International Research Journal of Public and Environmental Health Vol.3 (11),pp. 257-269, November 2016
Available online at http://www.journalissues.org/IRJPEH/
http://dx.doi.org/10.15739/irjpeh.16.032

ISSN 2360-8803

Original Research Article

Acute respiratory health effects of air pollution on asthmatic adolescents residing in a community in close proximity to-mine dump in South Africa: Panel study

Received 5 September, 2016 Revised 7 October, 2016 Accepted 13 October, 2016 Published 11 November, 2016

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Air pollution arising from mine dumps has been a major public health concern to communities located in close proximity to these facilities in South Africa. The study investigated the association between acute changes in lung function and ambient air pollutants on asthmatic children in Noordgesig, Gauteng, South Africa. A panel study design with repeated measures was used to carry out the investigation which involved 15 asthmatic children. Each participating child completed an asthma daily symptom diary and performed forced expiratory flows in one second (FEV1) for 21 consecutive days. The 24 h ambient air pollution concentrations were monitored over this period. Linear mixed effect models adjusted for temperature, relative humidity, the day of the week, first order autocorrelation and 10 µg.m^{-3} increase of the mean of pollutant concentrations were used to determine the association between morning FEV1 and air pollutants. The association between air pollutants, respiratory symptoms and medication use were evaluated with logistic mixed effect models. The mean 24-hour concentration of NO_x for current day was 0.762% (95% CI: -1.296 – -0.227), and for O_3, the respective current and previous days were 0.780% (95% CI: -1.461 – -0.099) and 0.716% (95% CI: -1.386 – -0.045), all of these were significantly associated with the morning FEV1 decline. Single pollutant models showed significant positive associations between chest tightness, cough and NO_2, O_3, NO_x, and SO_2 pollutants. Medication use such as corticosteroids and short-acting β_2 agonist were associated with NO_x (OR = 1.07; 95% CI: 1.00 – 1.28) and O_3 (OR = 1.57 95% CI: 1.03 – 2.72) respectively. Interestingly, a protective significant effect, was observed between SO_2 and cough (OR = 0.45; 95% CI: 0.21 – 0.97). The findings of this study provide evidence that an acute change of gaseous air pollutants in communities situated near mine dumps exacerbates lung function in vulnerable children.

Key words*:* Mine dumps, panel study, respiratory effects, asthma, Noordgesig, South Africa.

Abbreviations

Autoregressive covariance structure (AR1); Forced expiratory volumes in 1 second (FEV1); International Study of Asthma and Allergies in Childhood (ISAAC); Mine Health Safety Council of South Africa (MHSCSA), Microgram per cubic metre (µg.m^{-3}); Nitrogen Dioxide (NO_2); National Research Fund – Deutscher Akademischer Austausch Dienst (NRF – DAAD); Odds Ratio (OR), Oxides of Nitrogen (NO_x); Ozone (O_3); Particulate matter measured in fractions of ≤ 10 µm in diameter (PM_{10}); Particulate matter measured in fractions of ≤ 2.5 µm in diameter ($PM_{2.5}$); South African Department of Environmental Affairs (SADEA); South African Weather Services (SAWS); Sulphur dioxide (SO_2); Statistics South Africa (SSA).

INTRODUCTION

Air pollution arising from mine dumps has been a major public health concern to communities located in close proximity to these facilities. These facilities serve as a waste depository for materials formed by extraction and grinding methods of during mining process (Oguntoke et al., 2013; Bussieres et al., 2004; Moreno et al., 2010). The material consist of a complex mixture of metals such lead, cadmium, manganese, silver, arsenic, dust particles and particulate matter measured in fractions of $\leq$ 10 µm (PM_{10}) and $\leq$ 2.5 µm ($PM_{2.5}$) in diameter (Moreno et al., 2010; Hu et al., 2004; Meza-Figueroa et al., 2009; Mendez et al., 2008; Candeias et al., 2013). These metals and particulate matter constitute a serious health hazard on the human respiratory system.(Spicer and Weber 1991; Carreras et al., 2009; De Longueville et al., 2010; Tam et al., 2012) As a result of these mine dumps, ambient air quality is deteriorating due to dust particles that are released and transported via aeolian dispersion to nearby communities.(Mendez and Maier 2008; Ojelede et al., 2012) In dry windy seasons, for instance, the ambient air concentration of dust particles can reach the maximum of 2160 µg/$m^{3,}$ which is several times higher than the 24-hour limit value suggested by the South African Department of Environmental Affairs (SADEA, 2004). In communities where mine dumps are located, those are likely to be major contributors of air pollution, thus posing serious health risks to the people living within those communities (Ojelede et al., 2012). Usually, people living in exposed communities are found mainly in informal settlements and government funded houses of historically marginalised ethnic groups and are of lower socio-economic status. The most vulnerable in such communities are the elderly and children (Wright et al., 2014). Children are particularly more at risk because their respiratory system is still developing (Sacks et al., 2011). Epidemiological studies have linked short-term exposure to particulate matter with adverse health effects such as decreased lung function and premature death in people with lung diseases (Jalaludin et al., 2004; Dominici et al., 2006; Dockery 2009; Goldberg et al., 2013). In South Africa, higher prevalence of asthma symptoms was observed in children residing in communities situated close to the mine dumps than those located further away (Nkosi et al., 2015). So far no studies have been reported in the extant literature of whether air pollution as the result of mine dumps pose an increased risk for children who are asthmatic. The study reported here is part of a larger project on health related issues initiated by Mine Health Safety Council of South Africa (MHSCSA) around communities located near mine dumps in Gauteng and North West, South Africa. The purpose of the study was to investigate the association between acute changes in lung function with ambient air pollutants on asthmatic children in Noordgesig, Gauteng, South Africa.

MATERIALS AND METHODS

Study population

The study was conducted in Noordgesig (Figure 1), Gauteng, South Africa, with estimated with a population of about 12,155 in 2011 (SSA 2012). A unique aspect of the township is that it is located at the base of the mine dump. Children with asthma were identified from a self-administered questionnaire survey based on the International Study of Asthma and Allergies in Childhood (ISAAC) (Ellwood et al., 2005). The ISAAC study was carried out in the previous year, It included 400 secondary school children in Noordgesig (Nkosi et al., 2015). For the present study, children who had given a positive response to the question “Has a doctor/physician ever told you that you had asthma?” and whose parent or guardian had agreed to be contacted about future research were selected. Fifteen asthmatic children between 13 and 14 years old and lived in homes where no one is smoking cigarette participated in the study.

Study design

A panel study design with repeated measures was used to carry out the investigation which involved 15 asthmatic children. Each participant completed an asthma symptom daily diary and performed forced expiratory flows for 21 consecutive days. Children were studied in a dry season from 18 August to 8 September 2013.

Air pollution monitoring

City-wide background air pollution hourly levels were obtained from a fixed-site monitor located in the south-east of the area, upwind from the prevailing winds. The fixed-site monitoring station belongs to South African Weather Services (SAWS). Hourly levels of pollutants data such as nitrogen dioxide (NO_2), oxides of nitrogen (NO_x), ozone (O_3), sulphur dioxide (SO_2), particulate matter less than 2.5 ($PM_{2.5}$) and 10 (PM_{10}) µm in diameter were retrieved from the monitoring station. Weather data for the duration of the study including temperature and relative humidity were also retrieved from the monitoring station.

Lung functions assessment

Forced expiratory volumes in 1 second (FEV1) were measured using a pocket electronic flow meter (Piko-1). Each participant was trained to use Piko-1. The training also included the proper standing position during the use of Piko-1, breathing techniques and maintenance of the instrument. Participants were instructed to perform the FEV1 manoeuvre in the standing position three times in the

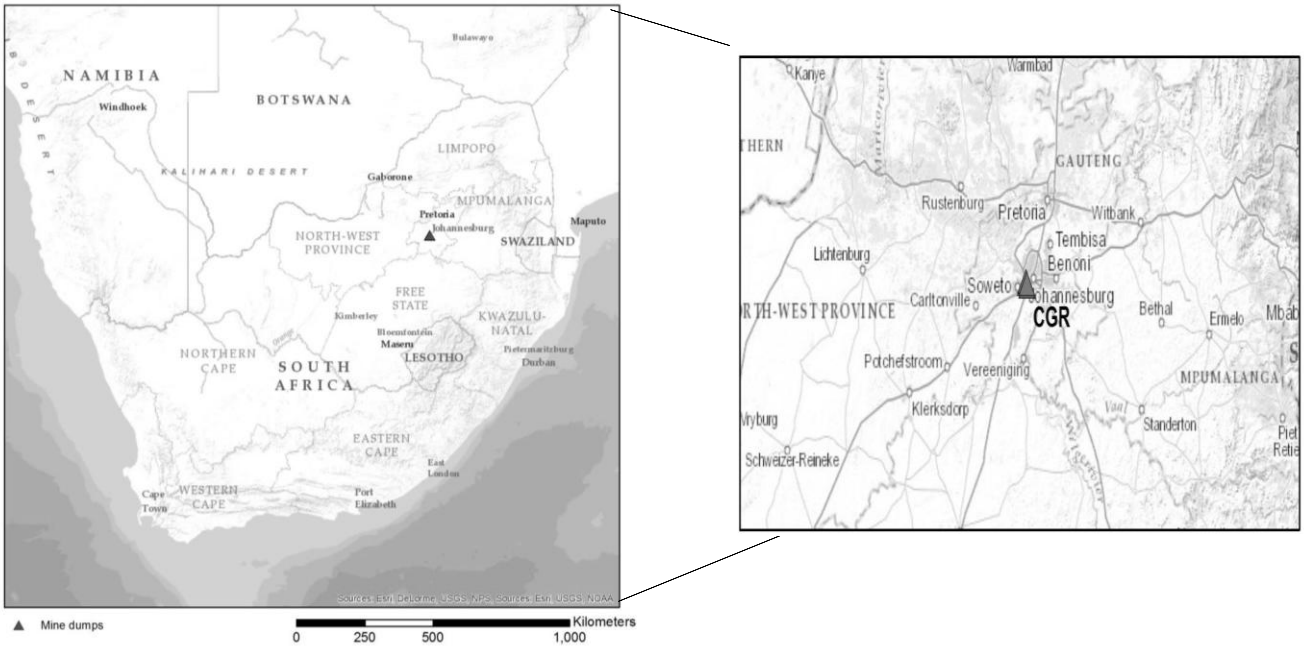


Figure 1: Location of mine dumps tailings in Noordgesig

morning and three in the evening prior use of breathing medication. For each participant, the mean morning FEV1 was calculated. Percentage morning FEV1 decrements variability was expressed as 100 % ×(individual morning FEV1 measured on that day – individual mean of morning FEV1 throughout the study period)/ individual mean of morning FEV1 throughout the study period.

Diary cards

All study participants were issued with asthma daily diary cards to record the presence of asthma symptoms and medication use such as breathlessness, chest tightness, cough, wheeze, short-acting β_2-agonist, inhaled corticosteroids and other asthma medication use on the diary.

Statistical analyses

All statistical analyses were performed using SAS statistical software package version 9.4. Prevalence of health outcomes was calculated by dividing the number of participants who recorded the presence of asthma symptoms divided by a number of completed diaries. The daily mean concentration of air pollutants, temperature and relative humidity were calculated by adding the hourly levels and dividing by twenty-four hours per day. Pearson correlation coefficients were estimated to better understand the interrelationship between air pollutants and weather variables.

The results obtained from linear mixed effect models were expressed as the percentage of morning FEV1 decrements corresponding to 10 $\mu g.m^{-3}$ increase in air pollutants concentration. Autoregressive covariance structure (AR1) was used to allow for a greater within-subject autocorrelation for FEV1 measures taken more closely in time. A random intercept and fixed slope were assumed. The effect of air pollutants concentration of the current day (lag 0), previous day (lag 1) and 2 days after the exposure (lag 2) on the lung function, asthma symptoms and asthma medication use were analysed separately.

The association between air pollutants, respiratory symptoms and asthma medication use were evaluated with logistic mixed effect models. Odds ratios (OR) were calculated for an increase of 10 $\mu g.m^{-3}$ in air pollutant levels. The final models with outcome variables were adjusted for daily mean temperature, relative humidity and day of the week for both linear and logistic mixed effect are reported in this study. The *p-value*< 0.05 obtained in both models for air pollutants, respiratory symptoms and asthma was deemed statistically significant. Two-pollutant models were used to characterise pollutants that were more strongly associated with associated with FEV1, respiratory symptoms and asthma medication use.

RESULTS

Demographic characteristics

A total of 15 pupils were involved in the study, 60% were girls and 40% boys with the mean age of 13 years (Table 1). All participants that were included in the study had a history of “doctor diagnosed asthma”. Of the participants,

Table 1. Demographic characteristics of the 15 participating children, by period of study in Noordgesig (Gauteng, South Africa) in 2013

Characteristics	Study period 18 August to 8 September	% (n)
Sex		
Girls		60 (9)
Boy		40 (6)
Age (years)		
Age;mean (SD)*		13 (0.4)
Height (m)		
Height; mean (SD)*		1.6 (0.1)
Weight (kg)		
Weight; mean (SD)*		59.5 (18.5)
***BMI*(kg/m^2)**		
BMI; mean (SD)*		24.9 (7.0)
Respiratory symptoms prevalence during the study period		
Breathlessness		67 (10)
Chest tightness		47 (7)
Cough		73 (11)
Wheeze		87 (13)
Medication use during the study period		
Inhaled corticosteroid		40 (6)
Short acting β$_2$-agonist		40 (6)
Other asthma medication		7 (1)
No asthma medication		14 (2)
MFEV1^{ǂ}; mean (SD)*		2.49 (0.37)

Figures in parentheses number of participants unless otherwise stated.
*SD: Standard deviation
ǂMFEV1: Morning forced expiratory volume in 1 second

the mean morning FEV1 was 2.49. During the study period, 40% reported the use of inhaled corticosteroids, 40% short-acting β$_2$agonist, 7% other asthma medication and 14% no asthma medication. The prevalence of respiratory symptoms reported by children was breathless (67%), chest tightness (47%), cough (73%) and wheeze (87%).

Air pollution

The mean 24-hour concentration of air pollutants was well below the South African Air Quality Standards set by the Department of Environmental Affairs (Table 2) (SADEA 2004) SO_2 and PM_{10} remained stable over the study period (Figure 2). NO_2, NO_x, $PM_{2.5}$, PM_{10} and SO_2 were positively correlated with each other, whereas ozone was negatively correlated with all these five ambient air pollutants (Table 3). The strongest correlation between two pollutants was 0.65 ($p = 0.001$), It was observed between $PM_{2.5}$ and PM_{10}.

Pollutant and FEV1 % change

Adjusted for temperature, relative humidity and day of the week and 10 μg.m^{-3} increases of pollutants concentration. The mean 24-hour concentration of NO_x of the previous day (lag 0) was associated with the morning FEV1 decline of 0.762% (95% CI: -1.296 – -0.227). The mean 24-hour concentrations of ozone (O_3) of the current (lag 0) and previous day (lag 1) were also significantly associated with the morning FEV1 decline of 0.780% (95% CI: -1.461 – -0.099) and 0.716% (95% CI: -1.386 – -0.045) respectively. Interestingly, SO_2 of the current day (lag 0) and one day later (lag 1) was associated with improved morning FEV1 of 0.248% (95% CI: 0.028 – 0.468) and 0.234% (95% CI: 0.013 – 0.467) respectively. Increases of 10μg.m^{-3} in NO_2, NO_x, O_3 and $PM_{2.5}$ two days later (lag 2) were associated with the decrease in morning FEV1, but no significant relationship was observed (Table 4).

Two-pollutant models and MFEV1 % change

In the two-pollutant models that included NO_x and O_3 as predictors for MFEV1, all lags were significantly associated with MFEV1 (Figure 3a), other combinations were not significantly associated with MFEV1 (Figure 3b – c) and supplementary materials (Figure 3d-e).

Single pollutant models and health outcomes

For asthma-related symptoms and medication use, single pollutant models revealed significant positive associations between chest tightness and cough with NO_2, O_3, NO_x, and SO_2 (Table 5). Asthma medication use such as corticosteroids was associated with NO_x (OR = 1.07; 95% CI: 1.00 – 1.28) and short-acting β$_2$-agonist with O_3 (OR =

Table 2. Distribution of the daily 24-h mean concentrations of selected outdoor air pollutants and meteorological characteristics in Noordgesig between 18 August and 8 September 2013

Pollution/weather variables#	Days (n)	Mean± SD (range)	25th percentile	Median	75th percentile	Interquartile range
NO_2 (ppb)	21	32.3 ± 8.4 (16.3 – 49.9)	28.0	31.8	38.3	10.3
NO_x (ppb)	21	47.0 ± 22.3 (13.5 – 99.6)	36.6	41.2	58.5	21.9
O_3 (ppb)	21	33.7 ± 13.5 (12.9 – 74.2)	24.7	32.6	40.3	14.6
$PM_{2.5}$ (μg/m^3)	21	21.0 ± 6.0 (9.1 – 32.9)	16.1	22.4	23.2	7.1
PM_{10} (μg/m^3)	21	45.0 ± 12.2 (20.8 – 63.9)	38.8	46.7	52.1	13.3
SO_2 (ppb)	21	5.9 ± 4.3 (0.2 – 14.9)	3.1	4.9	8.0	4.9
Relative humidity (%)	21	37.9± 11.0 (15.2 – 60.2)	33.8	39.0	40.5	6.7
Temperature (°C)	21	12.2 ± 1.8 (9.1 – 18.2)	11.4	12.0	12.8	1.4

NO_2: nitrogen dioxide; NO_x: oxides of nitrogen; O_3: ozone; $PM_{2.5}$: particulate matter <2.5 μm in diameter; PM_{10}: particulate matter <10 μm in diameter; SO_2: sulphur dioxide. $^{\#}$: Data were obtained from South African Weather Services

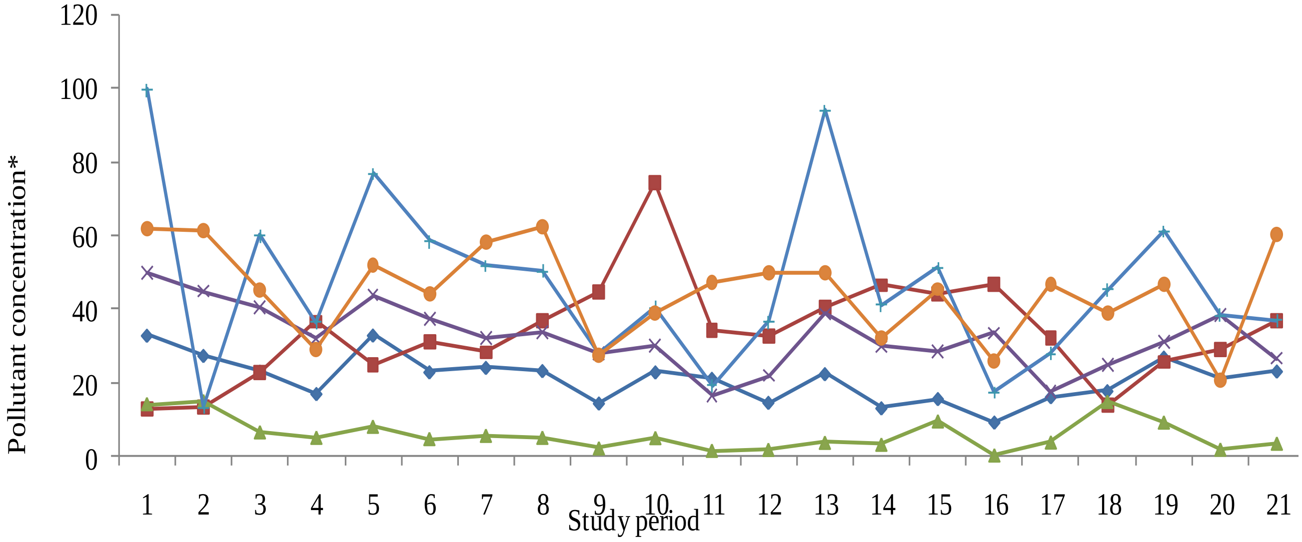


Figure 2: The 24-h mean concentrations of air pollutants during the study period, 18 August to 8 September 2013, in Noordgesig, Gauteng, South Africa.x: nitrogen dioxide;+: oxides of nitrogen; ■:ozone;♦:particulate matter <2.5μm in diameter;●: particulate matter <10μm in diameter; ▲: Sulphur dioxide. *: All pollutant concentrations are expressed in ppb except $PM_{2.5}$ and PM_{10}, which are in μg/m^3.

Table 3. Pearson's correlation coefficients for the pollutants (daily means) and meteorological characteristics in Noordgesig between 18 August and 8 September 2013

Pollutants/ weather variables	Pearson correlation coefficients							
	NO_2	NO_x	O_3	$PM_{2.5}$	PM_{10}	SO_2	Relative humidity	Temperature
NO_2 (ppb)	1.00							
NO_x (ppb)	0.56^{**}	1.00						
O_3 (ppb)	-0.35^{**}	-0.24^{**}	1.00					
$PM_{2.5}$ (μg/m^3)	0.62^{**}	0.59^{**}	-0.46^{**}	1.00				
PM_{10} (μg/m^3)	0.20^{*}	0.35^{**}	-0.39^{**}	0.65^{**}	1.00			
SO_2 (ppb)	0.45^{**}	0.33^{**}	-0.60^{**}	0.54^{**}	0.44^{**}	1.00		
Relative humidity (%)	-0.25^{**}	-0.38^{**}	-0.24^{**}	0.10	-0.13	-0.03	1.00	
Temperature (°C)	-0.03	-0.19^{*}	0.13^{*}	-0.29^{**}	-0.04	-0.30^{**}	-0.29	1.00

*: $p<0.05$; **: $p<0.001$. NO_2: nitrogen dioxide; NO_x: oxides of nitrogen; O_3: ozone; $PM_{2.5}$: particulate matter <2.5 μm in diameter

Table 4. The effects of 10µg.m^{-3}/ppb increase of pollutants on morning forced expiratory volume in 1 second (MFEV1) expressed as percentages among children with asthma in Noordgesig between 18 August and 8 September 2013[ǂ]

Pollutants[#]	**FEV 1 % change[+]**	**95% CI**	**p-value**
Single pollutant models			
NO_2:			
Lag 0	0.252	-1.095 – 1.600	0.712
Lag 1	0.095	-1.277– 1.467	0.892
Lag 2	-0.602	-1.948 – 0.745	0.379
NO_x:			
Lag 0	-0.426	-0.880– 0.028	0.066
Lag 1	-0.762	-1.296 – -0.227	0.005*
Lag 2	-0.448	-1.030 – 0.135	0.131
O_3:			
Lag 0	-0.780	-1.461 – -0.099	0.025*
Lag 1	-0.716	-1.386 – -0.045	0.036*
Lag 2	-0.375	-1.053 – 0.303	0.277
PM_{10}:			
Lag 0	0.566	-0.197– 1.329	0.145
Lag 1	0.511	-0.265 – 1.286	0.196
Lag 2	0.201	-0.558– 0.960	0.603
$PM_{2.5}$:			
Lag 0	0.129	-1.513 – 1.772	0.877
Lag 1	-0.123	-1.836 – 1.589	0.887
Lag 2	-0.645	-2.280 – 0.989	0.438
SO_2:			
Lag 0	0.248	0.028– 0.468	0.027*
Lag 1	0.234	0.013 – 0.467	0.039*
Lag 2	0.064	-0.193 – 0.322	0.623

NO_2: nitrogen dioxide; NO_x: oxides of nitrogen; O_3: ozone; $PM_{2.5}$: particulate matter <2.5 µm in diameter; PM_{10}: particulate matter <10 µm in diameter; SO_2: sulphur dioxide. [#]: Data were obtained from South African Weather Services. *: p<0.05. +: FEV1 % change = 100 %^{x} (individual morning FEV1 measured on that day – individual mean of morning FEV1 throughout the study period)/ individual mean of morning FEV1 throughout the study period. ǂ: a mix model was used with random intercept and fixed slope and autoregressive covariate structure adjusted for daily temperature, relative humidity, day of the week, sex, age and body mass index.

1.57 95% CI: 1.03 – 2.72). Interestingly a protective significant effect was observed between SO_2 and cough (OR = 0.45; 95% CI: 0.21 – 0.97).

Two-pollutant models and health outcomes

Cough was only the significant health outcome considered in this study for the following air pollutants combination that included SO_2+O_3, NO_x+SO_2 and NO_2+SO_2 (Table 6).

DISCUSSION

Findings of this study showed a significant association between short-term gaseous air pollution exposure and respiratory health outcomes in children residing in a community situated near mine dump, despite the fact that the daily ambient pollutants concentration were all well below South African Air Quality Standards set by the Department of Environmental Affairs. These findings suggest that the currently accepted air pollution standards for public safety should be revisited. Concentrations of NO_x, O_3, and SO_2 were significantly associated with decrements with FEV1, NO_x and O_3 had stronger effects. NO_x is considered to be a good marker of traffic-related air pollution (Holgate et al., 1999). The community included in the study is located near a busy highway, indicating that traffic is also a major contributor to ambient air pollution in this area. A cross-sectional study conducted in South Africa showed that heavy truck was a risk factor for asthma symptoms in communities located nearby mine dumps than those far away (Nkosi et al., 2015). All children in the study area are exposed to the ambient air pollution, resulting in a large number of children affected. Suppose that there is a population distribution of asthma severity and of sensitivity to air pollution, children with increased vulnerability to air pollution would be more likely to experience exacerbated asthma attacks on low or high air pollution days (Norris et al., 1999; Moshammer et al., 2006).

A recent systematic review showed the negative impact of the short-term effects NO_2 on respiratory health in children with asthma, NO_2 showed statistically significant associations with asthma symptoms when considering all

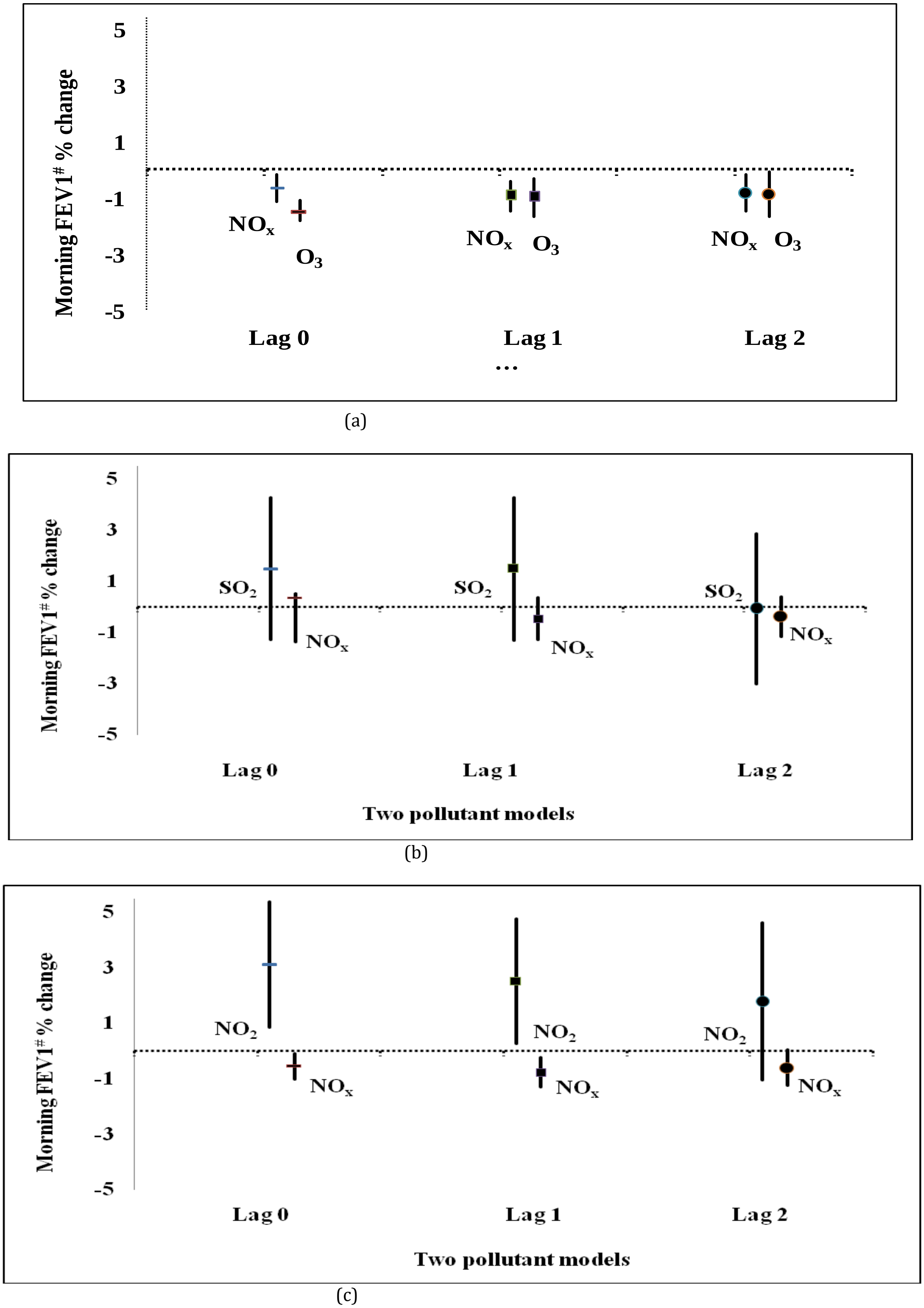
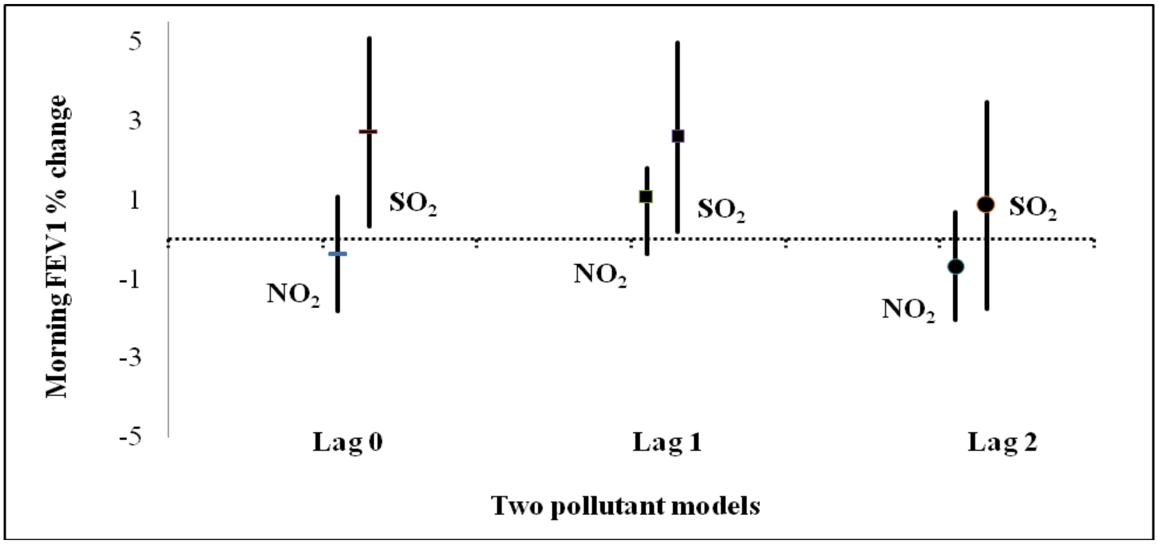
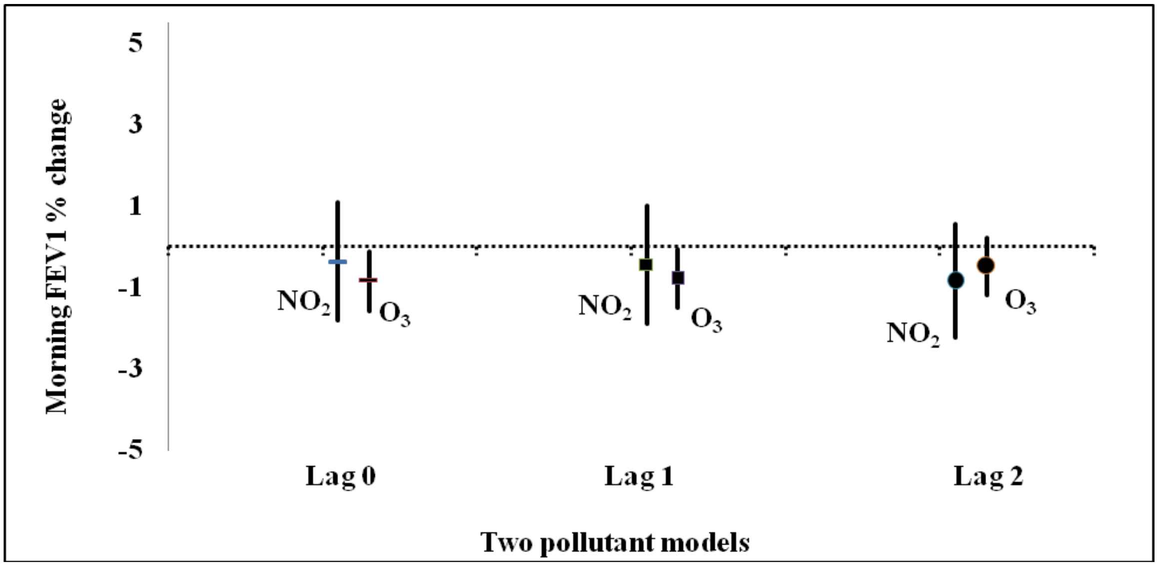


Figure 3 (a-c): Morning forced expiratory volume in 1 s associated with 10μg.m^{-3}increase in daily air pollutants concentration averaged for 24 hours on the test day, previous day and two previous days. A mix model was used with random intercept and fixed slope and autoregressive covariate structure adjusted for daily temperature, relative humidity, day of the week, sex, age and body mass index.



(d)



(e)

Figure 3 (d –e): Morning forced expiratory volume in 1 s associated with 10µg.m^{-3} increase in daily air pollutants concentration averaged for 24 hours on the test day, previous day and two previous days. A mix model was used with random intercept and fixed slope and autoregressive covariate structure adjusted for daily temperature, relative humidity, day of the week, sex, age and body mass index.

possible lags (WHO 2013) and decrements in lung function (Bate 1995; Liu et al., 2009; Witwatanadate et al., 2011). These findings are in contrast to those of this study, although NO$_2$ had the strongest effect on chest tightness and not for all the lags. The effects of SO$_2$ on the lung function of the asthmatics are well documented by research studies Witwatanadate et al., 2011; Peters et al., 1997; Chen et al., 2008). In this study, SO$_2$ was associated with asthma symptoms but improved lung function. In addition, two pollutant models indicated that SO$_2$ effect was not strong on the lung function. Due to various socio-economic reasons and high employment rate in South Africa, many households use paraffin and open fires for residential heating or cooking as alternative sources of energy as they are more affordable than electricity (Schwebel and Swart 2009) and this might contribute immensely to the SO$_2$ indoor and outdoor air pollution in this area. These findings are supported by the International study of Asthma and Allergies in Childhood that was conducted in communities that are located in close proximity to mine dumps in South Africa (Nkosi et al., 2015). However, it could not be explained as to why SO$_2$ had improved FEV1. Summer

Table 5. The effects of an increase of 10µg.m^{-3} of pollutants on respiratory symptoms among children with asthma in Noordgesig between 18 August and 08 September 2013ǂ

	Lag days	NO$_2$	NO$_x$	O$_3$	PM$_{10}$	PM$_{2.5}$	SO$_2$
Respiratory symptoms							
Breathlessness							
	0	1.16 (0.81 – 1.66)	0.95 (0.83 – 1.08)	0.95 (0.79 – 1.34)	1.01 (0.82 – 1.25)	0.95 (0.61 – 1.49)	1.02 (0.56 – 1.87)
	1	1.00 (0.73 – 1.55)	0.87 (0.75 – 1.01)	0.99 (0.81 – 1.19)	0.98 (0.79 – 1.21)	0.84 (0.53 – 1.34)	0.86 (0.46 – 1.61)
	2	0.99 (0.62 – 1.36)	0.94 (0.79 – 1.11)	1.08 (0.88 – 1.33)	0.91 (0.73 – 1.13)	0.75 (0.47 – 1.19)	0.45 (0.21 – 0.97)*
Chest tightness							
	0	1.54 (1.08 – 2.19)*	1.05 (0.93 -1.19)	0.81 (0.70 - 0.99)*	1.00 (0.97 – 1.01)	1.33 (0.86 – 2.03)	1.94 (1.09 – 3.44)*
	1	1.38 (1.00 – 2.01)*	0.96 (0.83 – 1.11)	0.88 (0.73 – 1.07)	0.93 (0.76 – 1.14)	1.14 (0.72 – 1.79)	1.61 (0.87 – 2.98)
	2	1.24 (0.84 – 1.83)	1.06 (0.90 – 1.25)	0.95 (0.77 – 1.16)	0.87 (0.70 – 1.07)	1.03 (0.65 – 1.64)	1.12 (0.54 – 2.33)
Cough							
	0	0.80 (0.55 – 1.18)	0.94 (0.82 – 1.08)	0.96 (0.79 – 1.18)	1.07 (0.86 – 1.34)	0.84 (0.52 –1.37)	1.87 (0.92 – 3.81)
	1	0.80 (0.53 – 1.21)	1.11 (1.01 – 1.41)*	0.95 (0.67 – 1.29)	1.09 (0.87 – 1.36)	0.85 (0.50 – 1.42)	2.24 (1.00 – 4.99)*
	2	0.77 (0.50 – 1.18)	0.93 (0.77 – 1.12)	0.85 (0.76 -1.19)	1.08 (0.81 – 1.37)	0.83 (0.49 – 1.40)	2.87 (1.09 – 7.52)*
Wheeze							
	0	1.26 (0.74 – 2.11)	0.99 (0.81 – 1.20)	1.07 (0.79 – 1.43)	1.05 (0.79 – 1.40)	1.23 (0.64 – 2.33)	0.76 (0.32 – 1.78)
	1	1.30 (0.75 – 2.25)	1.00 (0.79 – 1.24)	1.06 (0.78 – 1.44)	1.06 (0.80 – 1.42)	1.28 (0.65 – 2.52)	0.75 (0.31 – 1.84)
	2	1.22 (0.70 – 2.14)	1.04 (0.82 – 1.32)	1.14 (0.81 – 1.58)	1.03 (0.76 – 1.38)	1.19 (0.61 – 2.36)	0.56 (0.21 – 1.49)
Medication use corticosteroids							
	0	1.05 (0.78 – 1.42)	0.99 (0.87 – 1.12)	1.03 (0.85 – 1.24)	1.01 (0.83 – 1.25)	1.20 (0.78 – 1.83)	1.09 (0.60 – 1.99)
	1	1.01 (0.98 – 1.05)	1.02 (0.88 – 1.19)	1.00 (0.82 – 1.22)	1.05 (0.84 – 1.30)	1.38 (0.86 – 2.22)	1.27 (0.66 – 2.44)
	2	1.00 (0.97 – 1.03)	1.07 (1.00 – 1.28)*	1.04 (0.84 – 1.29)	1.02 (0.81 – 1.28)	1.33 (0.81 – 2.19)	1.13 (0.51 – 2.49)
β$_2$-agonist							
	0	0.80 (0.29 – 2.19)	1.06 (0.76 – 1.48)	1.31 (0.80 – 2.14)	0.88 (0.48 – 1.64)	0.65 (0.19 – 2.22)	0.77 (0.16 – 3.77)
	1	0.61 (0.20 – 1.81)	0.92 (0.61 – 1.38)	1.49 (0.89 – 2.50)	0.81 (0.43 – 1.50)	0.44 (0.12 – 1.70)	0.47 (0.08 – 2.84)
	2	0.58 (0.19 – 1.83)	0.89 (0.55 – 1.43)	1.57 (1.03 – 2.72)*	0.79 (0.41 – 1.51)	0.45 (0.12 – 1.71)	0.33 (0.04 – 3.09)

NO$_2$: nitrogen dioxide; NO$_x$: oxides of nitrogen; O$_3$: ozone; PM$_{2.5}$: particulate matter <2.5 µm in diameter; PM$_{10}$: particulate matter <10 µm in diameter; SO$_2$: sulphur dioxide. #: Data were obtained from South African Weather Services. *: $p<0.05$. ǂ: a mix model was used with random intercept and fixed slope and autoregressive covariate structure adjusted for daily temperature, relative humidity, day of the week

pollution is quantitatively different from winter air pollution, O$_3$ levels are higher and air pollution mixture is strongly influenced by photochemical reaction. Although this study was conducted in winter, a high concentration of O$_3$ was observed and consistently associated with decrements in lung function and use of asthma medication. There were no significant associations observed between FEV1 and PM$_{2.5}$ and PM$_{10}$. Nevertheless, PM$_{2.5}$ decreased FEV1. The ambient particulate matter is one the environmental risk factor that has been associated with respiratory morbidity (Gielen et al., 2015; Roemer et al., 2000; Brunekreef, 2002). The major effect of ambient particulate matter on the pulmonary system is the exacerbation of inflammation, mainly in vulnerable individuals. One of the mechanisms by which ambient particulate matter exerts its proinflammatory effects is the generation of oxidative stress by its chemical compounds.

The particulate matter induced oxidative stress

Table 6. The effects of 10µg.m^{-3} increase of two pollutants on respiratory symptoms among children with asthma in Noordgesig between 18 August and 08 September 2013[ǂ]

	Lag days	NO_x+O_3	SO_2+O_3	NO_x+SO_2	NO_2+SO_2	NO2+O_3
Respiratory symptoms						
Breathlessness						
		0.93 (0.80 – 1.07)	1.06 (0.51 – 2.22)	0.99 (0.87 – 1.12)	1.17 (0.80 – 1.73)	1.13 (0.77 – 1.66)
	0	0.91 (0.74 – 1.11)	0.91 (0.73 – 1.13)	1.32 (0.72 – 2.42)	0.94 (0.49 – 1.79)	0.97 (0.79 – 1.17)
		0.86 (0.73 – 1.01)	0.83 (0.39 – 1.76)	0.89 (0.77 – 1.03)	1.10 (0.74 – 1.63)	1.06 (0.71 – 1.57)
	1	0.94 (0.76 – 1.14)	0.93 (0.75 – 1.17)	0.97 (0.51 – 1.82)	0.82 (0.43 – 1.59)	0.99 (0.81 – 1.21)
		1.01 (0.85 – 1.22)	0.40 (0.17 – 0.94)	1.07 (0.89 – 1.28)	0.98 (0.66 – 1.47)	0.95 (0.64 – 1.42)
	2	1.10 (0.88 – 1.39)	0.97 (0.78 – 1.22)	0.38 (0.17 – 0.85)*	0.45 (0.21 – 0.98)*	1.08 (0.87 – 1.33)
Chest tightness						
		0.99 (0.88 – 1.13)	1.52 (0.74 – 3.10)	1.00 (0.89 – 1.13)	1.38 (0.94 – 2.02)	1.41 (0.97 – 2.07)
	0	0.86 (0.71 – 1.04)	0.93 (0.75 – 1.17)	1.74 (0.97 – 3.10)	1.59 (0.85 – 2.96)	0.90 (0.74 – 1.09)
	1	0.94 (0.81 – 1.09)	1.35 (0.64 – 2.85)	0.96 (0.83 – 1.02)	1.30 (0.88 – 1.92)	1.31 (0.89 – 1.95)
		0.88 (0.73 – 1.06)	0.95 (0.75 – 1.19)	1.52 (0.82 – 2.80)	1.42 (0.74 – 2.70)	0.92 (0.76 – 1.12)
		0.99 (0.82 – 1.18)	1.14 (0.50 – 2.61)	0.99 (0.84 – 1.18)	1.24 (0.83 – 1.84)	1.22 (0.82 – 1.83)
	2	0.93 (0.74 – 1.17)	0.96 (0.76 – 1.20)	1.25 (0.56 – 2.77)	1.05 (0.50 – 2.22	0.97 (0.79 – 1.19)
Cough						
		0.93 (0.80 – 1.08)	2.35 (0.98 – 5.62)	0.90 (0.77 – 1.04)	0.67 (0.45 – 1.02)	0.75 (0.49 – 1.14)
	0	0.92 (0.74 – 1.14)	1.13 (0.86 – 1.49)	2.22 (1.03 – 4.80)*	2.45 (1.13 – 5.38)*	0.91 (0.74 – 1.13)
		0.92 (0.78 – 1.10)	2.74 (1.07 – 6.99)*	0.92 (0.77 – 1.09)	0.69 (0.46 – 1.07)	0.76 (0.49 – 1.17)
	1	0.92 (0.74 – 1.15)	1.11 (0.84 – 1.47)	2.41 (1.05 – 5.54)*	2.70 (1.15 – 6.30)*	0.91 (0.73 – 1.13)
		0.90 (0.73 – 1.11)	3.39 (1.15 – 9.94)*	0.84 (0.70 – 1.03)	0.71 (0.46 – 1.09)	0.74 (0.47 – 1.16)
	2	0.89 (0.70 – 1.16)	1.02 (0.84 – 1.45)	4.24 (1.38 – 13.01)*	3.27 (1.19 – 8.96)*	0.92 (0.73 – 1.16)
Wheeze						
		1.04 (0.87 – 1.25)	0.91 (0.31 – 2.71)	1.04 (0.87 – 1.24)	1.34 (0.77 – 2.35)	1.33 (0.77 – 2.30)
	0	1.03 (0.78 – 1.37)	0.99 (0.71 – 1.39)	0.89 (0.38 – 2.08)	0.67 (0.28 – 1.62)	1.12 (0.81 – 1.54)
		1.01 (0.82 – 1.24)	0.80 (0.26 – 2.44)	0.99 (0.81 – 1.22)	1.37 (0.77 – 2.44)	1.36 (0.77 – 2.39)
	1	1.05 (0.78 – 1.41)	1.01 (0.71 – 1.43)	0.79 (0.32 – 1.94)	0.69 (0.27 – 1.73)	1.19 (0.80 – 1.54)
		1.20 (0.92 – 1.56)	0.48 (0.15 – 1.56)	1.20 (0.92 – 1.57)	1.28 (0.71 – 2.30)	1.28 (0.73 – 2.27)
	2	1.33 (0.89 – 2.00)	1.04 (0.73 – 1.49)	0.33 (0.12 – 0.98)*	0.54 (0.19 – 1.45)	1.17 (0.82 – 1.66)
Medication use						
corticosteroids						
		0.99 (0.86 – 1.14)	1.28 (0.59 – 2.78)	0.98 (0.86 – 1.11)	1.04 (0.74 – 1.46)	1.09 (0.78 – 1.53)
	0	1.03 (0.84 – 1.25)	1.08 (0.85 – 1.37)	1.13 (0.60 – 2.09)	1.06 (0.54 – 2.07)	1.05 (0.86 – 1.29)
		1.02 (0.88 – 1.21)	1.43 (0.64 – 3.19)	1.02 (0.88 – 1.20)	1.12 (0.78 -1.61)	1.17 (0.81 – 1.68)
	1	1.01 (0.82 – 1.24)	1.07 (0.84 – 1.36)	1.26 (0.65 – 2.44)	1.18 (0.59 – 2.37)	1.03 (0.84 – 1.27)
		1.12 (0.92 – 1.36)	1.27 (0.52 – 3.12)	1.08 (0.89 – 1.30)	1.09 (0.75 – 1.61)	1.12 (0.76 – 1.65)
	2	1.11 (0.87 – 1.41)	1.07 (0.84 – 1.37)	1.00 (0.42 – 2.35)	1.10 (0.50 – 2.45)	1.05 (0.85 – 1.31)
β_2-agonist						
		1.17 (0.81 – 1.69)	1.67 (0.29 – 11.73)	1.09 (0.78 – 1.54)	1.04 (0.74 – 1.46)	1.00 (0.33 – 3.03)
	0	1.37 (0.81 – 2.31)	1.39 (0.76 – 2.53)	0.77 (0.16 – 3.78)	1.06 (0.54 – 2.07)	1.34 (0.76 -2.35)

Table 6. Cont.

	0.97 (0.63 – 1.49)	0.95 (0.11 – 7.81)	0.92 (0.61 – 1.38)	1.12 (0.78 – 1.61)	1.17 (0.82 – 1.68)
1	1.47 (0.87 – 2.49)	1.47 (0.81 – 2.68)	0.48 (0.08 – 2.80)	1.18 (0.59 – 2.38)	1.03 (0.84 – 1.27)
	1.07 (0.64 - 1.79)	0.62 (0.05 – 737)	0.97 (0.59 – 1.59)	1.09 (0.75 – 1.62)	1.12 (0.76 – 1.65)
2	1.62 (0.88 – 2.98)	1.49 (0.82 – 2.72)	0.35 (0.03 – 0.96)	1.10 (0.50 – 2.46)	1.05 (0.84 – 1.31)

NO_x: oxides of nitrogen; O_3: ozone; SO_2: sulphur dioxide. $^{\#}$: Data were obtained from South African Weather Services. *: $p<0.05$. ǂ: a mix model was used with random intercept and fixed slope and autoregressive covariate structure adjusted for daily mean temperature, relative humidity, day of the week.

that may cause inflammation (Li et al., 2009; Mohan-Kumar et al., 2008).

Study limitation

First, it was assumed that personal exposure to ambient air pollutants could be characterised using the measurements of one fixed measurement site, and therefore it may have caused an underestimation of the effect. Second, no quantitative indoor air pollution exposure assessment was conducted; only children living in smoke-free homes were included. Third, days, when an individual spent outside the study area, were not included in the analyses to avoid misclassification of exposure. Fourth, the forced vital capacity manoeuvre for necessary for the FEV1 measurement was observed only during the training periods. Increased variability of the test could have reduced the power to detect true association with ambient air pollutants.

Study strengths

The strength of this study is that adverse biological effect on the lungs from low levels ambient air pollutants on a small number of study participants was observed. The results may be restricted to Noordgesig, because of the different composition of air pollutants caused by different sources in other communities.

Conclusion

The findings of this study provide evidence that an acute change of gaseous air pollutants in communities situated near mine dumps exacerbates lung function in vulnerable children.

Ethical considerations

Ethical approval (number: 235/2011) was obtained from the Research Ethics Committee of the Faculty of Health Sciences, University of Pretoria, and Gauteng Department of Education (number: D2012/79). School principals and governing bodies were approached and gave their consent for the study. Parents or guardians of participants were sent a letter explaining the details and nature of the study. All information was kept confidential. Anonymity was maintained and the names of the participants were not recorded.

Contributors

VN and KV participated in the design of the study, data collection, statistical analysis and interpretation of the results, drafted and critically revised the manuscript. GH and JW participated in the statistical analysis and interpretation of the results, drafted and critically revised the manuscript. All authors have read and approved the final manuscript. The majority of the work for this study was conducted at the University of Pretoria (UP). VN was registered as a PhD student at UP. VN was employed at UP until 31 August 2016. The editing and final submission of this manuscript was done at the South African Medical Research Council, where VN has been employed since 1 September 2016.

Acknowledgements

The authors gratefully acknowledge the South African Weather Services (SAWS), the school principal and the Education Department of Gauteng Province for giving permission to conduct the study and Mr Moses Kebalepile for assisting in data collection.

Funding

Funding for the field survey came from the Mine Health Safety Council of South Africa (MHSCSA) and National Research Fund – Deutscher Akademischer Austausch Dienst (NRF – DAAD).

Conflict of interests

Authors declare that there is no conflict of interests regarding the publication of the paper.

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