Inhalation health risk assessment of ambient $PM_{2.5}$ and its associated trace elements in Johannesburg, South Africa

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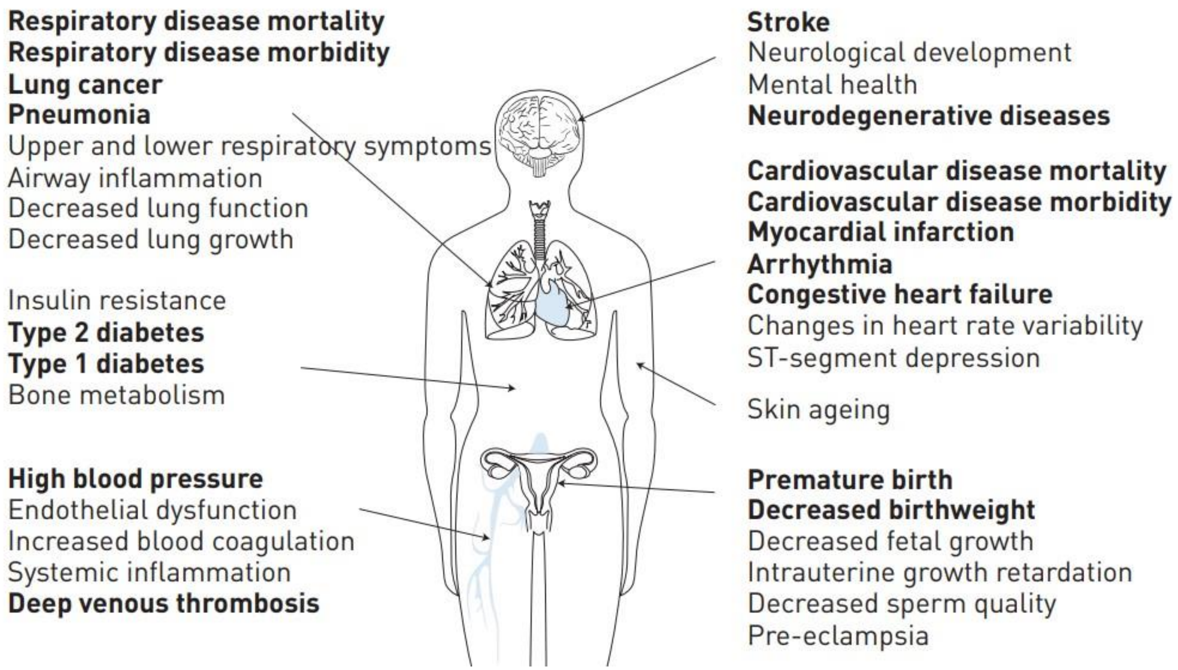
Introduction

- Despite some notable improvements in air quality, the global toll in deaths and lost years of healthy life has barely declined since the 1990s. Due to air pollution, the simple act of breathing leads to 7 million deaths annually.

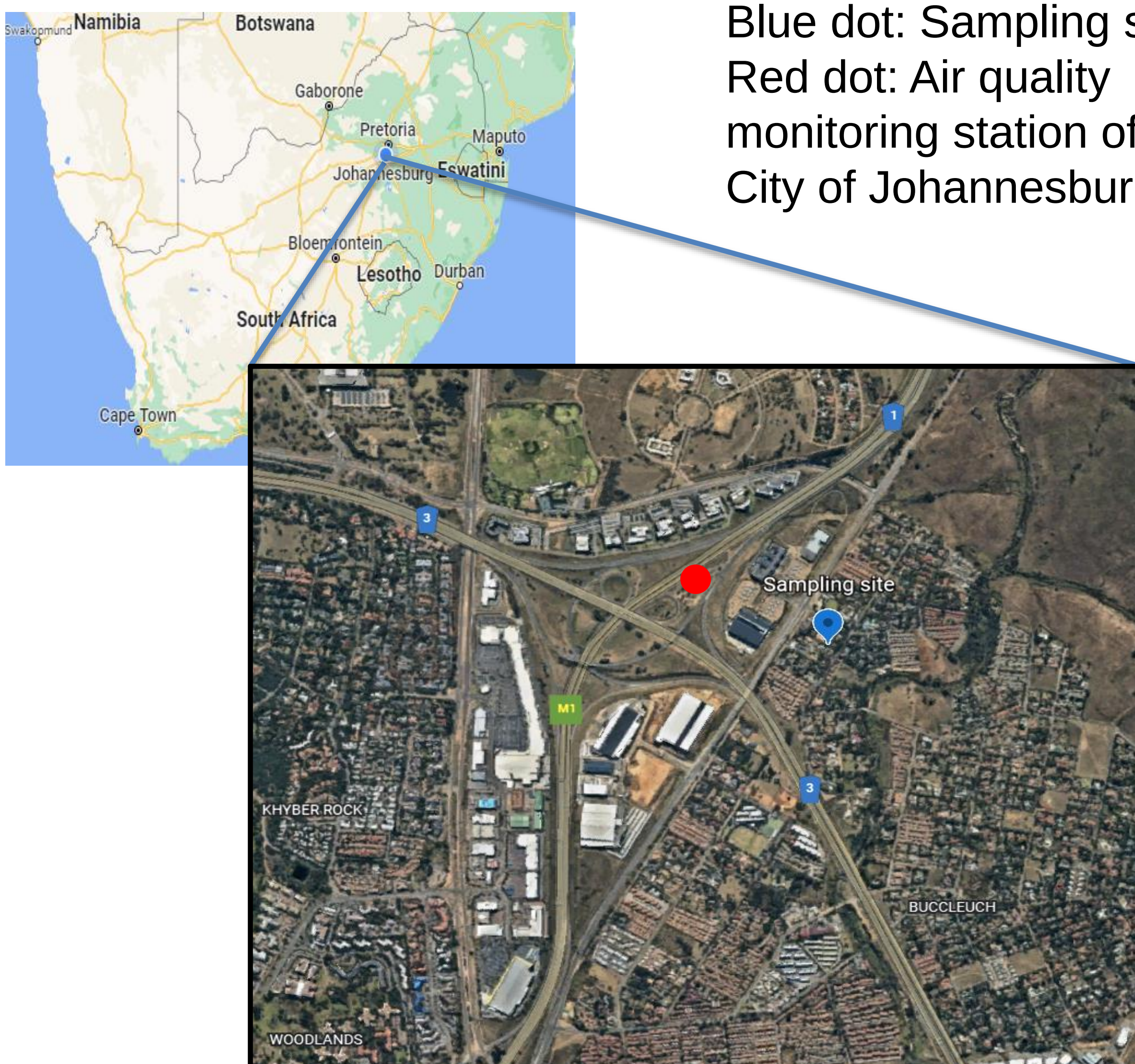
- The World Health Organization (WHO) concluded that the burden of disease attributable to air pollution is on a par with other major global health risks such as tobacco smoking and unhealthy diet. **Therefore, air pollution is now acknowledged as the single biggest environmental threat to human health.**

- Exposure assessment and health studies of $PM_{2.5}$ exposure are limited in Africa.



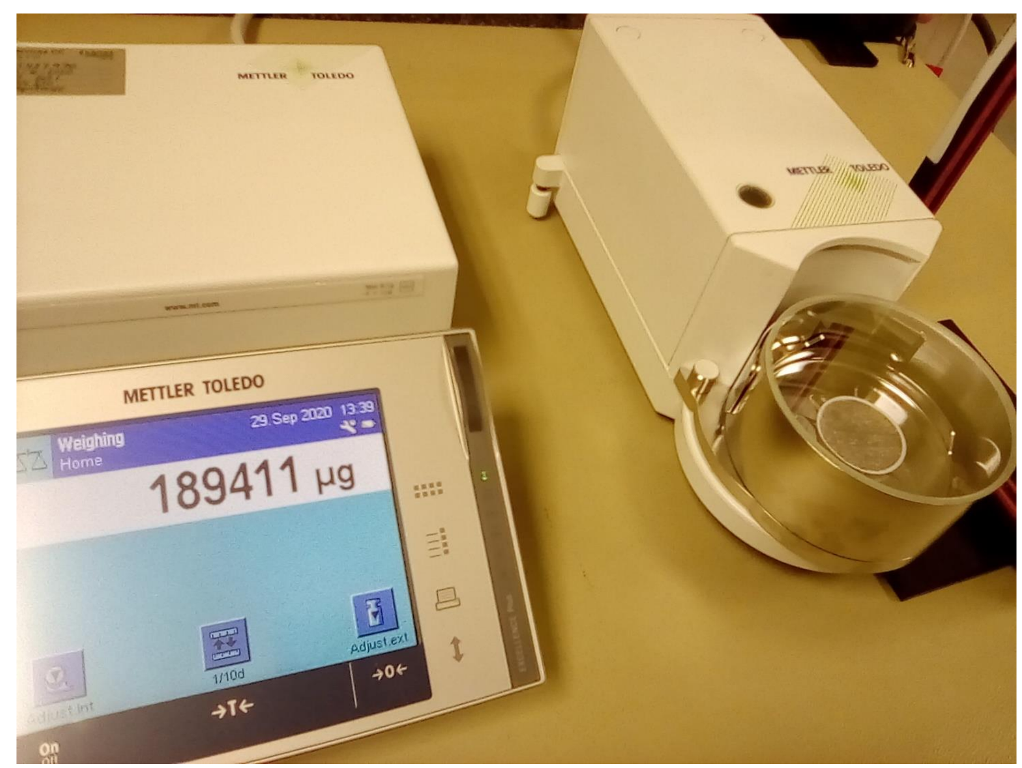
Methods

- The study site was in an urban background location.
- $PM_{2.5}$ filter samples were collected manually over 24 hours (9am to 9am) every sixth day from 3 October 2020 to 12 October 2021.



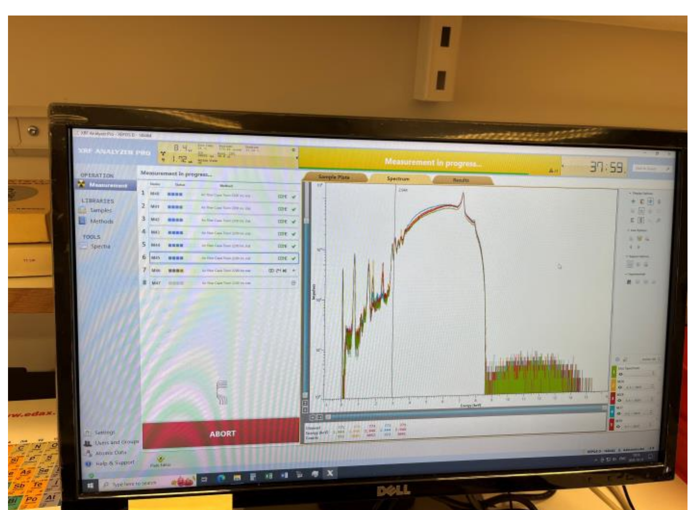
Blue dot: Sampling site
Red dot: Air quality monitoring station of City of Johannesburg

Sampling equipment mounted on the roof of the home at the study site (duplicate sampling)



Methods

- Trace element concentrations were determined by EDXRF spectroscopy.
- The methods of the United States Environmental Protection Agency Health Risk Assessment were applied.
- This method quantifies the non-cancer health risk by means of the hazard quotient (HQ), taking into account the body weight and the breathing rate of different age groups.
- For the HQ of $PM_{2.5}$, the yearly WHO guideline (5 µg.m^{-3}) and the yearly South African standard (20 µg.m^{-3}) were applied as references.



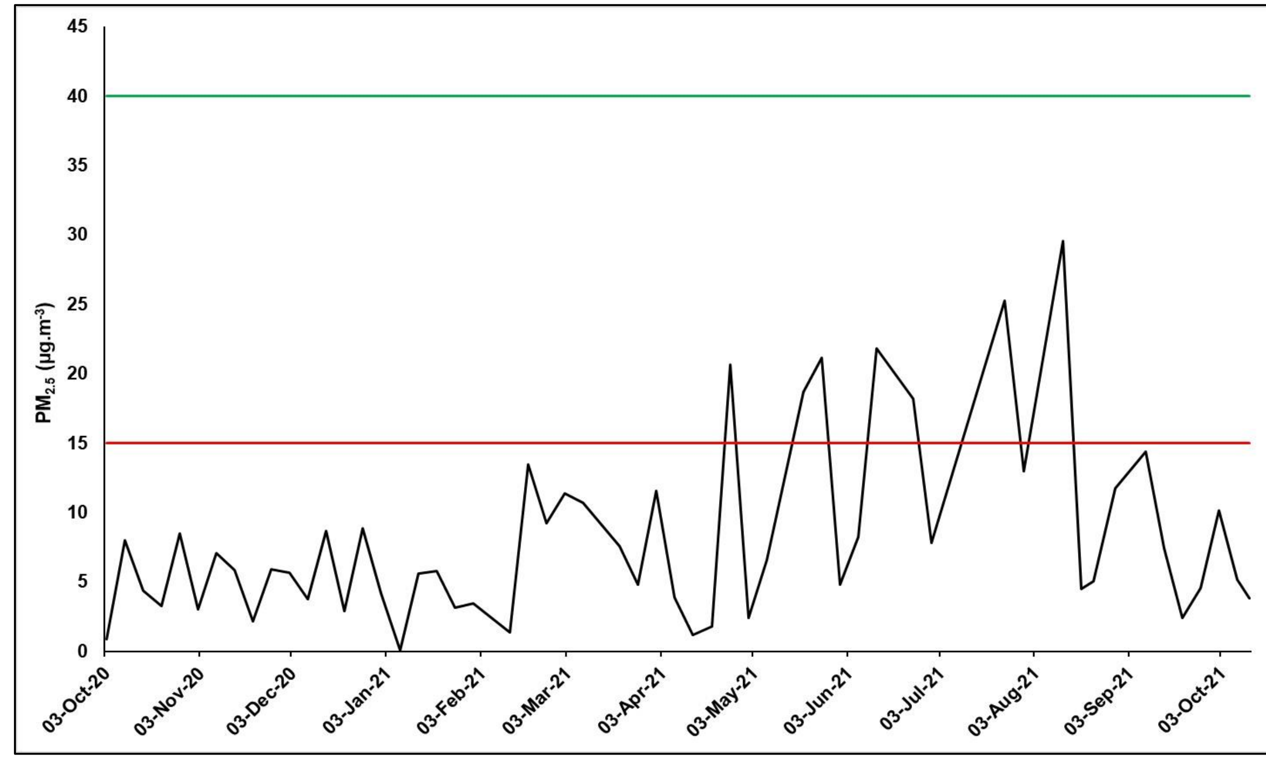
- Five of the 12 detected trace elements had reference concentration (RfC) values (Ba, Br (as $BrCH_4$), Cl, S (as H_2SO_4)) and Si (as crystalline and respirable silica)). Two elements had reference dose (RfD) values (Se and Ti). The RfC and RfD values were obtained from the resident air list (https://www.epa.gov/risk/regional-screening-levels-rsls-generic-tables).
- RfD values were converted to RfC values.
- Ethics approval was granted by the Research Ethics Committee, Faculty of Health Sciences, University of Pretoria (References 589/2020, 314/2021 and 268/2023).

Body weight and inhalation rate assumptions used in the study

Variable	Population	Value
Body weight (kg)	Adult (South Africa)	71.9
	Children (South Africa)	13.8
	Infants (South Africa)	7.6
	Adult (USA)	73.7
Inhalation rate (m^3.day^{-1})	Adult (USA)	15.9
	Children (USA)	9.0
	Infants (USA)	5.4

Results

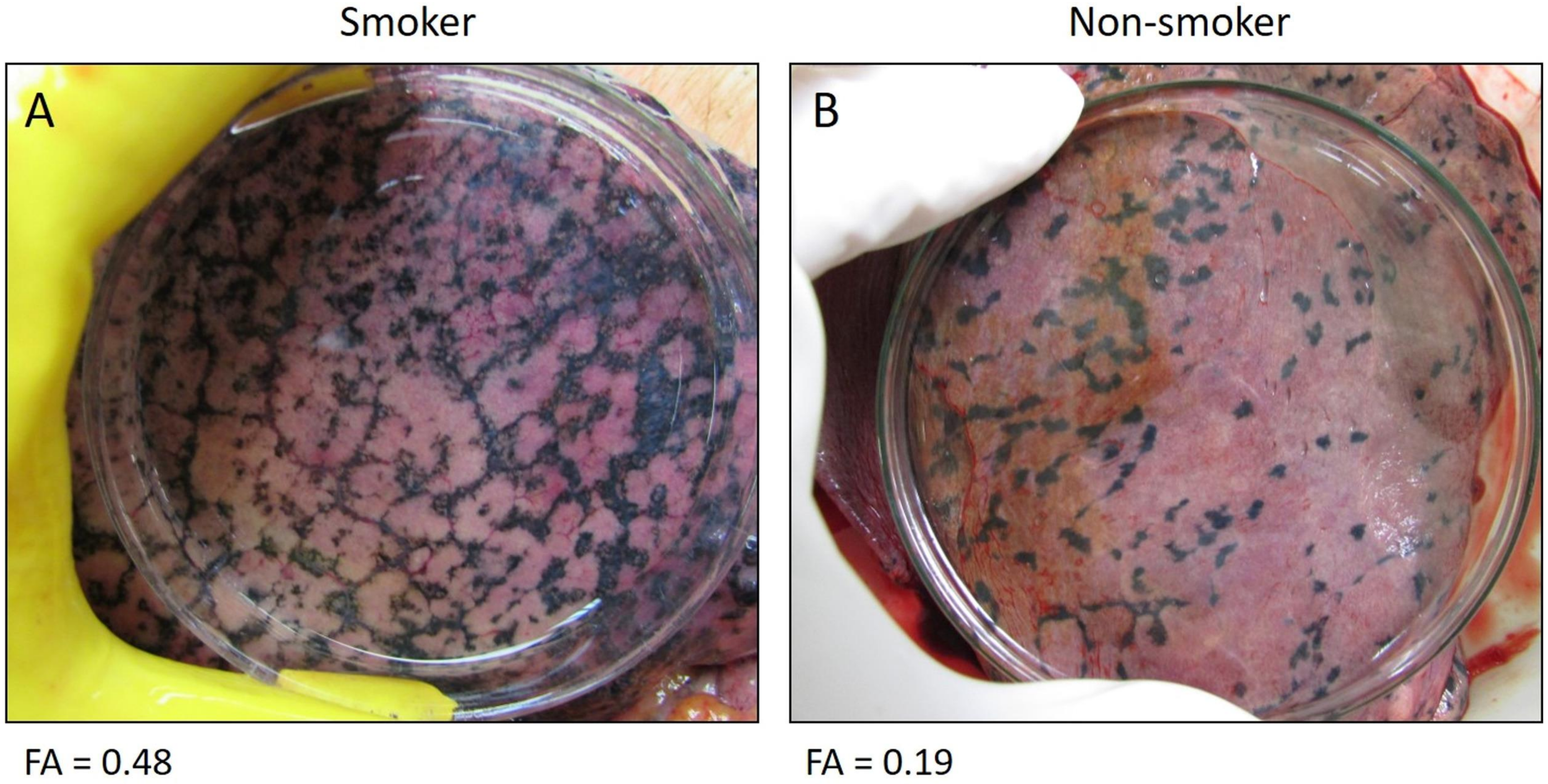
- The average $PM_{2.5}$ level was 8.1 µg.m^{-3} on the 55 sampling days; with daily levels ranging from 0.04 to 30 µg.m^{-3}.
- The average level exceeded the yearly WHO guideline (5 µg.m^{-3}), but not the yearly South African standard (20 µg.m^{-3}).
- The daily South African standard (40 µg.m^{-3}) was never exceeded, whilst the daily WHO guideline (15 µg.m^{-3}) was exceeded seven times during May-Oct (cold/dry season).
- The average $PM_{2.5}$ level was significantly higher during May-Oct than during Nov-Mar (warm/rainy season) ($p<0.05$).
- The average $PM_{2.5}$ level at the CoJ monitoring station in Buccleuch was 36 µg.m^{-3}. The daily WHO guideline and the daily South African standard were exceeded 38 and 11 times, respectively.
- S had the highest average concentration (470 ng.m^{-3}) followed by Si (230 ng.m^{-3}), K (190 ng.m^{-3}), Fe (100 ng.m^{-3}) and Ca (61 ng.m^{-3}).



$PM_{2.5}$ and trace element levels

Variables	Ave	SD	Median	Min	Max	Nov-Apr average	May-Oct average
$PM_{2.5}$	8.1	6.5	5.9	0	30	6.2	10
$PM_{2.5}$ (CoJ)	36	18	34	11	82	28	41
Ba	13	10	11	1	72	13	12
Br	5.2	7.2	3.2	0.1	38	3.2	7.2
Ca	61	66	47	1.6	260	50	79
Cl	16	31	5.2	0.1	180	17	16
Cu	6.3	8.2	3.3	0.6	39	8.8	3.8
Fe	100	80	86	8.3	400	96	100
K	190	230	100	0.8	1200	140	240
S	470	380	300	19	1800	500	430
Se	0.5	0.9	0.1	0	4.7	0.7	0.3
Si	230	190	160	5.7	850	180	280
Ti	13	9.1	10	1.2	39	9.9	15
Zn	18	32	5.4	0.2	150	21	14

$PM_{2.5}$ in µg.m^{-3} and trace elements in ng.m^{-3} (n=55)
CoJ: Buccleuch air quality monitoring station managed by the City of Johannesburg (n=41)



Macroscopic view of anthracosis. Representative lung images from upper lobe with areas of black carbon deposition in the pleural surface. A) smoker (50 pack years), 65-y old, one daily hour spent in traffic; B) non-smoker, 63-y old, four daily hours spent in traffic. Both individuals were male and Sao Paulo dweller for 50 years.

Takano et al 2019. Pleural anthracosis as an indicator of lifetime exposure to urban air pollution: An autopsy-based study in Sao Paulo. Environmental Research. https://doi.org/10.1016/j.envres.2019.03.006.

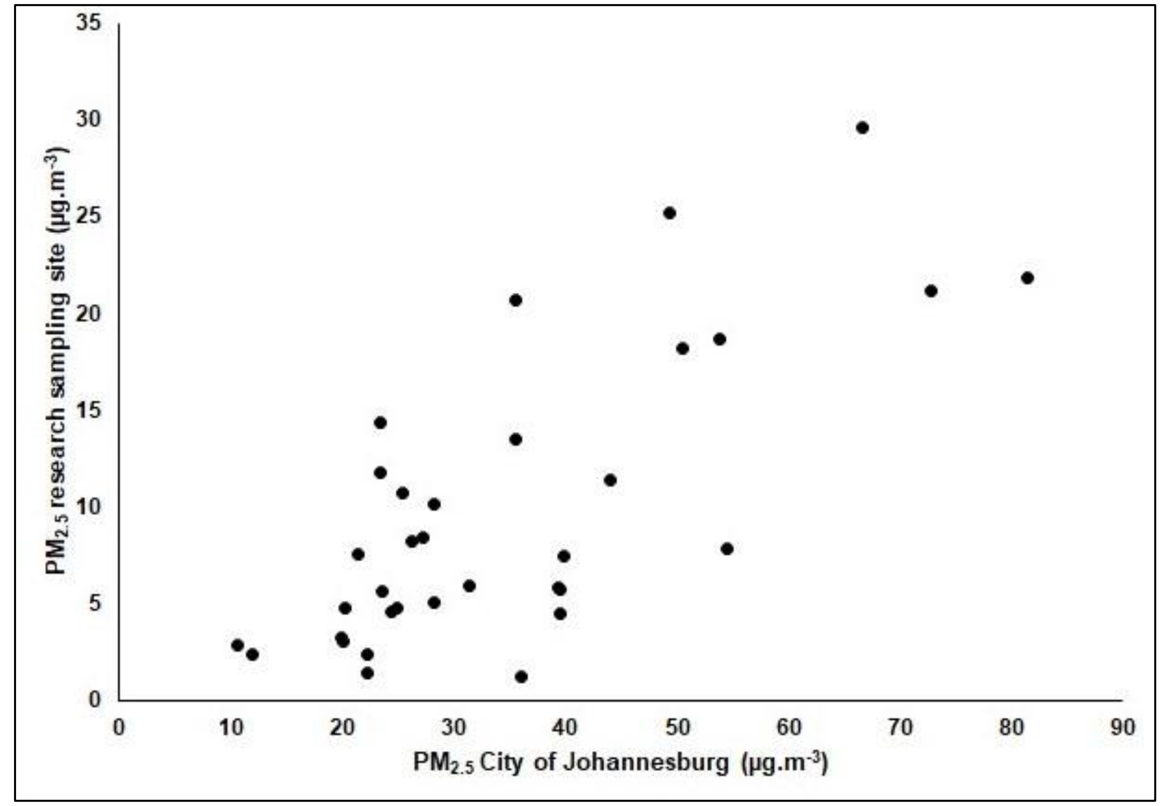
Results

- The $PM_{2.5}$ level at the study site (8 µg.m^{-3}), which is at an urban background location, was significantly lower than that at the CoJ Buccleuch monitoring site (36 µg.m^{-3}) which is located directly between the busy highways.

- The HQ results confirm that children and infants, when exposed to the same level of air pollutants as adults, are at higher risk of adverse health effects.

- A possible reason is that children's higher ratio of body weight to inhalation rate makes them more susceptible.

- Children are also more likely to be outdoors and engaging in physical activity and increased inhalation rate.



Hazard quotients for $PM_{2.5}$ and trace elemental composition

	RfC (µg.m^{-3})	Yearly level (µg.m^{-3})	Adults	Children	Infants
$PM_{2.5}$	20*	8.1	0.41	**1.19**	**1.30**
$PM_{2.5}$ (CoJ)	20*	36	**1.80**	**5.21**	**5.78**
$PM_{2.5}$	5**	8.1	**1.66**	**4.90**	**5.34**
$PM_{2.5}$ (CoJ)	5**	36	**7.38**	**21.77**	**23.71**
Ba	0.5	0.013	0.03	0.08	0.09
Br	5	0.0052	0.00	0.00	0.00
Cl	0.15	0.016	0.11	0.32	0.35
S	1	0.47	0.48	**1.42**	**1.55**
Se	3	0.0005	0.00	0.00	0.00
Si	3	0.23	0.08	0.23	0.25
Ti	0.1	0.013	0.13	0.39	0.43

HQ > 1 indicated as bold numbers.
*Yearly South African air quality standard for $PM_{2.5}$
**Yearly WHO air quality guideline for $PM_{2.5}$
CoJ: Buccleuch air quality monitoring station managed by the City of Johannesburg

Conclusions

- This study is the first to report on the health risks of $PM_{2.5}$ and its trace element levels at an urban background location in Johannesburg.
- The results can be applied in the updated CoJ Air Quality Management Plan
- However, sampling was conducted for only 12 months and at only one site.
- More research, including numerous $PM_{2.5}$ filter sampling sites, is needed in Johannesburg.

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Take home message

National policies for air quality standards should be in line with WHO guidelines.


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