Journal of Air Pollution and Health (Winter 2022); 7(1): 1-14

Original Article

Available online at http://japh.tums.ac.ir

Assessment of air pollution in the informal settlements of the Western Cape, South Africa

Benett Siyabonga Madonsela*, Thabang Maphanga, Boredi Silas Chidi, Karabo Shale, Vincent Zungu

Environmental and Occupational Studies, Faculty of Applied Science, Cape Peninsula University of Technology, Cape Town, South Africa

ARTICLE INFORMATION

Article Chronology:
Received 22 November 2021
Revised 19 January 2022
Accepted 02 February 2022
Published 29 March 2022

Keywords:
Air pollution levels; Ambient air pollution; Particulate matter less than 2.5 µm ($PM_{2.5}$); Nitrogen dioxide (NO_2); Informal settlement

CORRESPONDING AUTHOR:

Madonselab@cput.ac.za
Tel: +27214603427
Fax: +27214603911

ABSTRACT

Introduction: South Africa has the highest ambient air pollution exposure associated with morbidity in the Sub-Saharan region, accounting for a total number of 14356 confirmed cases of mortality on an annual basis. The study assessed air pollution exposure levels of Khayelitsha and Marconi-Beam neighbourhoods that are not monitored by the fixed-site monitoring station provided by the government.

Materials and methods: Weekly ambient air pollution measurements of Particulate Matter less than 2.5 µm ($PM_{2.5}$) and Nitrogen Dioxide (NO_2) were collected at households in neighbourhoods of Khayelitsha and Marconi-Beam during the summer and winter seasons. $PM_{2.5}$ measurements were collected using Mesa Labs GK2.05 (KTL) cyclone attached to a GilAir Plus air sampling pump. Gases of NO_2 were measured using passive diffusive samplers. Data were recorded on a Microsoft Excel 2016 spreadsheet. Statistical analyses were performed using IBM SPSS Statistics 28.0. The outcome of the seasonal exposure levels will be compared with the South African ambient air quality standards to ascertain the risk of potential exposure to significant levels of $PM_{2.5}$ and NO_2 that are hazardous to human health.

Results: The results suggest that summer NO_2 concentrations in the Khayelitsha neighbourhood ranged between (0 and 28 µg/m^3), while in winter NO_2 concentrations nearly doubled. A similar trend was observed regarding $PM_{2.5}$ behaviour with summer overall exposure level of 7 µg/m^3 and 13 µg/m^3 during winter.

Conclusion: Whilst there are no legislative guidelines to compare the measured weekly average results, the concentrations were still lower than the World Health Organization (WHO), and South African air quality standards values for $PM_{2.5}$ and NO_2 pollutants.

Introduction

Air pollution is “the world’s largest single environmental health risk” [1]. Air pollution has been identified as a major public health hazard facing our generation [2]. According to the World Health Organization (WHO), 91% of the world's population breathes contaminated air which frequently exceeds safe exposure levels [3]. Annually, about four million lives are lost

Please cite this article as: Madonsela BS, Maphanga Th, Silas Chidi B, Shale K, Zungu V. Assessment of air pollution in the informal settlements of the Western Cape, South Africa. Journal of Air Pollution and Health. 2022; 7(1): 1-14.

as a result of exposure to ambient air pollution around the globe, with low- and middle-income countries bearing the burden [4]. For example, pollutants such as Particulate matter less than 2.5 µm ($PM_{2.5}$) and Nitrogen dioxide (NO_2) have been internationally recognized as environmental priority air pollutants since they can constitute a threat to human health and the environment [5]. Africa as a continent is at the centre of this crisis given that it is predominantly characterized by low-income countries. However, many sub-Saharan African countries lack air pollution exposure data despite the global public health risks associated with exposure to air pollution. Air pollution exposure data is important for understanding and addressing public health impacts in developing countries. In Africa air pollution has been described to exceed all other forms of environmental pollution [6]. Moreover, air pollution is increasing at an alarming rate in Africa, inflicting more premature deaths than polluted water and childhood [6]. As a result, it has been linked to diseases like lung cancer, heart disease, chronic and acute respiratory infection, and asthma attacks [7]. Furthermore, long term exposure has been associated with a decrease in life expectancy and premature death [8]. South Africa is no exception to this statistic as some South African provinces to date continue to exceed air pollution exposure limits that regulate the prevention of exposure to hazardous air pollution levels [9].

South Africa has the highest ambient air pollution exposure associated with morbidity in the Sub-Saharan region, accounting for a total number of 14356 confirmed cases of mortality on an annual basis [10, 11]. Therefore, the detrimental effects of ambient air pollution necessitate the constant exposure monitoring of pollutants especially within the township location where the most vulnerable individuals to pollution reside [12]. To bridge this gap in South Africa, exposure assessment of air pollution is usually performed by government agencies that make use of fixed-site monitoring stations. However, fixed monitoring stations can only measure exposure assessment of pollutants within a very low spatial resolution. That is, measurements from the station only reflects the amount of air pollution within the close vicinity [13, 8]. The rest of the locations that are not within proximity are therefore not accounted for in the air pollution measurements. Therefore, this might significantly encourage exposure misclassification [14]. Unfortunately, Khayelitsha and Marconi-Beam neighbourhoods are situated far away from the fixed monitoring stations provided by the government agencies. As a result, the fixed monitoring stations do not account for their air pollution exposure. In light of this information, the current study aims at assessing the air pollution exposure levels of Khayelitsha and Marconi-Beam neighbourhoods that are not monitored by the fixed-site monitoring station. The objective is to evaluate the seasonal exposure levels of $PM_{2.5}$ and NO_2 in these neighbourhoods. The outcome of the seasonal exposure levels will be compared with the South African ambient air quality standards to ascertain the risk of potential exposure to significant levels of $PM_{2.5}$ and NO_2 that are hazardous to human health.

Materials and methods

Study areas and population

This research was carried out in the metropolitan area of Cape Town, which is located in the Western Cape province of South Africa. Weekly exposure measurements were simultaneously conducted in both summer and winter seasons in the two informal and low-cost neighbourhoods of Khayelitsha and Marconi-Beam to identify seasonal variations of pollutants. The Western Cape province has a Mediterranean climate. The summer season lasts from December to March. Whilst the winter season extends from June to late September. Khayelitsha and Marconi-Beam are two townships that have been identified as being at risk of being exposed to air pollution levels that exceed air quality standards [15-18]. Khayelitsha is a South African township comprising of informal settlements that approximately has a population of 820, 000 residents which make it the biggest township within the metropolis. It is 32 km from the city of Cape Town. In this neighbourhood, wood combustion, domestic garbage, and worn tires are the main causes of air pollution [19]. Excessive PM_{10} emissions beyond permissible limits are typical in this area [19]. Marconi-Beam, meanwhile, is a township in Milnerton comprised of informal settlements located 17 km from Cape Town and 30 km away from Khayelitsha. It has a population of 37000 residents [20]. Particulates and nitrogen oxides, which are emitted by a nearby petrochemical refinery, are pollutants of concern at Marconi-Beam [17]. Fig. 1 shows the two study areas of Khayelitsha and Marconi-Beam.

Study area map for the two informal settlements: Khayelitsha and Marconi-Beam.

Sampling and data analysis

Air pollution exposure measurements

The mass concentration of particles smaller than 2.5 μm and nitrogen dioxide were measured in two neighbourhoods of similar geographic characteristics. To select households that would maximize the spatial distribution of pollutants in the neighbourhoods the google earth map was generated. From the google earth map, the areas with households of interest for exposure assessment were divided into strata. From the selected strata of household's convenience non-probability sampling techniques were used to sample NO_2 and $PM_{2.5}$ in a total number of 40 sites in each neighbourhood. However, due to unanticipated issues such as sample theft in the neighbourhood, the target number of 40 households was not fulfilled in some cases. In each neighbourhood, the sampling train of NO_2 and $PM_{2.5}$ was attached right above the roof structure of the selected household.

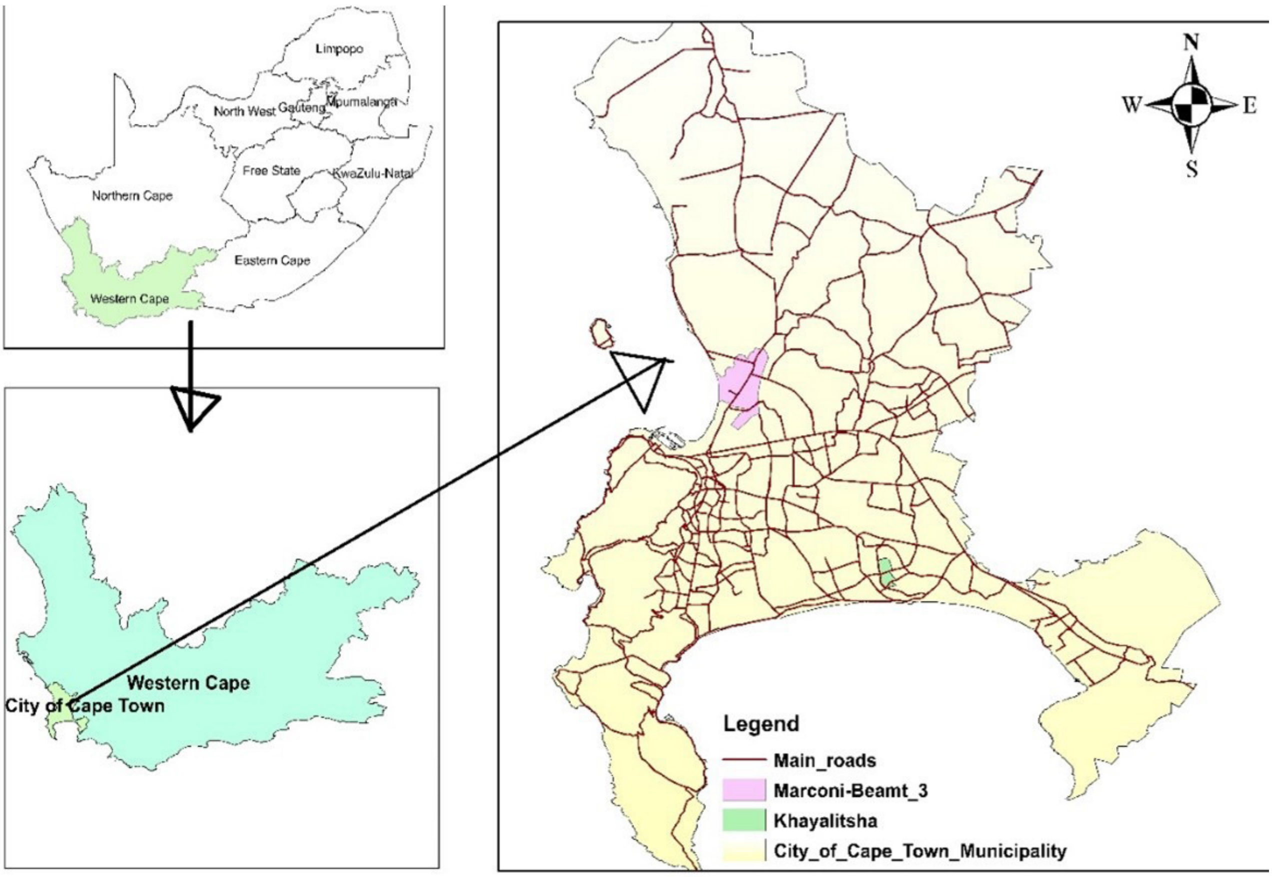

Fig. 1. Map of Khayelitsha and Marconi-Beam informal settlements

$PM_{2.5}$ was measured using Mesa Labs GK2.05 (KTL) cyclone with the GilAir Plus air sampling pump from Sensidyne. The SKC, PTFE, 2.0, 37 MM filters were used in leak-free 3 PCS filter cassettes. The filters pre sampling was weighted at the Swiss Tropical and Public Health Institute using a custom-made weighting chamber and a Mettler UMX2 microbalance. Similarly, post-exposure assessment, Teflon filters were again weighed on a microbalance at the Swiss Tropical and Public Health Institute using a custom-made weighting chamber and a Mettler UMX2 microbalance to analyse for $PM_{2.5}$ mass. $PM_{2.5}$ mass analyses followed procedures prescribed by the Environmental Protection Agency (EPA) [21]. The weighing facility's specifications have already been published elsewhere [22]. For at least 24 h before weighing, filters were conditioned to the weighing room's temperature (20–23 °C ± 2 °C) and relative humidity (30–40% ± 5%). A sampling of pollutants was conducted for a duration of seven days for four weeks. The sampling was designed such that the duration of four weeks extends throughout the summer and winter season. To avoid overloading the filters given the long duration of sampling, the GilAir Plus air sampling pump was programmed to run for 15 min/h for a period of 7 days. Whilst, on the other hand, NO_2 gases were measured using passive diffusion passam samplers and analysed in the Passam AG laboratory where the collected NO_2 was analysed photospectrometrically using the Saltzmann method. These passive diffusion samplers are capable of collecting integrated concentration with the averaging time being the same as exposure time [23]. Fig. 2 below depicts the equipment that was used to collect both NO_2 and $PM_{2.5}$ exposure concentrations.

Fig. 2. NO_2 and PM2.5 sampling devices

To ensure quality control compliance and that resultant data is representative and comparable, field blanks and duplicate samples were used as part of the exposure monitoring exercise. At the sampling field, field blanks were exposed in the environment for a few seconds. Duplicates of the original samplers were deployed in the sampling field for the same amount of time as the original samplers. Diffusive passive samplers and filter cassettes were stored in a refrigerator at 4°C to sustain the cold chain in the Occupational Health and Safety Laboratory at the Cape Peninsula University of Technology before sampling in compliance with the manufacturer's specifications. Whilst the GilAir personal air sampler pumps were calibrated in the Occupational Health and Safety laboratory using Gillibrator-2 [24]. A Gillibrator-2 primary calibrator uses a mild soap solution to create a bubble inside an internal chamber. The bubble is pulled from the bottom of the chamber to the top by the airflow created by the sampling pump. The bubble is timed by the Gillibrator-2 and a flow rate is calculated by the amount of time it takes the bubble to travel from the bottom of the chamber to the top [24]. Before going out into the field, Occupational Health and Safety Laboratory-based rotameters were used to confirm the correct pump flow rate of 4 L/min in the laboratory after calibration. To keep passive diffusive samplers and filer cassettes cool throughout the transition to the field, cooler boxes with ice blocks were used. Upon arrival in the field, specifically designed rotameters for field sampling were utilized to re-test the flow rate of the pumps and verify that the accuracy of the flow rate is still within 4 litres per minute. Subsequently, after takedown, to analyse passive diffusive samplers and filter cassettes were placed inside ziplock bags and cooler boxes to minimize contamination and to cool down the samples [25].

Data analysis

To contextualize the findings analysed data was compared with the prescribed air quality standards (Table 1). The function of the air quality standards is to regulate air quality management. Table 1 shows the prescribed South African ambient air quality standards for NO_2 and $PM_{2.5}$.

Table 1. South African ambient air quality standards for NO_2 and $PM_{2.5}$ [26]

Pollutants	Average period	Concentrations
Nitrogen dioxide (NO_2)	1 h	200 µg/m^3
Particulate matter ($PM_{2.5}$)	24 h	40 µg/m^3

Average period means a period over which an average value is determined.

The air quality standards in Table 1 above are used to estimate the maximum concentration of a substance that can be present in the atmosphere without being hazardous. To this end, air quality guidelines serve as a reference for determining and indicating the difference between polluted and non-polluted atmospheres. Furthermore, these standards are supposed to indicate what level of exposure is considered safe for public health and general welfare. So in general exposure concentrations that exceed air quality standards are likely to compromise public health and pollute the atmosphere even though there is no established threshold of safety below which there is no harm [27]. All statistical analyses were performed using IBM SPSS Statistics 28.0. Descriptive univariate statistics were generated for the total sample distribution. The Box and Whisker plots were used to illustrate the seasonal data distribution in terms of the lower quartile, upper quartile, median, minimum, and maximum in each of the two neighbourhoods. To describe the seasonal exposure variations in each neighbourhood, a paired t-test was generated. A t-test is a useful statistical analysis test that can be used to compare the means of two samples to determine if there is a significant difference between the sample means in a small sample size [28, 29]. In the current study, the t-test provides a p-value that represents the probability that there would be a difference between the mean concentration of pollutants samples in summer and winter. Thus, the paired t-test analysis was chosen to compare the summer and winter mean air pollutants concentrations of NO_2 and $PM_{2.5}$ in Khayelitsha and Marconi-Beam. The average concentrations from these neighbourhoods were later compared with the air quality guidelines indicated in Table 1.

Results and discussion

Fig. 3, illustrates the seasonal data distribution in each of the two neighbourhoods, Khayelitsha and Marconi-Beam, using box and whisker plots.

The Box and Whisker plots demonstrate the seasonal difference in the exposure levels of pollutants in each neighbourhood. The data suggest that summer NO_2 concentrations in the Khayelitsha neighbourhood ranged between (0 and 28 µg/m^3), while in winter NO_2 concentrations nearly doubled (Fig. 3). A similar trend was observed regarding $PM_{2.5}$ behaviour, with summer overall exposure level of 7 µg/m^3 and 13

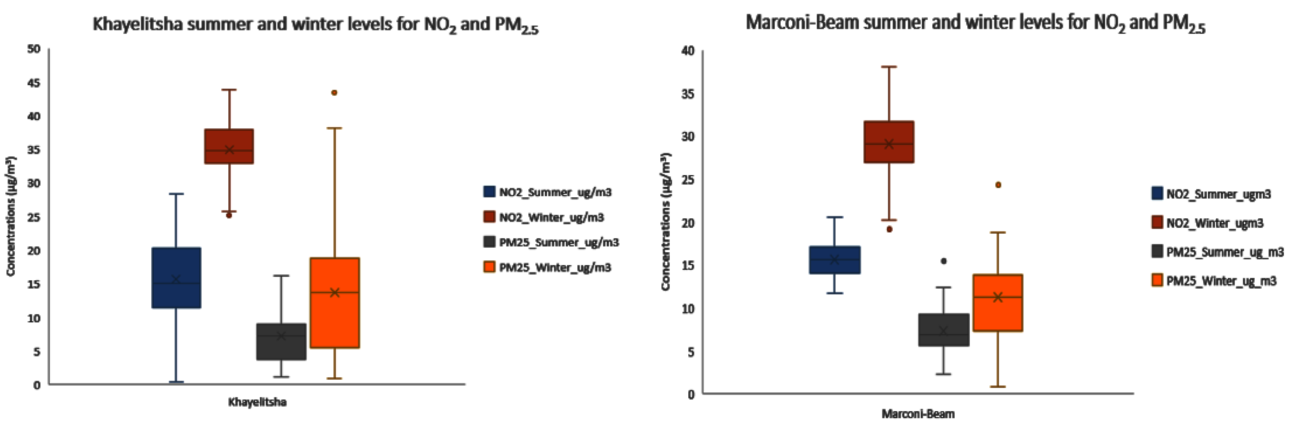

Fig. 3. Box and Whisker plots for NO_2 and $PM_{2.5}$ seasonal exposure levels in Khayelitsha and Marconi-Beam

μg/m³ during winter. Similarly, to Khayelitsha, the Box and Whisker plots in the Marconi-Beam neighbourhood illustrate seasonal variations in NO_2 and $PM_{2.5}$

Table 2 presents the seasonal exposure assessment outcome of Khayelitsha and Marconi-Beam informal settlements.

The seasonal exposure levels that characterize the pollutants behaviour across the neighbourhoods are listed in Table 2. As expected, intra comparisons of NO_2 and $PM_{2.5}$ exposure concentration in each neighbourhood indicate that pollution levels are generally affected by the change in seasons. In the current study, the phenomenon of pollutants increase during seasonal change has been observed when an overall increase of more than 50% in concentration was observed between NO_2 and $PM_{2.5}$ pollutants during the winter period. This finding of a direct link between $PM_{2.5}$ and NO_2 across neighbourhoods corroborate a long-standing relationship between the two pollutants. A similar trend was observed in the exposure assessment of $PM_{2.5}$ and NO_2 air pollutants undertaken in the urban neighbourhoods of north and south Durban [30]. The observed trend might be exacerbated by the fact that nitrogen dioxide has been identified as a secondary precursor for particulate matter [31, 32]. The increase of pollutants concentrations during the winter season were all statistically significant ($p \leq 0.05$). The results of this study indicate that, as expected, weekly measured ambient NO_2 levels were relatively higher in winter (mean concentration of 34.86 μg/m³) than in summer (mean concentration of 15.72 μg/m³) in Khayelitsha. This observation accounts for a double fold increase of NO_2 exposure concentration during the winter period. Whilst a similar pattern of pollutants behavior was observed in Marconi-Beam.

Furthermore, in Marconi-Beam, NO_2 exposure levels almost increase two-fold during the winter season (Fig. 3). The seasonal behaviour of NO_2 in these two neighbourhoods is identical. Exposure assessment results indicate that the NO_2 exposure

Table 2. Environmental exposure levels of NO_2 and $PM_{2.5}$ (μg/m³) in Khayelitsha and Marconi-Beam neighbourhoods

SUMMER						WINTER			
Neighbourhood	N	M	SD	SEM	p	N	M	SD	SEM
					NO_2				
Khayelitsha	40	15.72	6.46	1.02	≤0.05	40	34.86	4.03	0.63
Marconi-Beam	35	15.62	1.99	0.34	≤0.05	35	29.08	4.18	0.71
					$PM_{2.5}$				
Khayelitsha	40	7.25	3.95	0.62	≤0.05	40	13.74	9.89	1.56
Marconi-Beam	35	7.34	2.81	0.47	≤0.05	35	11.31	5.09	0.86

N: Number of measurements; M: Mean; SD: Standard Deviation; SEM: Standard Error Mean; p: p-Value level trend is comparable to results obtained elsewhere, where high exposure levels of NO_2 were discovered during the winter season compared to the summer season [33]. These high exposure levels are likely influenced by the common land-use activities between the two neighbourhoods of Khayelitsha and Marconi-Beam, such as combustion of wood, biomass, and vehicular traffic emissions. Moreover, levels of NO_2 during the summer and winter periods are significantly influenced by "an enhanced oxidation process where a reduction in photochemical reactions occur between NO_2 and Hydroxyl (OH) radicals that form Nitric Acid (HNO_3)". Multiple researches on ambient air quality monitoring has similarly noticed this trend [34, 35].

Although the seasonal results in Khayelitsha and Marconi Beam cannot be statistically compared due to differences in the number of measurements used to determine exposure concentrations, the spatial variability results show that exposure concentrations in both winter and summer sampling campaigns in Marconi Beam and Khayelitsha were relatively similar (Table 2). But with overall concentrations relatively higher in the Khayelitsha neighbourhood as shown in Fig. 3. Comparing the observed seasonal exposure concentrations in Khayelitsha and Marconi-Beam to those in other African states indicates that the observed seasonal exposure concentrations were comparable to those in Ugandan studies that measured mean concentrations of 26.69 $\mu g/m^3$ and 17.49 $\mu g/m^3$ [36]. The findings of NO_2 seasonal behaviour are consistent with the study conducted in Durban south, as well as Durban metropolis [37, 38]. Several studies in the continent have previously recorded similar observations [39, 40] except for Kenya that recorded the highest exposure concentrations of (159 $\mu g/m^3$) in summer and (139 $\mu g/m^3$) in winter [41]. The pollutants behaviour has been attributed to low wind speed and wind direction [41]. Interestingly, this behaviour of NO_2 pollutants increasing in summer and decreasing during winter seasons in the Athi river neighbourhood in Kenya is inverse to cases that have been observed in South Africa and many other countries in the continent. Therefore, it is worth noting that the case of the Athi river in Kenya is an unusual occurrence in terms of the seasonal variability of air pollutants.

As reflected in Table 2, there is a significant increase ($p \leq 0.05$) in the exposure concentration of $PM_{2.5}$ during summer and winter in both Khayelitsha and Marconi-Beam. In a study of seasonal variation, a similar pattern was reported, with particulate matter concentrations significantly increasing over the winter [42]. In Khayelitsha, the exposure levels of $PM_{2.5}$ almost doubles up in the winter period in contrast to summer (Table 2). Whereas in Marconi-Beam only a slight increase of $PM_{2.5}$ was observed. Be as it may, exposure levels of $PM_{2.5}$ in these neighbourhoods during summer and winter were relatively low when associated with those in other African countries like Kenya (67-166 $\mu g/m^3$) and Ghana (21- 39 $\mu g/m^3$) that exceeded WHO's guidelines [43, 44]. On the other hand, substantially higher exposure levels were recorded in the neighbourhoods of Thohoyandou in Limpopo during summer (8.64 $\mu g/m^3$) and winter season (9.83 $\mu g/m^3$) in South Africa [45]. However, lower concentrations were observed in Kwadela in summer (51.39 $\mu g/m^3$) and winter (32.18 $\mu g/m^3$) [46]. More so, lower concentrations were recorded in Marikana village in Rustenburg that exceeded both national ambient air quality standards and the international standards [47].

To contextualize the exposure measurements in Khayelitsha and Marconi-Beam, the measured concentrations were compared to the national ambient air quality standards (Table 1). However, the comparisons are difficult and not straightforward to make because none of the two studied pollutants observed in Table 1 have monthly standard limit values [48]. However, to this end, $PM_{2.5}$ summer concentration in the

Khayelitsha neighbourhood ranged from 1 μg/m^3 to 16 μg/m^3. During the winter, exposure values of 1 μg/m^3 to 43 μg/m^3 were observed (Fig. 3). In contrast to particulate matter, summer NO_2 exposure concentrations fluctuated between 0.43μg/m^3 and 28.4 μg/m^3 whereas winter concentrations ranged between 25 μg/m^3 and 43 μg/m^3 (Fig. 3). In Marconi-Beam, summer $PM_{2.5}$ concentration ranged between 2 μg/m^3 and 15 μg/m^3 whereas winter concentrations ranged from 0.81 μg/m^3 and 24.3 μg/m^3. Regardless, all these seasonal concentrations were significantly lower than the South African ambient air quality standards highlighted in Table 1.

The notable seasonal changes are therefore linked to a variety of factors that contribute to a substantial increase in ambient air pollution exposure [49]. During the winter season, the spike in pollutants exposure levels is mostly attributable to factors such as combusting biomass, tyres, and the contribution of motor vehicle traffic emissions [50]. Such practices are very common in informal settlements, where tyres are burned as a source of space heating during the winter season [51]. In addition to these sources of significant pollutants exposure, stable meteorological conditions are also a contributing factor towards pollutants level increase during the cold seasons [52]. This is partly because stable meteorological conditions in winter do not promote the dispersion of contaminants [53]. Thus, episodes such as the brown haze are common during the winter season [54].

Conclusion

This study determined the exposure concentrations of the most severe air pollutants, NO_2 and $PM_{2.5}$, in two neighbourhoods that lack monitoring facilities. The ambient air quality concentrations in Khayelitsha and Marconi-Beam demonstrated significant seasonal heterogeneity ($p \leq 0.05$) of exposure levels. Overall, winter average weekly concentrations were generally higher than the levels recorded in summer for all pollutants. The seasonal heterogeneity pattern observed in the neighbourhoods of Khayelitsha, and Marconi-Beam is indicative of NO_2 and $PM_{2.5}$ comparable sources of emissions. The NO_2 and $PM_{2.5}$ average exposure levels in the current study proved to be lower in contrast to other African countries and international studies. Whilst there are no legislative guidelines to compare the current weekly averages of the study, the concentrations for $PM_{2.5}$ and NO_2 were lower than the World Health Organization ($PM_{2.5}$: 24 h=25μg/m^3, NO_2: 1 h=200 μg/m^3) and South African air quality standards values (NO_2: 1 h =200 μg/m^3). Thus, exposure risk to significant levels of $PM_{2.5}$ and NO_2 that are hazardous to human health in these neighbourhoods are low. In as much as exposure levels are below the prescribed South African air quality standards values, but in the interest of continuous air quality monitoring, there is a need for multiple active monitoring stations in the informal settlements of vulnerable communities that will maximize spatial distribution of pollutants, consistently measure the concentrations of $PM_{2.5}$ and NO_2, proactively detect the risks to substantial exposure levels associated with a risk factor for human health and maintain compliance with the prescribed standards. Moreover, as a result of this practice, exposure misclassification might be reduced and exposure monitoring increased.

Limitations

• Although this study covered the harmful pollutants of $PM_{2.5}$ and NO_2, many other criteria pollutants such as CO, SO_2 and O_3 were not studied due to budget constraints.

• The sampling equipment could not measure the atmospheric meteorological factors.

• Collected data could not be directly compared with the prescribed South African Air Quality Standards

• The data set was not big enough and not consistent between the two study neighbourhoods thus results between the two neighbourhoods could not be compared.

Recommendations

• There is a need for long-term exposure assessment studies for air pollution that will consider investigating the exposure levels of indoor and outdoor pollutants.

• Exposure measurements sampling should be designed such that it is comparable with the prescribed South African air quality standards to ascertain the actual health risks associated with exposure.

• Additionally, focus on other hazardous gaseous pollutants such as CO and O_3.is recommended.

• A detailed study that will incorporate a temporal-spatial variation of air quality is also recommended.

• Instruments used to assess exposure should be capable of reading and recording (in real-time) 1-h and 24-h average pollutant concentrations to enable comparisons to South African legislation. This will provide a clear picture of whether average exposure levels of pollutants exceed recommended limits or not.

• Future studies must focus on the atmospheric meteorological factors that influence air pollutants behaviour in different seasons.

• Finally, developing models to better explain the spatial variability of air pollution in informal settlements is encouraged. This would be a cost-effective method of establishing the spatial distribution of air pollution, which might assist in local policymaking decisions.

Financial supports

No funds, grants or other financial support was received to conduct this study or to prepare the manuscript

Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Authors' contributions

Benett Siyabonga Madonsela conducted the study and the collection of data relevant for the writing of the article. All authors contributed to conceptualisation, structuring and writing of the article.

Acknowledgements

The authors would like to acknowledge Cape Peninsula University of Technology for encouraging and on the writing of the article. Gratitude is also extended to their families for support and encouragement.

Ethical considerations

Ethical issues (Including plagiarism, Informed Consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc) have been completely observed by the authors.

References

1. World Health Organization. 7 million premature deaths annually linked to air pollution; 2014. Accessed [18 October 2021] Available from: https://www.who.int/news/item/25-03-2014-7-million-premature-deaths-annually-linked-to-air-pollution.

2. International Federation of Environmental Health. World Environmental Health Day; 2017. Accessed [21 September 2018] Available from: https://www.ifeh.org/wehd/2017/WEHD2017.

3. Das P, Horton R. Pollution, health, and the planet: time for decisive action. The Lancet. 2018 Feb 3;391(10119):407-8.

4. World Health Organization. Health Topics - Air Pollution; 2020. Accessed [18 September 2021] Available from: https://www.who.int/health-topics/air-pollution#tab=tab_1.

5. Mustafić H, Jabre P, Caussin C, Murad MH,

Escolano S, Tafflet M, Périer MC, Marijon E, Vernerey D, Empana JP, Jouven X. Main air pollutants and myocardial infarction: a systematic review and meta-analysis. Jama. 2012 Feb 15;307(7):713-21.

6. Roy R. The cost of air pollution in Africa; 2016. Accessed [2 April 2020] Available from :https://www.oecd-ilibrary.org/development/the-cost-of-air-pollution-in-africa_5jlqzq77x6f8-en.

7. Ramacher MO, Karl M. Integrating modes of transport in a dynamic modelling approach to evaluate population exposure to ambient NO_2 and PM2. 5 pollution in urban areas. International journal of environmental research and public health. 2020;17(6):2099.

8. Xie X, Semanjski I, Gautama S, Tsiligianni E, Deligiannis N, Rajan RT, Pasveer F, Philips W. A review of urban air pollution monitoring and exposure assessment methods. ISPRS International Journal of Geo-Information. 2017 Dec;6(12):389.

9. World Health Organization. Ambient (outdoor) air quality and health; 2018. Accessed [10 May 2018] Available from: http://www.euro.who.int/en/health-topics/environment-and-health/air-quality/activities/update-of-who-global-air-quality-guidelines.

10. World Health Organization. WHO's urban ambient air pollution database update; 2016. Accessed [25 July 2020] Available from: https://www.who.int/airpollution/data/AAP_database_summary_results_2016_v02.pdf

11. Coker E, Kizito S. A narrative review on the human health effects of ambient air pollution in Sub-Saharan Africa: an urgent need for health effects studies. International journal of environmental research and public health. 2018;15(3):427.

12. Piketh SJ, Wernecke B, Burger R. Household air pollution in South African low-income settlements: a case study. WIT Transactions on Ecology and the Environment. 2016;207:227-36.

13. Baxter LK, Dionisio KL, Burke J, Sarnat SE, Sarnat JA, Hodas N, Rich DQ, Turpin BJ, Jones RR, Mannshardt E, Kumar N. Exposure prediction approaches used in air pollution epidemiology studies: key findings and future recommendations. Journal of exposure science and environmental epidemiology. 2013 Nov;23(6):654-9.

14. Schwela D. Review of urban air quality in Sub-Saharan Africa. Clean Air Initiative in Sub-Saharan African cities, Washington DC: The World Bank. 2007..

15. Air Quality Cape Town. Gail Jennings. 2007. Air Quality in Cape Town: What we can do to clear the air; [uploaded 2017; cited 5 August 2021]. Available from: http://www.gailjennings.co.za/wp-content/uploads/2017/01/Air-Quality

16. Nuwarinda H. Air pollution study of a Highveld township during a Basa njengo Magogo rollout (Doctoral dissertation, University of Johannesburg). 2007.

17. White N, van der Walt A, Ravenscroft G, Roberts W, Ehrlich R. Meteorologically estimated exposure but not distance predicts asthma symptoms in schoolchildren in the environs of a petrochemical refinery: a cross-sectional study. Environmental Health. 2009;8(1):1-0.

18. Keen S, Altieri K. The health benefits of attaining and strengthening air quality standards in Cape Town. Clean Air Journal. 2016;26(2):22-7.

19. Muchapondwa E. A cost-effectiveness analysis of options for reducing pollution in Khayelitsha township, South Africa. TD: The Journal for Transdisciplinary Research in Southern Africa. 2010;6(2):333-58.

20. Census. Milnerton; 2011. Accessed [5 May 2019] Available from: https://census2011.adrianfrith.com/place/199014011

21. Environmental Protection Agency. Quality Assurance Guidance Document 2.12. [internet].

1998 [cited 28 July 2021]. Available from: https://www3.epa.gov/ttnamti1/files/ambient/pm25/qa/m212.pdf

22. Allen R, Box M, Liu LJ, Larson TV. A cost-effective weighing chamber for particulate matter filters.Journal of the Air & Waste Management Associations. 2001;51(12):1650-3.

23. Passam AG. Laboratory for environmental analysis and air pollution. 2016.

24. Sensidyne. Gilian Gilibrator-2 NIOSH primary standard air flow calibrator. 2016. Accessed [26 June 2019] Available from: https://www.sensidyne.com/air-sampling-equipment/calibration-equipment/gilibrator-2/.

25. United States Environmental Protection Agency. Additional Guidance on $PM_{2.5}$ Cassette Handling and Transportation; 2000. Accessed [20 July 2021] Available from: https://www3.epa.gov/ttnamti1/files/ambient/pm25/pm25caset.pdf

26. Department of Environemntal Affairs. National ambient air quality standards. 2009. Accessed [18 October 2021] Available from: https://www.environment.gov.za/sites/default/files/legislations/nemaqa_airquality_g32816gon1210_0.pdf

27. Gray HA, Solutions GS. Air quality impacts and health effects due to large stationary source emissions in and around South Africa's Mpumalanga Highveld Priority Area (HPA). 2019.

28. McDonald JH. Handbook of biological statistics. Baltimore, MD: sparky house. 2009.

29. Valsamakis SK. Ambient air quality monitoring: a comparison between two urban parks in Soweto, South Africa (Doctoral dissertation, University of the Witwatersrand, Faculty of Science, School of Geography, Archaeology and Environmental Studies). 2015.

30. Tularam H, Ramsay LF, Muttoo S, Naidoo RN, Brunekreef B, Meliefste K, de Hoogh K. Harbor and intra-city drivers of air pollution: Findings from a land use regression model, Durban, South Africa. International journal of environmental research and public health. 2020 Jan;17(15):5406.

31. Hodan WM, Barnard WR. Evaluating the contribution of PM2. 5 precursor gases and re-entrained road emissions to mobile source PM2. 5 particulate matter emissions. MACTEC Federal Programs, Research Triangle Park, NC. 2004 Jun 8.

32. Pineda L, Blumberg K, Schade M, Koupal J, Perez I, Zirath S, Fu J, Huang K, Jin L, Hernandez U. Air quality and health benefits of improved fuel and vehicle emissions standards in Mexico. 2018 Jan 3.

33. Levy I, Mihele C, Lu G, Narayan J, Brook JR. Evaluating multipollutant exposure and urban air quality: pollutant interrelationships, neighborhood variability, and nitrogen dioxide as a proxy pollutant. Environmental Health Perspective. 2014;122(1):65-72.

34. Nguyen HT, Ki-Hyun K. Changes in NO_2 concentration from major cities and provinces in Korea: a case study from 1998 to 2003. TAO: Terrestrial, Atmospheric Oceanic Science. 2006;17(1):277.

35. Al Katheeri E, Al Jallad F, Al Omar M. Assessment of gaseous and particulate pollutants in the ambient air in Al Mirfa City, United Arab Emirates. Journal of Environmental Protection. 2012;3(7):640-7.

36. Kirenga BJ, Meng Q, Van Gemert F, Aanyu-Tukamuhebwa H, Chavannes N, Katamba A, Obai G, Molen TV, Schwander S, Mohsenin V. The state of ambient air quality in two Ugandan cities: a pilot cross-sectional spatial assessment. International journal of environmental research and public health. 2015 Jul;12(7):8075-91.

37. Muttoo S, Ramsay L, Brunekreef B, Beelen R, Meliefste K, Naidoo RN. Land use regression modelling estimating nitrogen

oxides exposure in industrial south Durban, South Africa. Science of Total Environment. 2018;610:1439-47.

38. Moodley KG, Singh S, Govender S. Passive monitoring of nitrogen dioxide in urban air: A case study of Durban metropolis, South Africa. Journal of environmental management . 2011;92(9):2145-50.

39. Khoder MI. Diurnal, seasonal and weekdays–weekends variations of ground level ozone concentrations in an urban area in greater Cairo. Environmental Monitoting and Assessment. 2009;149(1):349-62.

40. Hassan SK, El–Abssawy AA, Khoder MI. Characteristics of gas–phase nitric acid and ammonium–nitrate–sulfate aerosol, and their gas–phase precursors in a suburban area in Cairo, Egypt. Atmospheric Pollutione Resarch. 2013;4(1):117-29.

41. Birgen JC. Assessment of levels of selected Air Polluntant in Athi river, Kenya (Doctoral dissertation, University of Nairobi). 2017.

42. Chen R, Peng RD, Meng X, Zhou Z, Chen B, Kan H. Seasonal variation in the acute effect of particulate air pollution on mortality in the China Air Pollution and Health Effects Study (CAPES). Science of the total environment. 2013;450:259-65.

43. Dionisio KL, Rooney MS, Arku RE, Friedman AB, Hughes AF, Vallarino J, Agyei-Mensah S, Spengler JD, Ezzati M. Within-neighborhood patterns and sources of particle pollution: mobile monitoring and geographic information system analysis in four communities in Accra, Ghana. Environmental health perspectives. 2010 May;118(5):607-13.

44. Egondi T, Muindi K, Kyobutungi C, Gatari M, Rocklöv J. Measuring exposure levels of inhalable airborne particles ($PM_{2.5}$) in two socially deprived areas of Nairobi, Kenya. Environmental research. 2016;148:500-6.

45. Edlund KK, Killman F, Molnár P, Boman J, Stockfelt L, Wichmann J. Health Risk Assessment of PM2. 5 and PM2. 5-Bound Trace Elements in Thohoyandou, South Africa. International journal of environmentl research and public health. 2021;18(3):1359.

46. Xulu NA, Piketh SJ, Feig GT, Lack DA, Garland RM. Characterizing light-absorbing aerosols in a low-income settlement in South Africa. 2020.

47. Venter AD, Jaars K, Booyens W, Beukes JP, Van Zyl PG, Josipovic M, Hendriks J, Vakkari V, Hellén H, Hakola H, Aaltonen H. Plume characterization of a typical South African braai. South African Journal of Chemistry. 2015;68:181-94.

48. Ngoasheng M, Beukes JP, van Zyl PG, Swartz JS, Loate V, Krisjan P, Mpambani S, Kulmala M, Vakkari V, Laakso L. Assessing SO_2, NO_2 and O_3 in rural areas of the North West Province. Clean Air Journal. 2021;31(1):1-4.

49. Gurley ES, Homaira N, Salje H, Ram PK, Haque R, Petri W, Bresee J, Moss WJ, Breysse P, Luby SP, Azziz-Baumgartner E. Indoor exposure to particulate matter and the incidence of acute lower respiratory infections among children: a birth cohort study in urban Bangladesh. Indoor air. 2013 Oct;23(5):379-86.

50. Lodhi A, Ghauri B, Khan MR, Rahman S, Shafique S. Particulate matter ($PM_{2.5}$) concentration and source apportionment in Lahore. Journal of the Brazillian Chemical Society. 2009;20:1811-20.

51. Mahlangu ML. Waste tyre management problems in South Africa and the possible opportunities that can be created through the recycling thereof (Doctoral dissertation, University of South Africa). 2009.

52. Wang Y, Ali M, Bilal M, Qiu Z, Mhawish A, Almazroui M, Shahid S, Islam MN, Zhang Y, Haque M. Identification of NO_2 and SO_2 pollution hotspots and sources in Jiangsu Province of China. Remote Sensing. 2021 Jan;13(18):3742.

53. Lourens AS, Fourie GD, Burger JW, Pienaar JJ, Read CE, Jordaan JH, Van Zyl PG, Beukes JP. Spatial and temporal assessment of gaseous pollutants in the Highveld of South Africa. South African Journal of Science. 2011 Jan 1;107(1):1-8.

54. Wicking-Baird MC, De Villiers MG, Dutkiewicz RK. Cape Town brown haze study. 1997.