particulate Matter Levels (PM_{10} and $PM_{2.5}$)" form, which provided information on air quality during the study period. These tools enabled the collection of data on the incidence of cardiopulmonary conditions and ambient PM levels in the study area.

The sample for this study consisted of all available health records from the Kriel Community Health Centre (CHC), covering a period of six months from January to June. A total of 62 patient records were included in the analysis. The study aimed to examine the association between particulate matter (PM) exposure and cardiopulmonary health outcomes among the residents of Kriel, a community located within proximity to the Eskom Kriel coal-power station. Ambient PM data, specifically for PM_{10} and $PM_{2.5}$, were obtained from the Kriel village air monitoring station, situated approximately 8 kilometres from the power station. This monitoring station is equipped to measure both PM_{10} and $PM_{2.5}$ levels and provides the necessary air quality data for the study period. The data collected allowed for the assessment of PM exposure levels and their potential impact on the health of Kriel residents, who were considered an exposed population due to their proximity to the coal-power station. The study included health records of individuals who had resided in Kriel for at least one year and children from birth, and adults up to 60 years of age. Individuals older than 60 years of age and individuals diagnosed with occupational health-related conditions such as asbestosis, coal worker's pneumoconiosis, and mesothelioma were excluded from the study. The data collection process for this study utilised two primary forms to gather information. The form for recording Cardiopulmonary conditions was used to collect demographic data and health information for each individual, including gender, age, race, duration of residence in Kriel, and the type of cardiopulmonary condition diagnosed (e.g., asthma, bronchitis, pneumonia, emphysema, and bronchiectasis).

These records were obtained from the Kriel Community Health Centre (CHC), covering the period from January 1, 2017, to June 30, 2017. The recording of Ambient Particulate Matter Levels (PM_{10} and $PM_{2.5}$) form was used to capture data on ambient air quality, including meteorological variables such as monitoring period, temperature, wind speed, and wind direction. The data were collected from the Kriel village air monitoring station, which is equipped to measure both PM_{10} and $PM_{2.5}$ levels and is located approximately 8 kilometres from the Eskom Kriel coal-power station. The station provided 24 hr data for the study period, offering realistic estimates of PM exposure for residents living within a 10 kilometre radius of the power station. The data collection process was conducted in two phases. The first phase involved obtaining health records from the Kriel CHC. The researcher collected data on all individuals meeting the inclusion criteria, recording demographic details and the specific cardiopulmonary conditions diagnosed during the study period. The CHC, located in the central business area of Kriel and operating 24 hours a day, provided a comprehensive source of health information for approximately 213 patients per week. The second phase involved collecting air quality data from the Kriel village air monitoring station. The monitoring station's data were accessed to record 24 hr average concentrations of PM_{10} and $PM_{2.5}$, as well as meteorological factors that could affect air quality, such as wind speed, wind direction, and temperature. The air monitoring network, maintained by Eskom Research Centre and the Department of Environmental Affairs, was regularly tested and calibrated by trained technicians to ensure data accuracy throughout the study period.

Validity of the data was ensured by using a calibrated air monitoring network, which was regularly maintained to provide reliable PM measurements. The data collection tools were adapted from existing research instruments used in similar studies to ensure that the information gathered was accurate and applicable to the study's objectives. To enhance reliability, the data collection instruments employed clear, concise, and standardised terminology to ensure consistency in data recording. The forms were designed to be user-friendly, minimising the risk of errors during data entry. Additionally, regular calibration and maintenance of the air monitoring equipment further ensured the reliability of the environmental data collected. The data processing and analysis involved correlating the daily particulate matter (PM) concentrations recorded at the Kriel village air monitoring station with the incidence of cardiopulmonary conditions documented at the Kriel Community Health Centre (CHC) for the corresponding day. The collected data underwent thorough examination to ensure accuracy, with any errors or omissions addressed. Information was consistently and uniformly entered, facilitating subsequent coding and tabulation. Data classification was performed according to specific attributes and common characteristics, including gender, race, and age, to enable a more detailed analysis. Descriptive statistics were employed to organise and summarise the quantitative data, providing an overview of the key trends. Univariate analysis focused on measures of central tendency, such as the mean, and measures of dispersion, such as the standard deviation, to describe the distribution of interval data. Correlation and regression analyses were conducted to determine the relationship between the incidence of cardiopulmonary conditions and PM pollution levels, assessing the strength and direction of this association. Additionally, the t-test was applied to compare the mean values of PM_{10} and $PM_{2.5}$ concentrations with the incidence of cardiopulmonary conditions, allowing for statistical evaluation of differences between the air quality levels and health outcomes.

The study received ethical approval from the Durban University of Technology's Institutional Research Ethics Committee (reference number REC 101/16). This ethical clearance was subsequently submitted to the Mpumalanga Provincial Health and Ethics Committee to obtain permission to access patient health records. Access to the health records was further requested from the District Manager at the Kriel Community Health Centres (CHCs). All patient health records and information collected during the study were treated with strict confidentiality. Data were securely stored in a locked and safe location at the Kriel CHC to ensure the protection of patient privacy. No personal identifiers were used in the analysis or reporting, maintaining the anonymity of the individuals involved in the study. A total number of 62 records of patients from the Kriel CHC (located within 10 kilometres of the Eskom Kriel coal-power station) were obtained for the period of 01 January 2017 to 30 June 2017. The result shows there were more females (77%, n = 48) than males (23%, n = 14), more blacks (68%, n = 42) than whites (32%, n = 20), and the largest age group was 55–60 years (27%, n = 17).

Findings

Results obtained from clinical data covering asthma, pneumonia, emphysema, chronic bronchitis and bronchiectasis per age group at Kriel are presented in Table 1.

Table 1. Incidence of cardiopulmonary conditions at Kriel.

Age groups	**Cardiopulmonary conditions (n = 36)**					
	Asthma	Pneumonia	Chronic bronchitis	Bronchi-ectasis	Bronchitis	Emphysema
(0–4 year)	2 (1)	0	2 (1)	2 (1)	0	0
(5–9 year)	2 (1)	2 (1)	0	0	0	0
(10–14 year)	2 (1)	0	2 (1)	0	0	0
(15–19 year)	2 (1)	0	0	0	0	0
(20–24 year)	3 (2)	0	0	2 (1)	0	0
(25–29 year	2 (1)	0	0	0	0	0
(30–34 year)	13(8)	0	0	0	0	0
(35–39 year)	3 (2)	0	0	0	0	0

(*Continued*)

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Table 1. (Continued)

Age groups	**Cardiopulmonary conditions (n = 36)**									
(40–44 year	0	0	0	0	0	0				
(45–49 year)	8 (5)	2 (1)	0	0	0	0				
(50–54 year)	10(6)	0	0	0	0	0				
(55–60 year)	3 (2)	0	0	0	0	0				
Total	50% (n = 30)	4% (n = 2)	4% (n = 2)	4% (n = 2)						
Month	Cardiopulmonary conditions and gender (n = 49)									
	Asthma		Pneumonia		Chronic bronchitis		Bronchi-ectasis		Emphysema	
	M	F	M	F	M	F	M	F	M	F
Jan	0	8 (5)	0	0	0	0	2 (1)	0	0	0
Feb	2 (1)	6 (4)	0	0	0	0	0	0	0	0
Mar	0	6 (4)	0	0	0	2 (1)	2 (1)	0	0	0
Apr	3 (2)	13 (8)	0	0	0	2 (1)	0	0	0	2 (1)
May	3 (2)	10 (6)	0	2 (1)	0	0	0	0	0	2 (1)
Jun	6 (4)	8 (5)	0	2 (1)	0	0	0	0	0	0
Total	14% (n = 9)	51% (n = 32)	0	4% (n = 2)	0	4% (n = 2)	4% (n = 2)	0	0	4% (n = 2)
Number of years resided	Cardiopulmonary conditions (n = 46)									
	Asthma	Pneu-monia	Chronic bronchitis	Bronchi-ectasis	Bronchitis	Emphysema				
1–5 years	5	0	1	2	0	0				
6–10 years	15	1	1	0	0	0				
11–15 years	9	0	0	0	0	0				
16–20 years	7	0	0	0	0	0				
21–25 years	4	1	0	0	0	0				
Total	65% (n = 40)	3% (n = 2)	3% (n = 2)	3% (n = 2)						

Note: values are represented as a percentage (%) and the number of elements in a sample are represented by (n).

Table 1 illustrates the distribution of cardiopulmonary conditions across different age groups, genders, and durations of residence in Kriel. Asthma emerged as the most prevalent condition, with the highest incidence of 13% occurring in the 30–34 age group, followed by 10% in the 50–54 age group. The lowest incidence (2%) for asthma, chronic bronchitis, and bronchiectasis was observed in the 5–9 age group, indicating variability in the occurrence of respiratory conditions across age demographics. When considering gender differences, asthma was the most common condition for both males and females. However, a significantly higher percentage of females were affected compared to males. For instance, during February, 6% of females presented with asthma compared to 2% of males. Similarly, in May, the incidence of asthma was 10% among females and 3% among males. No cases of pneumonia, chronic bronchitis, or emphysema were recorded for either gender in January, highlighting the predominance of asthma as the key respiratory condition.

The incidence of cardiopulmonary conditions also varied by the number of years residents had lived in Kriel. Asthma was most prevalent among those who had resided in the area for 6–10 years, accounting for 24% of cases, followed by 15% among those who had lived in the area for 11–15 years. Chronic bronchitis and bronchiectasis were most evident in individuals who had lived in Kriel for 1–5 years. The lowest incidence of asthma, at 6%, was recorded among those who had resided in the area for 21–25 years. These findings underscore the relationship between age, gender, and duration of residence with the prevalence of respiratory conditions, highlighting asthma as the predominant health concern in the Kriel community. The data suggests potential links between prolonged exposure to environmental pollutants and respiratory health risks, particularly among specific demographic groups.

Particulate Matter (PM) concentration data

$PM_{2.5}$ Concentration measured at kriel village monitoring station

January

Figure 1 shows that on the 13th of January, the atmospheric concentration of $PM_{2.5}$ ranged from 46 to 53 µg/m^3. The monthly $PM_{2.5}$ average was 28 µg/m^3. The horizontal dotted line depicts the National Ambient Air Quality Standard (NAAQS) set for $PM_{2.5}$ by the Department of Environmental Affairs in South Africa, which cannot be exceeded within a 24-hour period.

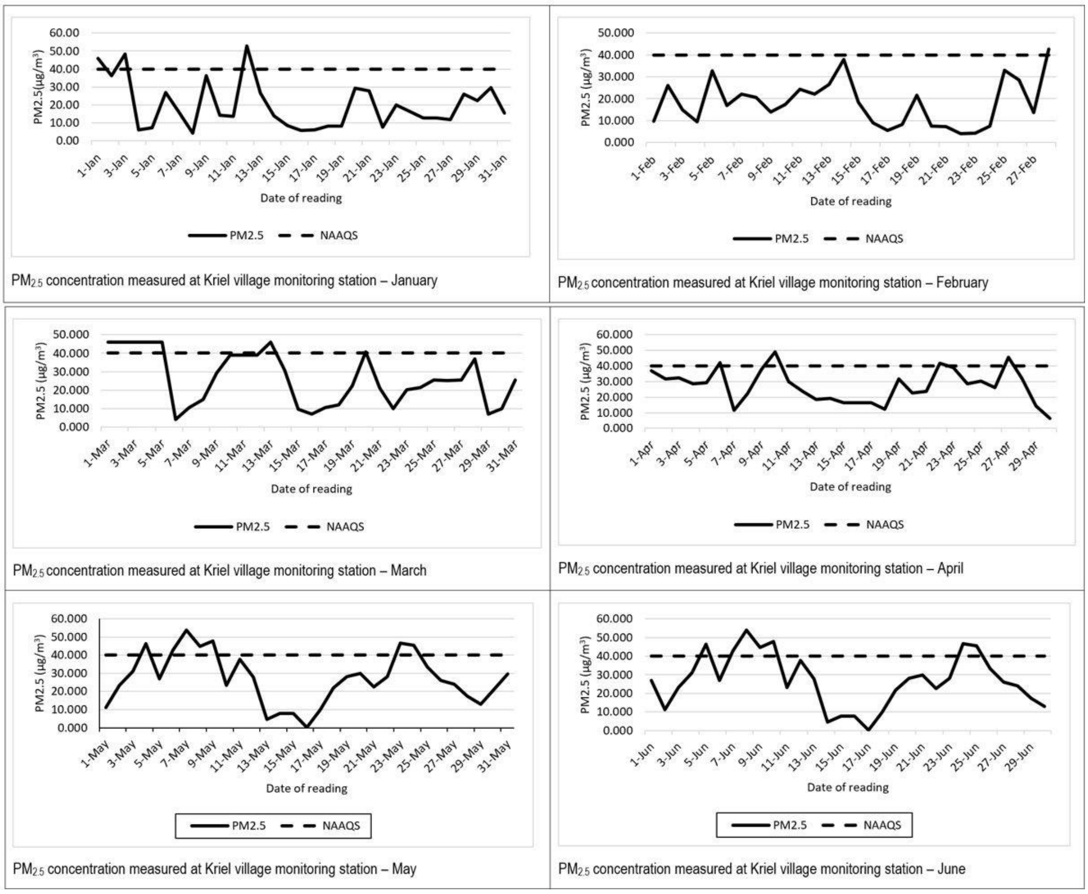

Figure 1. PM2.5 concentration measured at Kriel village monitoring station from January to June.

February

It was noted that from the 2nd of February to the 14th of February, the atmospheric concentration of $PM_{2.5}$ ranged between 26 µg/m^3 and 38 µg/m^3 (peak to peak) and the monthly $PM_{2.5}$ average was 27 µg/m^3. The 22nd of February 2017 and 23rd of February 2017 were the days on which the atmospheric concentration of $PM_{2.5}$ was the least, ranging between 4 µg/m^3 and 7 µg/m^3 (peak to peak) as presented in Figure 1.

March

It was noted that on the 5th of March until the 13th of March, the $PM_{2.5}$ concentration ranged between 46 µg/m^3 to 45 µg/m^3, and the monthly PM_{10} average was 37 µg/m^3 as presented in Figure 1. The 15th of March 2017 and the

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18th of March were the days on which the measured atmospheric concentration for $PM_{2.5}$ was the least, ranging between 4 µg/m^3 and 5 µg/m^3 (peak to peak).

April

On the 10th of April and the 27th of April, the atmospheric concentration of $PM_{2.5}$ ranged between 49 µg/m^3 and 45 µg/m^3 and the monthly $PM_{2.5}$ average was 50 µg/m^3 as presented in Figure 1. The 18th of April and the 30th of April were the days on which the atmospheric concentration of $PM_{2.5}$ was the least, ranging between 6 µg/m^3 and 12 µg/m^3 (peak to peak).

May

From the 7th of May until the 23rd of May, the atmospheric concentration of $PM_{2.5}$ ranged between 47 µg/m^3 and 54 µg/m^3 and the monthly $PM_{2.5}$ average was 59 µg/m^3 as presented in Figure 1. The 13th of May, as well as the 16th of May, were the days when the atmospheric concentration of $PM_{2.5}$ was the least, ranging between 0.2 µg/m^3 and 5 µg/m^3. (peak to peak).

June

It was noted that on the 5th of June and the 8th of June, the atmospheric concentration of $PM_{2.5}$ was 46 µg/m^3 and 54 µg/m^3, respectively, and the monthly $PM_{2.5}$ average was 27 µg/m^3 as presented in Figure 1. The 14th of June, including the 17th of June, were the days on which the atmospheric concentration of $PM_{2.5}$ was the least, ranging between 0.2 µg/m^3 and 5 µg/m^3 (peak to peak).

PM_{10} Concentration measured at the kriel monitoring station

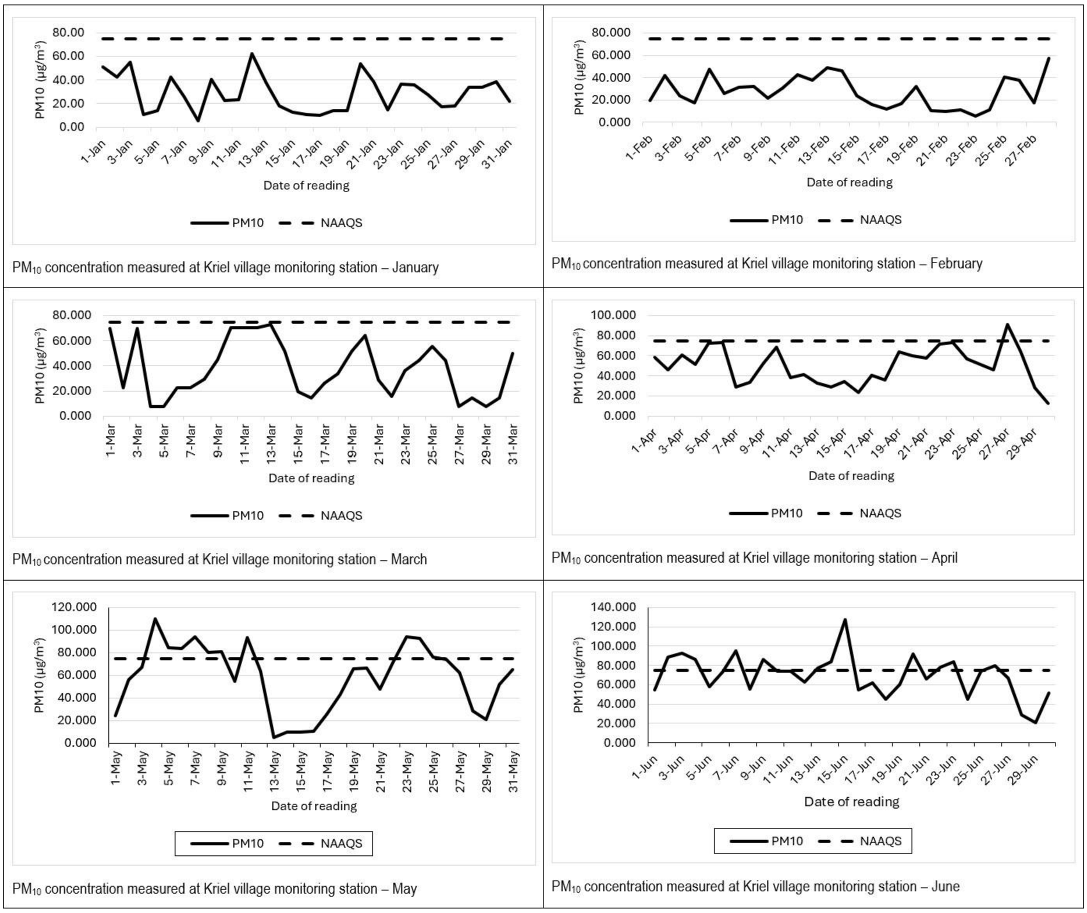

Figure 2. PM_{10} concentration measured at the Kriel monitoring station from January to June.

January

It was noted that on the 1st of January, the atmospheric concentration of PM_{10} ranged between 55 µg/m^3 and 62 µg/m^3, and the monthly PM_{10} average was 20 µg/m^3. The 14th of January and the 19th of January were the days on which the atmospheric concentration of PM_{10} was the least, ranging between 18 µg/m^3 and 14 µg/m^3 (peak to peak) as presented in Figure 2. The horizontal dotted line depicts the National Ambient Air Quality Standard (NAAQS) set for PM_{10} by the Department of Environmental Affairs in South Africa, which cannot be exceeded within a 24-hour period.

February

It was noted that from the 5th of February to the 13th of February, the atmospheric concentration of PM_{10} ranged between 47 µg/m^3 and 49 µg/m^3 (peak to peak), and the monthly PM_{10} average was 18 µg/m^3. The 20th of February and 24 February were the days on which the atmospheric concentration of PM_{10} was the least, ranging between 6 µg/m^3 and 10 µg/m^3 (peak to peak) as presented in Figure 2.

March

From the 1st of March until the 13th of March, the atmospheric concentration of PM_{10} ranged between 69 µg/m^3 and 73 µg/m^3 (peak to peak), and the monthly PM_{10} average was 23 µg/m^3 as presented in Figure 2. From the 4th of March until the 6th of March, as well as on the 27th of March, the atmospheric concentration for PM_{10} was the lowest, ranging between 8 µg/m^3 and 15 µg/m^3 (peak to peak).

April

It was noted that on the 5th of April and 27th of April, the atmospheric concentration of PM_{10} ranged between 72 µg/m^3 and 91 µg/m^3, and the monthly PM_{10} average was 50 µg/m^3, as presented in Figure 2. The 16th of April and the 30th of April were the days on which the atmospheric concentration of PM_{10} was the least, ranging between 13 µg/m^3 and 24 µg/m^3 (peak to peak).

May

It was noted that on the 4th of May and the 23rd of May, the atmospheric concentration of PM_{10} ranged between 94 µg/m^3 and 110 µg/m^3 (peak to peak), and the monthly PM_{10} average was 27 µg/m^3 as presented in Figure 2. The 13th of May and 16th of May were the days when the atmospheric concentration of PM_{10} was the least, ranging between 5 µg/m^3 and 10 µg/m^3 (peak to peak).

June

On the 3rd of June and the 15th of June, the atmospheric concentration of PM_{10} was 93 µg/m^3 and 127 µg/m^3, respectively, and the monthly PM_{10} average was 70 µg/m^3 as presented in Figure 2. The 28th of June and the 29th of June were the days on which the atmospheric concentration of PM_{10} was the least, ranging between 21 µg/m^3 and 29 µg/m^3 (peak to peak).

Regression analysis

The statistical analysis of particulate matter (PM) concentrations measured at the Kriel village air monitoring station indicated that the mean PM2.5 concentration was 24.31 ± 13.21 µg/m^3, which was significantly elevated ($p < 0.005$; Mann-Whitney U test). Similarly, the mean PM_{10} concentration was 46.25 ± 25.23 µg/m^3, also above acceptable health-based thresholds. Correspondingly, the incidence of cardiopulmonary conditions among Kriel residents was found to be significantly high ($p < 0.05$). These findings suggest a strong correlation between elevated PM2.5 and PM_{10} concentrations and the increased prevalence of cardiopulmonary conditions, with the community of Kriel recording a disproportionately higher burden of respiratory health outcomes compared to what would be expected under normal air quality conditions. This provides compelling evidence that exposure to poor air quality, largely attributable to emissions from the nearby coal-power station, has a measurable adverse impact on public health in the area.

Wind frequency and speed, as well as average temperature and rainfall at Kriel village from 01 January - 30 June

Wind frequencies and speed

The wind frequencies and speeds at Kriel village, as outlined in Table 2, show a significant occurrence of calm winds between March and June, with wind speeds ranging between 0.5 m/s and 2.1 m/s during this period. The highest frequency of such calm winds occurred in May (10%) and March (6%), while April (3%) and June (5%) recorded lower percentages of calm winds. Notably, higher wind speeds were recorded earlier in the year, with January seeing wind speeds between 7–11 m/s (12%), and February experiencing moderate winds between 2.1–3.6 m/s (12%).

Table 2. Wind frequency and speed, as well as Average temperature and rainfall at Kriel village from 01 January - 30 June.

Wind frequency and wind speed			**Average temperature and rainfall**		
Month	**Wind speed (m/s)**	**Frequency (%)**	**Month**	**Temperature in (degrees Celsius)**	**Rainfall in (millimetres)**
January	7–11	12	Jan	20	0
February	2.1–3.6	12	Feb	20	0
March	0.5–2.1	6	Mar	18	0.01
April	0.5–2.1	3	Apr	16	0.06
May	0.5–2.1	10	May	11	0.01
June	0.5–2.1	5	Jun	9	0

Temperature and the rainfall patterns

As for temperature and rainfall patterns, the data in Table 2 reveals a steady decrease in both temperature and rainfall from January to June. In January and February, temperatures remained at 20°C with no rainfall, while March marked a slight decrease in temperature (18°C) accompanied by minimal rainfall (0.01 mm). This downward trend continued through April (16°C, 0.06 mm), May (11°C, 0.01 mm), and June (9°C, no rainfall).

Discussion

The findings on the incidence of cardiopulmonary conditions among Kriel residents illustrate the possible health risks associated with living near industrial sources of particulate matter (PM) pollution. This study's observation of asthma incidence at 13% among the 30–34 age group and 10% in the 50–54 age group, as well as cases of chronic bronchitis and bronchiectasis in children, aligns with prior research highlighting the adverse health impacts of PM exposure. Anderson et al. (2012) demonstrated a 40% increased risk of bronchitis among children exposed to PM, while Sacks et al. (2011) showed a similar trend in asthma prevalence among adults in Paris. These findings reinforce the view that PM pollution significantly contributes to respiratory ailments (Wafula et al., 2023).

The elevated asthma cases observed in this study, particularly among residents aged 30–34 and 50–54, suggest that prolonged exposure to PM from the nearby coal-power station may be a potential contributing factor. Previous research has demonstrated the harmful effects of long-term PM exposure. For example, Kiser et al. (2020) and Gross et al. (2025) reported a higher likelihood of cardiopulmonary diseases among individuals with extended exposure to industrial emissions. Similarly, Monoson et al. (2023) found increased risks for both adults and children. The pattern of higher asthma prevalence with longer residence in Kriel supports this evidence, where individuals residing for over a decade presented with more cases of asthma and other respiratory conditions. Conversely, the study's weaker association between PM exposure and respiratory conditions among children aged 0–4 and 5–9 years contradicts previous findings by Anderson et al. (2012) and Marchwinska-Wyral et al. (2011), which showed children as highly susceptible to PM pollution due to their developing immune systems. This discrepancy might be explained by factors such as shorter exposure duration, indoor confinement of children reducing outdoor pollution exposure, or underdiagnosis due to the difficulty in assessing respiratory conditions in young children.

Meteorological factors also play a crucial role in PM concentration and the incidence of health conditions. The high levels of PM_{10} and $PM_{2.5}$ observed from March to June 2017 exceeded the National Ambient Air Quality Standards (NAAQS), with $PM_{2.5}$ peaking at 54 µg/m³ and PM_{10} reaching 197 µg/m³. These concentrations suggest poor air quality during this period, likely exacerbated by temperature inversions during the colder months of May and June, which trapped pollutants near the ground. The statistical analysis of the PM concentration of the air monitoring stations indicated that the $PM_{2.5}$ mean for Kriel was 24.31 ± 13.21 μg/m^3. The mean of the PM_{10} concentration monitored at Kriel village was 46.25 ± 25.23 μg/m^3. This scenario aligns with findings by Souza et al. (2025) and Holgate et al. (1999), who noted that temperature inversions contribute to higher PM levels, increasing respiratory health risks. Additionally, low rainfall levels during this time reduced the natural dispersion of pollutants, as wet deposition helps wash away airborne particles, thus potentially elevating the risk for cardiopulmonary conditions.

Gender differences in the incidence of asthma and other respiratory conditions also emerged from the data, with women showing higher prevalence rates. The 51% asthma incidence in women, compared to 14% in men, could be attributed to biological factors and differential exposure or susceptibility to environmental risks. The literature, such as research by Gut-Gobert et al. (2019), suggests that women may develop respiratory conditions at a younger age and with less exposure than men. Cultural factors affecting help-seeking behaviours may also play a role, where men might underreport or delay seeking treatment for respiratory conditions due to societal norms around masculinity, as discussed by Gough and Novikova (2020). Our findings align with previous studies indicating that cardiopulmonary conditions correlate with longer residence near industrial pollution sources (Hamanaka & Mutlu, 2018). The dose-response relationship suggested by Kampa and Castanas (2008) implies that even lower PM exposure over a prolonged period can result in significant health impacts, similar to the elevated asthma incidence in Kriel. Therefore, reducing PM exposure, especially in heavily industrialised regions like Mpumalanga, may evidently be a key consideration for mitigating adverse health outcomes. This study highlights the significant impact of PM pollution from the Kriel coal-power station on respiratory health, emphasising the need for stringent air quality management and mitigation strategies to protect vulnerable populations. Authorities should prioritise reducing PM emissions and enhancing public health measures to manage the associated disease burden.

The study on the health risks associated with air pollution in Kriel has several strengths that contribute to the robustness of its findings. One key strength is the comprehensive nature of data collection, which incorporates both clinical data on cardiopulmonary conditions and environmental measurements of particulate matter (PM_{10} and $PM_{2.5}$) from air quality monitoring stations. The use of well-calibrated equipment ensured that the air quality data was reliable and accurately reflected real-world exposure conditions near the Eskom coal-power station. Furthermore, the study's setting provided a valuable opportunity to assess the health impacts of industrial air pollution in an area characterised by significant coal-based energy production, thus offering insights applicable to similar industrial environments globally. The study also benefited from the inclusion of a diverse demographic dataset, capturing variations in age, gender, ethnicity, and duration of residence. This enabled the analysis to identify vulnerable subpopulations, such as older adults and long-term residents, who might be at greater risk for pollution-related health conditions. Additionally, by focusing on a low-income, under-resourced setting, the research addresses an important gap in the literature on air pollution's health effects in South Africa. The findings thus contribute to the understanding of health challenges faced by communities living near industrial facilities, informing public health policy and regulatory decisions in these regions.

However, the study had some limitations that could affect the interpretation and generalizability of its findings. The small sample size (n = 62) and limited observation period of six months constrained the statistical power and the ability to detect long-term health effects of PM exposure. This relatively short duration might not fully capture seasonal variations or chronic impacts; thus, longer-term studies with larger sample sizes would be needed to better understand the cumulative effects of air pollution. Additionally, there was a notable gender imbalance in the sample, with a higher proportion of females (77%) than males (23%). This discrepancy could introduce bias, as the higher observed prevalence of cardiopulmonary conditions among females might reflect sampling rather than true gender differences in disease incidence. The study's ability to control for confounding factors was limited, as it did not fully account for variables such as smoking history, occupational exposures, or pre-existing health conditions. These factors could influence respiratory health and potentially confound the association between PM exposure and cardiopulmonary conditions. Another challenge was the diagnosis of respiratory conditions in young children, which may have led to underreporting and contributed to the weaker associations observed in this age group. Diagnosing conditions like asthma in children under five can be difficult, potentially resulting in an underestimation of the true impact on this vulnerable population. Finally, the study's focus on a single location limits the generalisability of the results. While the findings provide valuable insights into the health risks for the Kriel community, comparisons with other regions experiencing different pollution sources, socio-economic conditions, or health infrastructure would help contextualise the results. Despite these limitations, the study makes a significant contribution by highlighting the health risks posed by industrial air pollution in a real-world setting, underscoring the need for continued monitoring and targeted interventions. The results emphasise the importance of addressing air quality in heavily industrialised areas to protect public health, particularly for vulnerable populations residing near sources of PM pollution.

To effectively address the public health concerns identified in this study, it is essential to strengthen air quality regulations. Authorities should implement stricter standards for permissible particulate matter (PM) concentrations and ensure compliance among industrial activities, particularly coal-based power generation. By lowering allowable limits for PM emissions and closely monitoring adherence to these regulations, it is possible to significantly mitigate health risks associated with air pollution in affected communities. In addition to regulatory measures, expanding monitoring and research efforts is crucial. Long-term studies with larger sample sizes will provide a more comprehensive understanding of the chronic health impacts of PM exposure. Establishing an expanded air quality monitoring network in industrial regions will yield valuable data on pollution trends and their health effects, facilitating informed public health responses. Public health interventions targeting respiratory health should also be implemented in high-risk areas such as Kriel. Awareness campaigns aimed at educating community members about the risks associated with air pollution and protective measures—such as staying indoors during periods of high pollution—can significantly reduce exposure to harmful PM levels. Such initiatives can empower residents to take proactive steps in safeguarding their health.

Improving access to healthcare services for communities located near industrial facilities is another critical recommendation. Ensuring that residents have adequate resources for early diagnosis and treatment of respiratory conditions can help reduce the overall disease burden. This may include establishing more health clinics, providing mobile health services, or offering subsidised healthcare options for low-income families. Finally, addressing the socioeconomic disparities that increase vulnerability to air pollution is imperative. Initiatives aimed at improving living conditions, such as better housing and infrastructure, alongside efforts to reduce inequalities, can enhance community resilience against pollution-related health risks. By integrating public health policies with socioeconomic development strategies, authorities can foster healthier environments for residents.

Conclusion

The findings of this study reveal a significant association between elevated particulate matter (PM) levels, particularly PM_{10} and $PM_{2.5}$, and the incidence of cardiopulmonary conditions among Kriel residents. Asthma emerged as the most prevalent condition, with higher incidence rates observed among individuals aged 30–34 and 50–54, indicating a potential link between prolonged PM exposure from the nearby coal-power station and respiratory health outcomes. While the study highlighted a higher prevalence of respiratory conditions in women compared to men, the potential influence of gender-related differences in susceptibility and health-seeking behaviour warrants further investigation. The results also suggest that meteorological factors, including low rainfall and temperature inversions, may exacerbate the effects of PM pollution by limiting pollutant dispersion. The study underscores the urgent need for ongoing air quality monitoring and interventions aimed at reducing PM emissions, especially in heavily industrialised regions like Mpumalanga, to protect public health.

Declarations

Interdisciplinary Scope: This study adopts an interdisciplinary scope by integrating insights from environmental science, health policy, environmental and public health to investigates the relationship between particulate matter (PM) air pollution and the incidence of cardiopulmonary conditions in the Kriel community near the Eskom Kriel coal-power station in Mpumalanga, South Africa.

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