

# Evaluation of Ambient NO<sub>2</sub> and SO<sub>2</sub> Concentrations at Lephhalale, Polokwane, and Steelpoort Area in the Limpopo Province of South Africa

Collet Maswanganyi<sup>1,2\*</sup>, James Tshilongo<sup>1,3</sup>, Andile Mkhohlakali<sup>3\*</sup>, Lynwill Martin<sup>4</sup>

<sup>1</sup>Department of Chemistry, University of South Africa, Pretoria, South Africa

<sup>2</sup>Department of Chemistry, University of Limpopo, Limpopo, South Africa

<sup>3</sup>Analytical Chemistry Division of Mintek, Randburg, South Africa

<sup>4</sup>Cape Point Global Atmosphere Watch Station, South Africa Weather Service, c/o CSIR, Stellenbosch, South Africa

Email: \*collet.maswanganyi@ul.ac.za, \*Andilem@mintek.co.za

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## Abstract

Sulfur dioxide (SO<sub>2</sub>) and nitrogen dioxide (NO<sub>2</sub>) are some of the air pollutants in industrial and urban areas. These are the most prevalent inorganic pollutants that are a serious risk to public health in populated areas. However, Lephhalale, Polokwane and Steelpoort have not received enough attention to date. Therefore, this study investigated seasonal levels of NO<sub>2</sub> and SO<sub>2</sub> concentrations using passive sampling during summer, winter, autumn and spring of 2021. The sampling was done the first seven days of the month. The relationship of inorganic pollutants with meteorological factors was performed statistically using multiple linear regression model. Lephhalale exhibited the highest NO<sub>2</sub> concentration, 1.74 µg/m<sup>3</sup>, in spring. Whereas Polokwane and Steelpoort peaked at 1.57 µg/m<sup>3</sup> and 0.84 µg/m<sup>3</sup> in winter, respectively. The concentrations of SO<sub>2</sub> were higher in winter than in other seasons in all areas. The multiple linear regression models showed that NO<sub>2</sub> and SO<sub>2</sub> dispersion was influenced by meteorological parameters such as temperature, wind speed and relative humidity. In Polokwane and Steelpoort, NO<sub>2</sub> and SO<sub>2</sub> concentrations are inversely correlated to temperature and relative humidity. Similarly, NO<sub>2</sub> concentrations are inversely correlated, while SO<sub>2</sub> concentrations are directly correlated to both temperature and relative humidity in Lephhalale. Wind speed had positive and inverse correlations to the concentrations of both air pollutants. The SO<sub>2</sub> and NO<sub>2</sub> concentrations did not exceed the annual average of 50 µg/m<sup>3</sup> and 94 µg/m<sup>3</sup> as set by National Ambient Air Quality Standards and World Health Organization. However, it is important

to keep pollution concentrations of SO<sub>2</sub> and NO<sub>2</sub> to relatively safe for humans and the environment in the studied areas.

## Keywords

Seasonal Monitoring, SO<sub>2</sub>, NO<sub>2</sub>, Meteorological Parameters

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## 1. Introduction

One environmental issue that affects people worldwide, in both developed and developing nations, is air pollution. It is linked to emissions from regional and local sources as well as atmospheric reactions with gaseous pollutants [1] [2]. Natural and anthropogenic sources contribute to the air pollutants in the ambient environment [3]. Burning biomass and engaging in industrial and automotive activity are examples of anthropogenic activity emissions [4]. About 40% of people use biomass fuels for cooking and heating, such as wood, charcoal, crop residues, and animal dung. These fuels release a complex mixture of pollutants, including gases and fine particles, that are harmful to human health [5] [6].

The World Health Organization (WHO) states that air pollutants like nitrogen dioxide (NO<sub>2</sub>) and sulphur dioxide (SO<sub>2</sub>) pose a major risk to human health. Even though SO<sub>2</sub> and NO<sub>2</sub> are known to be toxic, they also play a role in particle formation because of intricate atmospheric photochemical reactions that involve ammonia from agricultural practices [7] [8]. Cardiovascular diseases have been reported as the prime cause of high mortality rates due to long-term exposure to NO<sub>2</sub>. There are various detrimental diseases such as pulmonary edema, suffocation and laryngeal edema, that result from SO<sub>2</sub> gas inhalation. It has been reported that the changes related to NO<sub>2</sub> have led to hospital admissions, upper and lower respiratory illness, bronchitis and chronic cough [9] [10].

Many people in South Africa, a developing nation plagued by poverty and inequality, heat their homes with biomass fuels. In addition, the energy sector in South Africa produces a lot of air pollution, which exacerbates local environmental problems and public health issues as well as global climate change. Hence, South Africa has air pollution legislation with international comparable pollution limits [11] [12]. The National Ambient Air Quality Standards (NAAQS) cover priority air pollutants such as SO<sub>2</sub> and NO<sub>2</sub> [13]. The annual ambient air quality guidelines and standards for SO<sub>2</sub> and NO<sub>2</sub> are 50 µg/m<sup>3</sup> and 94 µg/m<sup>3</sup>, respectively [14]. This legislation primary objective is to reduce the pollution levels to concentrations relatively safe for humans and the environment. However, this aim is currently not being reached, resulting in a serious health problem due to the lack of capacity to implement the existing legislation by the government and provincial authorities. Currently, all municipalities are required to monitor air pollution. However, this route has negative implications since it is not cost-efficient and does not provide high-quality data with correct interpretations [13] [15].

There are air quality monitoring networks all over South Africa, according to the 2018 Department of Forestry, Fisheries and Environmental (DFFE) state of air report (2005-2016). The report presented data from networks that met minimum requirements of  $50 \mu\text{g}/\text{m}^3$   $\text{SO}_2$  concentrations, which included Western Cape, Gauteng, Limpopo and KwaZulu Natal [16] [17]. The Air Quality Act of 2004, Sections 15 and 16, prompted Limpopo Department of Economic Development, Environment and Tourism (LEDET) to launch an Air Quality Management Planning process in 2013. The primary goal was to supply the province with an implementable Air Quality Management Plan (AQMP) that complies with national standards and enhances the AQMPs already in place for District Municipalities [18].

In many parts of the Province of Limpopo, the environment, human health, and life expectancy are seriously threatened by the poor quality of the air. The province is experiencing air quality issues due to high levels of particulate matter, volatile organic compounds,  $\text{SO}_2$ , and  $\text{NO}_2$ . These elevated concentrations are caused by a variety of sources, including mining activities, power generation, metallurgical activities, burning biomass, vehicle tailpipe emissions, and burning domestic fuel [19]. The province of Limpopo mines coal, iron, platinum, chromium, manganese, copper, gold, diamonds, lime, and asbestos, among other minerals and resources. In the mining sector, drilling, blasting, hauling, collection and transportation are done. When some of these functions are performed, they have significant environmental impact and public health effects. This is due to constant exposure to air pollutants such as  $\text{SO}_2$  and  $\text{NO}_2$  [20] [21].

A network of monitoring stations is used to measure ambient concentrations throughout South Africa. The industrial, rural, and urban areas in and around Limpopo are home to the monitoring stations. Under the direction of the DFFE and the LEDET, there are more than 21 government-owned air quality monitoring stations in the province. Only a few uses continuous samplers, with most using passive samplers [22] [23]. There are several hot-spot areas in Limpopo, viz. Polokwane, Lephalale, Phalaborwa and Steelpoort. However, no air quality monitoring has been conducted on a small scale in Steelpoort, Lephalale and Polokwane to investigate if the mining industries, smelters and quarries are associated with the poor air quality to the surrounding environment. This study is part of the knowledge-building process by investigating compliance of  $\text{NO}_2$  and  $\text{SO}_2$  to the NAAQS in various areas in Limpopo within the residential area situated in the mining industries, urban and coal-powered industry. Also, to investigate the effects of meteorological parameters on  $\text{NO}_2$  and  $\text{SO}_2$  concentrations. The study focused on two pollutants namely  $\text{SO}_2$  and  $\text{NO}_2$  due to their environmental impact and public health effects. Therefore, this study was aimed to determine seasonal variations of  $\text{NO}_2$  and  $\text{SO}_2$  in Limpopo rural, urban and industrial areas using passive sampling from January 2021 to December 2021.

## 2. Materials and Methods

Sampling sites, shown in **Figure 1**, were chosen because of mining activities,

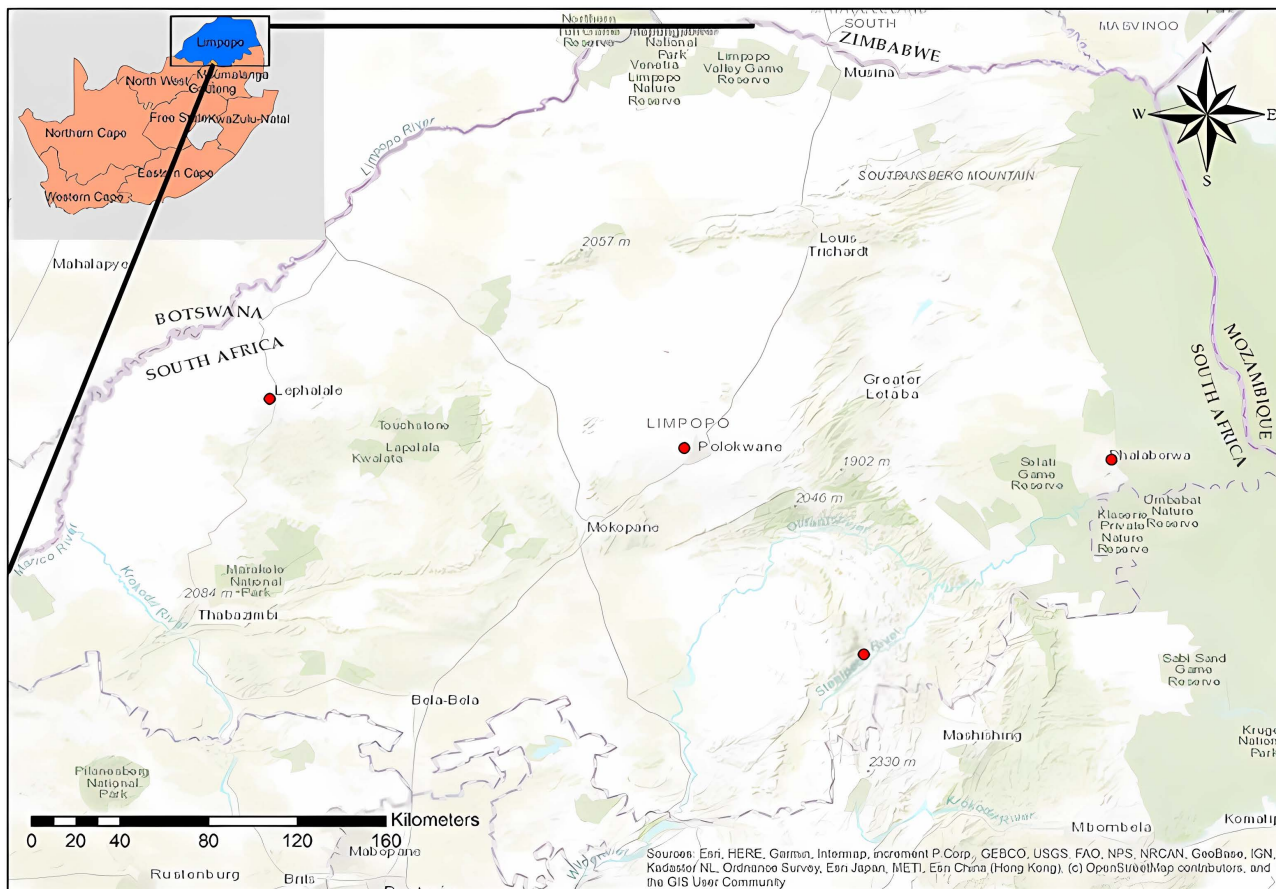


Figure 1. Study areas showing (red dots) Lephallale, Polokwane and Steelpoort.

vehicle-dense areas and where the coal-powered station is located. Samples were collected at Lephallale (23.6665° South, 27.7448° East), Polokwane (23.8962° South, 29.4486° East) and Steelpoort (24.43°48" South; 30.11°59" East). Polokwane, formerly known as Pietersburg, is a city and capital of the Limpopo Province. It covers an area of about 106.8 km<sup>2</sup> with an altitude of 1310 m and a population of more than 130,000 people. Over the past ten years, the city has seen seasons that are noticeably warmer than average. It also has a dry climate, with July being the driest month and December or January (less frequently) being the wettest with annual rainfall of about 495 mm. Anglo American Smelter is situated about 19 km south of Polokwane city. Lephallale is a town found in the western part of the Limpopo province of South Africa and covers about 66.94 km<sup>2</sup> with a population of about 19,000 people. This town experiences long, hot, and partly cloudy summers. In contrast, there are the short, chilly, clear, and dry winters. Throughout the year, the temperature typically varies from 7°C to 32°C. The town hosts two power stations, namely Matimba and Medupi, which use coal to produce electricity. Steelpoort is a mining area in Sekhukhune District Municipality in the Limpopo province. The elevation above sea level varies from 1500 to 2400 meters. The average yearly rainfall fluctuates between 630 and 1000 mm, mostly as summer thunderstorms. The settlement has an estimated population of

approximately 1,105, 380 (122.09 per km<sup>2</sup>) households and covers 3.11 km<sup>2</sup> (Census 2011). Additionally, five villages, namely, Ga-Mahlokwane (3.8 km), Tukakgomo (3.8 km), Ga-Phasha (3.8 km), Ga-Mampuru (8.4 km), and Stocking (9.4 km) are located within a radius of ±10 km around it. Eight mines surround Steelpoort as well: Mototolo Platinum Mine, Two Rivers Platinum: Modikwa Platinum, Dwarsrivier Chrome, Tweefontein Chrome, Tubatse Ferrochrome, Lion Ferrochrome Smelter, and Marula Platinum (Pty) Ltd.

## 2.1. Data Collection

Sampling was performed approximately 10 km west of Polokwane CBD, 18 km east of Medupi power station in Lephalale and 6 km west of Steelpoort. This is where the provincial monitoring stations are housed. South African Weather Services (SAWS), which is overseen by the South African Air Quality Information System (SAAQIS), provided the temperature, relative humidity (%), and air pollution data for Steelpoort, Polokwane, and Lephalale from January to December 2021. Radiello passive samplers were deployed for 7 successive days to monitor SO<sub>2</sub> and NO<sub>2</sub>. The samplers consist of a microporous polyethylene and polycarbonate cylindrical diffusive body coaxially containing a cylindrical adsorbing cartridge. A 530 ± 30 mg of 35 - 50 mesh activated carbon are held within the adsorbing cartridge, which is a 3 × 8 μm with 4.8 mm external diameter stainless-steel net cylinder mesh. The sampler was protected from bad weather and direct sunlight by the mountable polypropylene shelter on the pole. The samplers were positioned 1.5 meters above the ground at each sampling location. The NO<sub>2</sub>/SO<sub>2</sub> sampler is made up of a blue, microporous high-density polyethylene diffusive body placed on a polycarbonate supporting plate and a microporous polyethylene chemiadsorbing cylindrical cartridge coated with 270 mg triethanolamine (TEA). While SO<sub>2</sub> is partially oxidized to sulphate on the cartridge as a sulphite ion, TEA is used to chemiadsorbed NO<sub>2</sub> as a nitrite ion. According to the supplier's instruction (Ielpo *et al.*, 2019), the sampling rate ( $Q_R$ ) of NO<sub>2</sub> at 298 K (25°C) is 0.141 ± 0.007 ng ppb<sup>-1</sup>.min<sup>-1</sup>. The effect of temperature on the sampling rate of NO<sub>2</sub> is given by Equation (1) as:

$$Q_K = Q_R (K/298)^{7.0} \quad (1)$$

In Equation (1),  $Q_K$  represents the rate of sampling at temperature  $K$  (in Kelvin) within the experimental range between 263 and 313 K (−10°C to 40°C). The sampling rate at 298 K, the reference temperature, is denoted by  $Q_R$ . Equation (2) below is used to calculate the  $C_{\text{NO}_2}$  concentration in parts per billion (ppb):

$$C_{\text{NO}_2} = m_{\text{NO}_2} / Q'_K \quad (2)$$

where  $m_{\text{NO}_2}$  is the nitrite mass in ng found on the cartridge,  $t$  is the exposure time in minutes, and  $Q_K$  is the sampling rate at temperature  $K$ .

At 298 K (25°C), the SO<sub>2</sub> sampling rate ( $Q_{\text{SO}_2}$ ) is 0.466 ± 0.022 ng.ppb<sup>-1</sup>.min<sup>-1</sup>. Using the masses of sulphite ( $m_{\text{SO}_3}$ ) and sulphate ( $m_{\text{SO}_4}$ ) on the cartridge, the uptake rate, and the exposure time  $t$  in minutes, the concentration  $C_{\text{SO}_2}$  in parts

per billion is computed using the following Equations (3) and (4):

$$m_{\text{SO}_4}(\text{T}) = m_{\text{SO}_4} + 1.2m_{\text{SO}_3} \quad (3)$$

$$C_{\text{SO}_2} = m_{\text{SO}_2}(\text{T})/0.466t \quad (4)$$

where  $m_{\text{SO}_2}(\text{T})$  is the mass of sulphate in ng found on the cartridge (wherein the original sulphate mass and mass of sulphite are converted to sulphate).

## 2.2. Analyses of SO<sub>2</sub> and NO<sub>2</sub>

Following exposure, adsorption cartridges were put back into their original tubes and 5 mL of ultrapure water (having a conductivity of 0.055 mS·cm<sup>-1</sup>) was added for desorption. To guarantee total analyte extraction, the tubes were vigorously shaken for two minutes using a Vortex-style stirrer. After that, the solution with the cartridge was left for an additional one and half hours. The desorption liquid was then transferred to IC injection vials after the tubes had been shaken for 30 seconds. Using Dionex equipment, including the Dionex LC20 chromatography enclosure with ED40 electrochemical detector, the Dionex AG22 guard column (4 × 50 mm) and the Dionex AS22 analytical column (4 × 250 mm), SO<sub>2</sub> and NO<sub>2</sub> were measured by ion chromatography. The DX-120 ion chromatograph, equipped with an ASRS-ultra II suppressor and a Dionex AS40 automatic injector, was used to measure sulphate. The ion chromatographic system consisted of an AS12A separator column and an AG12A guard column with an isocratic eluent of Na<sub>2</sub>CO<sub>3</sub>/NaHCO<sub>3</sub> (2.1 mM - 0.8 mM).

## 2.3. Quality Control/Quality Assurance (QC/QA)

The analytical quality of the data was evaluated using calibration linearity, instrument status monitoring, and limit of detection (LOD) [24]. Each sampling site always had a minimum of one set of unexposed samplers during the sampling campaign. These samplers served as blank samples and were filled with adsorbent solution and blank filters. All these blank samples were sampled and returned to the labs for appropriate analysis. The average of the amounts in the blanks multiplied by three times the standard deviation was used to calculate the limits of detection, which were based on the blanks. The LODs for SO<sub>2</sub> 18.8 - 52.3 was ng/sample, while NO<sub>2</sub> was 6.4 - 40.8 ng/sample. All the concentrations from the passive sampling were reported here without any blank value deduction because the blank values were negligible. Regression analysis was used to determine the linearity of calibration standards, and the results ranged from 0.99 to 1.00 ( $r^2$ ) for both NO<sub>2</sub> and SO<sub>2</sub> as determined by spectrophotometry and IC. Standard-spiked samples were subjected to routine analysis to verify the instrument's functionality.

## 2.4. Statistical Analyses of Data

Statistical analyses were performed using IBM SPSS® to observe the relationships between the air pollutant concentrations and the meteorological factors, such as temperature (T), wind speed (WS) and relative humidity (RH). Multiple linear

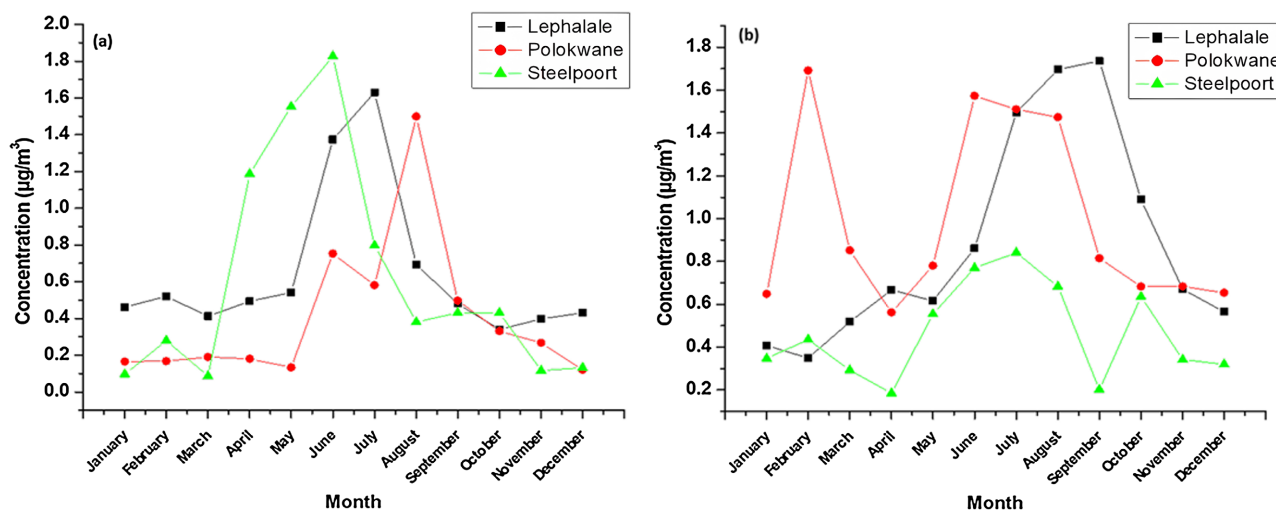
regression (MLR) analysis was conducted to investigate the relations between  $\text{SO}_2$  and  $\text{NO}_2$  concentrations using meteorological factors and to obtain mathematical expressions. In formulating the regression equations,  $\text{SO}_2$  and  $\text{NO}_2$  concentrations were taken as dependent variables and the meteorological factors as independent variables. Since there is more than one independent variable, the multiple linear regression analysis was performed. A general MLR equation can be expressed by Equation (5):

$$y_i = C + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 \quad (5)$$

where  $y_i$  is the dependent variable ( $\text{NO}_2$  or  $\text{SO}_2$ ),  $C$  is the constant of regression,  $\beta$  is a regression coefficient and  $x_1$ ,  $x_2$ ,  $x_3$  are independent variables,  $x_1$  (temperature,  $T$ , °C),  $x_2$  (wind speed, WS, m/s) and  $x_3$  (relative humidity, RH, %).

### 3. Results

**Figure 2** shows the  $\text{SO}_2$  concentrations obtained in three different areas, Lephallale, Polokwane and Steelport.



**Figure 2.** Monthly concentrations of  $\text{SO}_2$ , (a), and  $\text{NO}_2$ , (b) from January to December 2021.

#### 3.1. $\text{NO}_2$ and $\text{SO}_2$ Data

The results of concentrations of  $\text{NO}_2$  and  $\text{SO}_2$  during the period of study (January 2021 to December 2021) are shown in **Figure 2** for Lephallale, Polokwane and Steelport. These set of data are for the four seasons which are defined as follows: winter (June, July, and August); spring (September, October, and November); and summer (December, January, and February); and autumn (March, April, and May). It is indicated in **Figure 2(a)** that the concentration of  $\text{SO}_2$  is higher in winter than in other seasons. Even though the highest peaks occur in different month, viz. June in Steelport, July in Lephallale and August in Polokwane. The order of increasing concentration of air pollutant,  $\text{SO}_2$ , is Steelport > Lephallale > Polokwane. Maximum pollution levels of sulphur dioxide for Steelport, Lephallale and Polokwane are  $1.9 \mu\text{g}/\text{m}^3$ ,  $1.6 \mu\text{g}/\text{m}^3$  and  $1.4 \mu\text{g}/\text{m}^3$ , respectively. The expectation

was that Lephalale would have high SO<sub>2</sub> concentrations due to Medupi power station location and coal, which is the source of SO<sub>2</sub> [25] [26]. Low levels of SO<sub>2</sub> in Lephalale might be due to the sampling site, which is 18 km from the Medupi power station. Furthermore, the wind direction is predominantly north-easterly. The levels of SO<sub>2</sub> in Steelpoort are due to the closeness of the monitoring station to vehicular emission and domestic biomass. The highest SO<sub>2</sub> concentrations during winter in this study's areas were due to increased fossil fuel, increased traffic volumes and meteorological conditions [27]. The wintertime inversion layer formation is another reason for the elevated SO<sub>2</sub> concentration. As a result, SO<sub>2</sub> is prevented from escaping into the atmosphere and the dispersion rate of emission is decreased. The SO<sub>2</sub> and NO<sub>2</sub> concentrations did not exceed the annual average of 50 µg/m<sup>3</sup> and 94 µg/m<sup>3</sup> as set by NAAQS and WHO.

Variations in NO<sub>2</sub> concentrations from January 2021 to December 2021 are shown in **Figure 2(b)**. Different maximum concentration values of NO<sub>2</sub> are attained in different monitoring stations and months. Lephalale, Polokwane and Steelpoort have highest NO<sub>2</sub> concentration of 1.74 µg/m<sup>3</sup> in September, 1.57 µg/m<sup>3</sup> in June and 0.84 µg/m<sup>3</sup> in July, respectively. The annual non-exceedance of NO<sub>2</sub> for the two standards, *i.e.*, NAAQS and WHO, was observed in all areas under this study. A slightly different seasonal trend was observed for NO<sub>2</sub> compared to SO<sub>2</sub>. The higher concentration of NO<sub>2</sub> in Lephalale and Polokwane are due to traffic around the areas. Similar studies have reported direct vehicle emissions as a major source of NO<sub>2</sub> concentrations [28]. Polokwane was expected to have higher concentration because it is a capital city with many vehicles moving in and out of the city. However, the sampling site is about 10 km away from the city. NO<sub>2</sub> concentration in Steelpoort is due to domestic heating and heavy-load vehicles around the area.

### 3.2. Evaluation of the Effect of Meteorological Parameters on SO<sub>2</sub> and NO<sub>2</sub> Levels

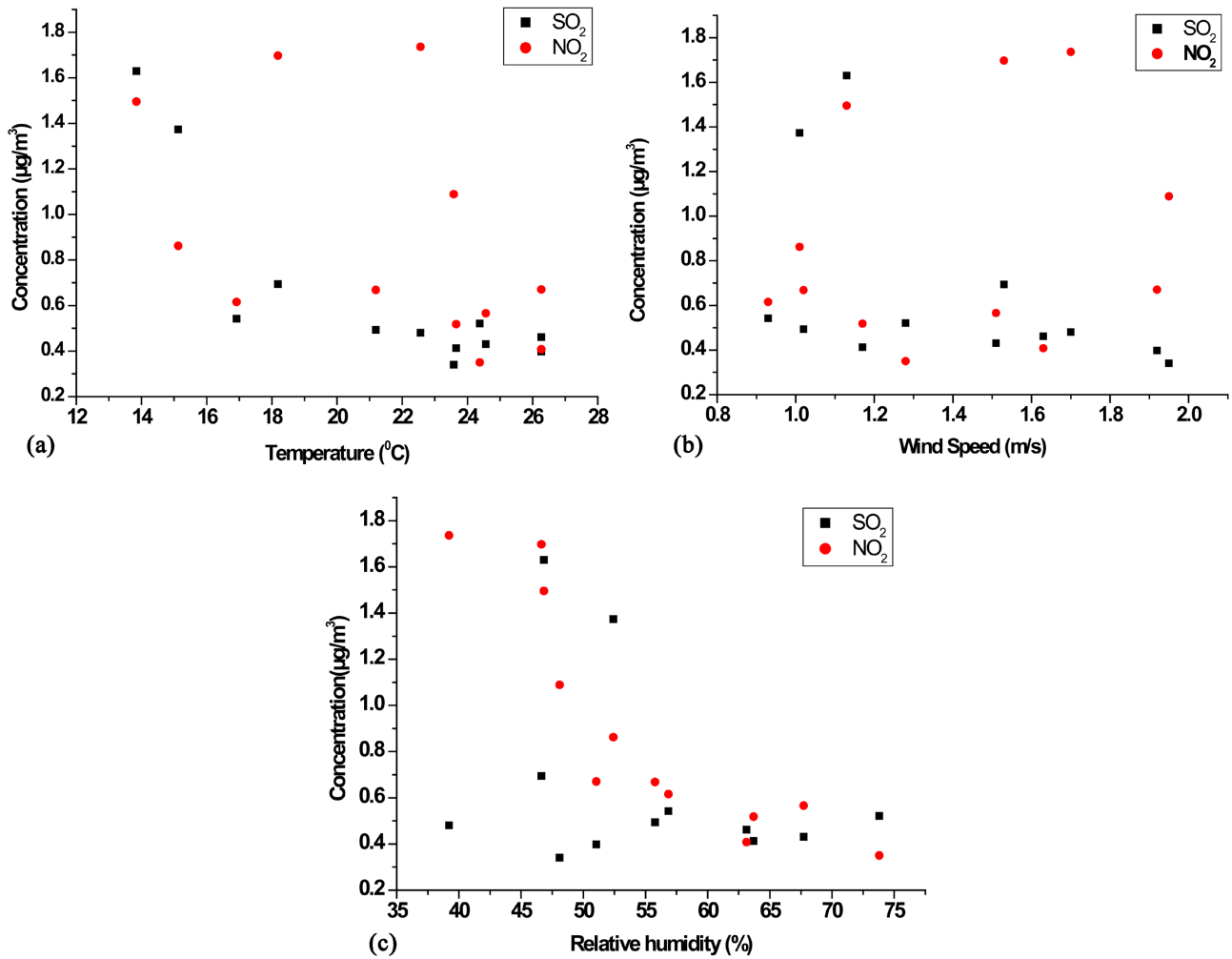
**Figures 3-5** illustrate the effect of atmospheric factors on concentrations of air pollutants under study.

The relationship between temperature, wind speed, and relative humidity and the concentrations of NO<sub>2</sub> and SO<sub>2</sub> in Steelpoort is depicted in **Figure 5**.

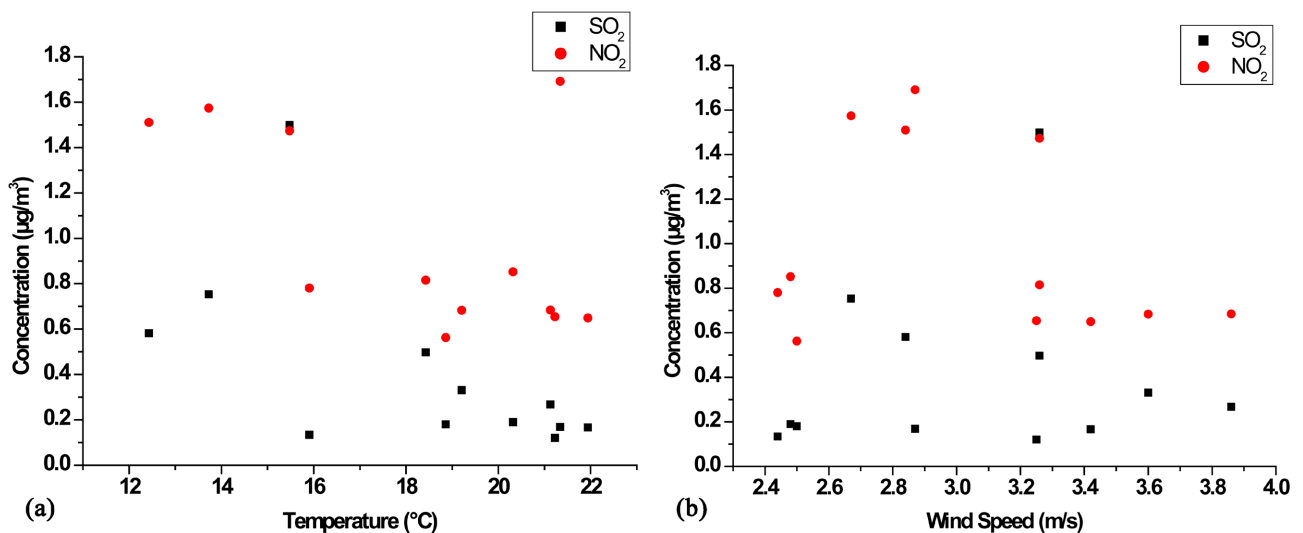
The monthly concentrations of SO<sub>2</sub> and NO<sub>2</sub> differ in relation to the meteorological factors as shown in the figure. NO<sub>2</sub> concentrations depend on relative humidity as decreases as relative humidity increases. A maximum value of 1.7 µg/m<sup>3</sup> was achieved when the relative humidity of 39.21% is low. Moreover, the temperature and the wind speed have little effect on the influence of NO<sub>2</sub> concentration. The impact of atmospheric factors in Polokwane is shown in **Figure 4**.

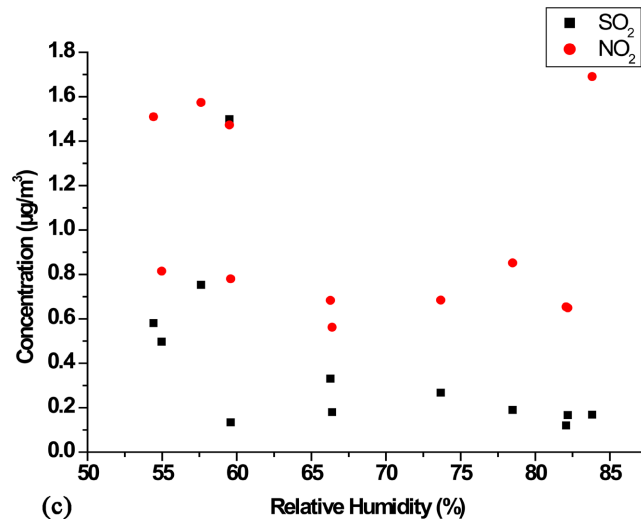
The two air pollutants' respective concentrations are influenced by temperature. The concentrations of NO<sub>2</sub> and SO<sub>2</sub> are highest at low temperatures, or between 12 and 17°C. Nonetheless, the temperature range of 18 to 20°C is where the concentrations of these air pollutants are concentrated. Low SO<sub>2</sub> and NO<sub>2</sub>

concentrations are found at slower wind speeds. Nevertheless, the dependence of concentration on wind speed is independent of the speed. When the wind speed

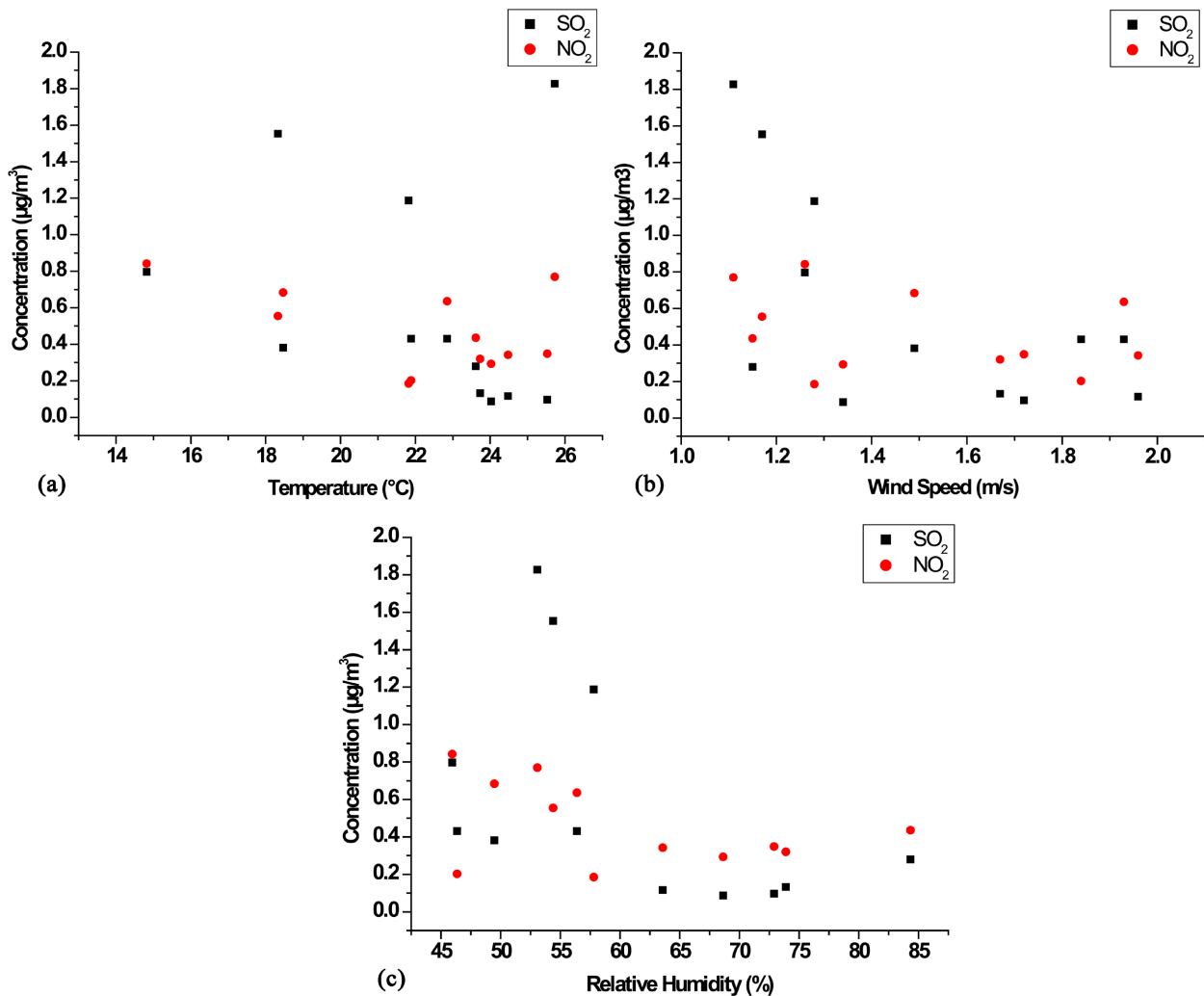


**Figure 3.** Scatter plots of (a) temperature, (b) wind speed, and (c) relative humidity on  $\text{SO}_2$  and  $\text{NO}_2$  concentrations in Lephalale.





**Figure 4.** Dependency of air pollutants concentrations on meteorological parameters (a) Temperature, (b) Wind speed, and (c) Relative humidity in Polokwane.



**Figure 5.** Variations of air pollutants as a function of meteorological factors in Steelpoort: wind speed (a), wind speed (b) and relative humidity (c).

is between 2.6 and 2.8 m/s, there are significant variations in the levels of SO<sub>2</sub> and NO<sub>2</sub>. At a relative humidity of 59.52%, the concentration of SO<sub>2</sub> is high, while at 83.32%, the level of NO<sub>2</sub> is at its maximum.

The relationship between temperature, wind speed, and relative humidity and the concentrations of NO<sub>2</sub> and SO<sub>2</sub> in Steelpoort is depicted in **Figure 5**.

As seen in the figure, relative humidity has little effect on concentrations of NO<sub>2</sub> and SO<sub>2</sub>. At relative humidity between 55% and 60%, the SO<sub>2</sub> concentrations are high (1.2 to 1.8 µg/m<sup>3</sup>) compared to NO<sub>2</sub>. In other relative humidity values, there is not much difference with respect to the concentrations of both pollutants. The effect of temperature depicts high levels of NO<sub>2</sub> and SO<sub>2</sub> at temperatures 15°C and 26°C, respectively, for the Steelpoort area. There was not much temperature effect on the air pollutants levels. Wind speed affects the concentration level of SO<sub>2</sub> when the wind speed was low, that is, between 1.1 to 1.3 m/s, the concentrations of SO<sub>2</sub> were high as shown in **Figure 5**. Whereas, at speed between 1.4 m/s to 2.0 m/s, the concentrations range from 0.05 to 0.8 µg/m<sup>3</sup>.

### 3.3. Evaluation of the Effect of Meteorological Parameters on SO<sub>2</sub> and NO<sub>2</sub> Levels

In order to estimate how the NO<sub>2</sub> and SO<sub>2</sub> concentrations depend on meteorological factors a MLR was performed. The MLR coefficients of NO<sub>2</sub> and SO<sub>2</sub> concentrations with respect to meteorological parameters in different monitoring areas are illustrated in **Table 1**. The null hypothesis, according to the table's results, that there is no significant difference between any seasonal mean, is rejected. All p-values were less than 0.01.

The initial models, derived from Equation (5), for NO<sub>2</sub> are given by Equations

**Table 1.** Summary of coefficients of air pollutants using MLR model.

MLR		NO <sub>2</sub>	SO <sub>2</sub>	NO <sub>2</sub>	SO <sub>2</sub>	NO <sub>2</sub>	SO <sub>2</sub>
		$\beta$ (p-value)	$\beta$ (p-value)	$\beta$ (p-value)	$\beta$ (p-value)	$\beta$ (p-value)	$\beta$ (p-value)
1	C	2.894 (0.003)	1.814 (0.028)	1.898 (0.058)	1.583 (0.111)	1.419 (0.021)	3.310 (0.003)
	T	-0.055 (0.208)	-0.114 (0.020)	-0.127 (0.027)	-0.018 (0.721)	-0.14 (0.620)	0.080 (0.096)
	WS	0.517 (0.293)	0.420 (0.373)	-0.094 (0.618)	0.080 (0.677)	-0.04 (0.379)	0.420 (0.004)
	RH	0.280 (0.076)	0.012 (0.387)	0.026 (0.153)	-0.016 (0.381)	-0.006 (0.428)	0.012 (0.009)
2	C	3.439 (<0.001)	2.316 (<0.001)	1.654 (0.040)	1.508 (0.098)	1.316 (0.014)	--
	T	-0.016 (0.458)	0.104 (0.718)	-0.0120 (0.022)	0.100 (0.568)	-0.245 (0.243)	--
	WS	--	-0.085 (0.005)	--	--	--	--
	RH	-0.040 (0.001)	--	0.023 (0.154)	0.023 (0.154)	0.023 (0.154)	--
3	C	3.256 (<0.001)	2.343 (<0.001)	2.292 (0.003)	1.758 (0.027)	0.944 (0.015)	--
	RH	-0.043 (<0.001)	-0.079 (<0.001)	--	--	-0.008 (0.165)	--
	T	--	--	-0.070 (0.048)	--	--	--

NB: C: Constant, T: Temperature, WS: Wind Speed, RH: Relative Humidity.

(6) to (8) for Lephallale, Polokwane and Steelpoort, respectively. Furthermore, models for SO<sub>2</sub> are shown in Equations (9) to (11).

$$\text{NO}_2 = 2.894 - 0.055T + 0.517\text{WS} - 0.028\text{RH} \text{ (Lephallale)} \quad (6)$$

$$\text{NO}_2 = 1.898 - 0.127T - 0.094\text{WS} - 0.026\text{RH} \text{ (Polokwane)} \quad (7)$$

$$\text{NO}_2 = 1.419 - 0.014T - 0.204\text{WS} - 0.006\text{RH} \text{ (Steelpoort)} \quad (8)$$

$$\text{SO}_2 = 1.814 - 0.114T + 0.420\text{WS} + 0.012\text{RH} \text{ (Lephallale)} \quad (9)$$

$$\text{SO}_2 = 1.583 - 0.018T + 0.080\text{WS} - 0.016\text{RH} \text{ (Polokwane)} \quad (10)$$

$$\text{SO}_2 = 3.310 - 0.080T - 1.449\text{WS} - 0.038\text{RH} \text{ (Steelpoort)} \quad (11)$$

According to the statistical model Equation (6) through Equation (11), the NO<sub>2</sub> and SO<sub>2</sub> concentrations are inversely correlated to temperature and relative humidity apart from SO<sub>2</sub> in Lephallale, as shown in Equation (9). The pattern is consistent with the results obtained by Ebrahimi and Qaderi, 2021 [23] [29]. Also, this means that when temperature and relative humidity are increased by one °C and 1.0%, the concentration of NO<sub>2</sub> decreases by 0.006 µg/m<sup>3</sup> to 0.028 µg/m<sup>3</sup>. Meanwhile, the concentrations of SO<sub>2</sub> decrease by 0.016 µg/m<sup>3</sup> and 0.038 µg/m<sup>3</sup> in Polokwane and Steelpoort. At the same time, the concentration of SO<sub>2</sub> increases by 0.012 µg/m<sup>3</sup>. It is worthwhile noting that wind speed has both positive Equations (6), (9) and (10), and inverse, Equations (7), (8) and (11) correlations to the concentrations of both air pollutants and this is due to the impact of vehicular traffic. The positive correlation of both NO<sub>2</sub> and SO<sub>2</sub> with wind speed in a low-income community [30].

The backward elimination method in the MLR model was used to remove independent variables that are insignificant where alpha,  $\alpha = 0.1$ . The final models are presented in Equations (12) to (17). This method begins by entering all terms specified on the stepwise list into the model. At each step, the least significant stepwise term is removed from the model until all the remaining stepwise terms have a statistically significant contribution to the model. After eliminating the non-significant variables, the final models indicate that relative humidity has an inverse correlation with the concentrations of NO<sub>2</sub> in all studied sites, which implies that lowering of the NO<sub>2</sub> concentration is followed by the increase of relative humidity and vice versa. However, the relationships between SO<sub>2</sub> and the independent variables differ. In Lephallale and Polokwane, there is an inverse correlation of temperature and relative humidity with SO<sub>2</sub> concentration, respectively. There is no statistical significance between the SO<sub>2</sub> concentrations and the meteorological parameters in Steelpoort. This demonstrates that meteorological conditions have a significant impact on how air pollutants are distributed.

According to the statistical model Equation (6) through Equation (11), the NO<sub>2</sub> and SO<sub>2</sub> concentrations are inversely correlated to temperature and relative humidity apart from SO<sub>2</sub> in Lephallale, as shown in Equation (9). The pattern is consistent with the results obtained by Ebrahimi and Qaderi, 2021 [23] [29]. Also, this means that when temperature and relative humidity are increased by one °C and 1.0%, the concentration of NO<sub>2</sub> decreases by 0.006 µg/m<sup>3</sup> to 0.028 µg/m<sup>3</sup>.

Meanwhile, the concentrations of SO<sub>2</sub> decrease by 0.016 µg/m<sup>3</sup> and 0.038 µg/m<sup>3</sup> in Polokwane and Steelpoort. At the same time, the concentration of SO<sub>2</sub> increases by 0.012 µg/m<sup>3</sup>. It is worthwhile noting that wind speed has both positive Equations (6), (9) and (10), and inverse, Equations (7), (8) and (11) correlations to the concentrations of both air pollutants and this is due to the impact of vehicular traffic. The positive correlation of both NO<sub>2</sub> and SO<sub>2</sub> with wind speed in a low-income community [30].

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$$\text{NO}_2 = 3.256 - 0.43\text{RH (Lephallale)} \quad (12)$$

$$\text{NO}_2 = 2.292 - 0.70\text{RH (Polokwane)} \quad (13)$$

$$\text{NO}_2 = 0.944 - 0.008\text{RH (Steelpoort)} \quad (14)$$

$$\text{SO}_2 = 2.343 - 0.079\text{T (Lephallale)} \quad (15)$$

$$\text{SO}_2 = 1.758 - 0.020\text{RH (Polokwane)} \quad (16)$$

$$\text{SO}_2 = \text{Null hypothesis (Steelpoort)} \quad (17)$$

#### 4. Conclusion and Future Research

The findings of this study demonstrate that throughout the winter, SO<sub>2</sub> concentrations are high in all areas, viz., Steelpoort, Polokwane, and Lephallale. Higher SO<sub>2</sub> levels were found in Steelpoort, followed by Lephallale and lastly in Polokwane. However, this might be due to the distance between the Medupi power station and the sampling site. Lephallale had the highest levels of NO<sub>2</sub> as compared to Polokwane and Steelpoort. Air pollutants in Steelpoort come from various sources such as mining activities, domestic heating and vehicular emissions. The results of the multiple linear regression models demonstrated that meteorological factors like temperature, wind speed, and relative humidity have an impact on the dispersion of NO<sub>2</sub> and SO<sub>2</sub>. However, the meteorological factors affect the air pollution levels differently. In Polokwane and Steelpoort, NO<sub>2</sub> and SO<sub>2</sub> concentrations are inversely correlated to temperature and relative humidity except for SO<sub>2</sub>

in Lephalale. Wind speed has positive and inverse correlations to the concentrations of both air pollutants. The final model showed that relative humidity negatively influences air pollutants. Future research such as collecting daily data concentrations of SO<sub>2</sub> and NO<sub>2</sub>; assessment of impact of climate change as well as the impact of these air pollutants on human health around the areas, needs to be studied as a preventative measure of air pollution.

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### Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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