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The Influence of Outdoor Exposure Concentrations on Indoor Air Quality in Rudimentary Designed Household Structures: Mpumalanga Province, South Africa

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ABSTRACT

There is a belief that ambient air pollution is accountable for degrading the air quality indoors. Although in principle the indoor air quality should be better than that of outdoor air quality given the shielding effect of a house structure. However, ambient air quality can infiltrate and influence indoor air pollution concentrations in low-income urban informal settlements due to rudimentary designed household structures. Given this phenomenon, the current study endeavoured to explore the influence of outdoor exposure concentration on indoor air quality within the informal settlements of urban neighbourhoods. The exposure concentrations of indoor and outdoor particulate matter and nitrogen dioxide pollutants were simultaneously measured during summer and winter seasons. The GilAir Plus air sample pump was used to acquire measurements of particulate matter collected over 48 hours. While nitrogen dioxide gases were measured using passive diffusive samplers. All statistical analyses were performed using Python (version 3.8) Spyder. The current study has discovered that in many instances the results were comparable indoors and outdoors. For instance, this has been corroborated by the nitrogen dioxide discoveries where the current results were slightly comparable as indoor exposure concentrations values were recorded to be between (4 $\mu g/m^3$ and 13 $\mu g/m^3$), whilst the outdoor concentration ranged between (6 $\mu g/m^3$ and 11 $\mu g/m^3$). Likewise, a similar trend was observed for particulate matter exposure concentrations indoors (14 $\mu g/m^3$) and (12 $\mu g/m^3$) outdoors. The statistical inferences futher confirmed that the exposure values of indoor and outdoor were not significant ($p>0.05$) within the study areas of concern.

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INTRODUCTION

It is well proven that overall air pollution has a negative impact on mortality, morbidity, and life expectancy (Ghorani-Azam, et al., 2016; Juginović et al., 2021; Madonsela et al., 2023). This premise accentuates that exposure to indoor, and outdoor air pollution are fundamental obstacles that make it complex to realize the Sustainable Development Goals (SDGs 3) for good health and well-being (Madonsela, 2023) . Especially since a substantial number of people usually spend a considerable amount of time (between 70% and 90% of the time) indoors, they are exposed to numerous sources of indoor air pollution (Odeh & Hussein 2016; Kapwata et al., 2018; Stafoggia et al., 2022). As such given the amount of time they spend indoors, children and elderly people are reported to be at high risk of exposure to indoor air pollutants (Almeida-Silva et al., 2014; Abdel-Salam 2022). The main culprit of exposure to indoor air pollution is cited to be the use of solid fuels intended to meet the demands of space heating as well as cooking particularly within the low-and middle-income countries (Jafta et al., 2017). It is important to note, however, that in low- and middle-income countries, some indoor exposure sources, such as solid fuels, are relatively the same as outdoor air pollution sources (Nkosi et al., 2021). This notion is bolstered, for instance, by the fact that many vendors in the informal urban settlements in low-income nations grill meat using solid fuels (Venter et al., 2015). A lack of reliable, modern energy sources often contributes to this behaviour. In addition to solid fuels, outdoor exposure sources in the residential neighbourhood of informal settlements are still characterised by the heterogenous complex triggers comprised of vehicular emissions and indiscriminate waste burning amongst others (Worobiec et al. 2011; Adesina et al., 2020).

Therefore, given the heterogenous complex sources of outdoor air pollutants within the informal settlements of urban areas, numerous studies have embarked on evaluating the impact of outdoor air pollutants on indoor air quality (Smedje et al., 2006; Argunhan & Avci, 2018). There is a belief that indoor air quality is degraded by air pollutants of outdoor origins (Shrestha et al., 2019). However, Leung (2015) believes that indoor air quality should be better than outdoor air quality due to the shielding effect of buildings and the possible installation of ventilation. This phenomenon is likely true for developed countries given that such countries have the technological infrastructure required to support an indoor air quality management strategy in contrast to their counterparts in the developing countries. Nevertheless, in the informal settlements of urban areas given the poor infrastructural structure associated with poor socio-economic conditions the ambient air quality can infiltrate and influence indoor air pollution concentrations (Ferguson et al., 2020). The poor material used to construct the household infrastructure is one of the understudied enablers of indoor air pollution infiltrators that aggravate elevated concentrations within the informal settlements. For instance, the informal settlement in South Africa is characterised by shacks that are often built from industrial by-products, scraps, and unwanted materials (Chikoto, 2010). Such structures, which are primarily shacks or slums, are not insulated from a variety of environmental hazards (Turok & Borel-Saladin, 2016) including ambient air pollution. Be as it may, decades of research on air pollution in low-income urban areas of South Africa have distinguished household solid fuel combustion as a major source of indoor air pollution (Pauw, 2020). This has been observed in numerous studies conducted at Mpumalanga Highveld (Wernecke et al. 2015), Kwadela township (Nkosi et al., 2017), KwaZamokuhle (Adesina et al.2020) as well as Giyani (Kapwata et al., 2018) and Phalaborwa (Adeeyo et al., 2022) in Limpopo. However, there are limited studies that have monitored the risks of indoor exposure to elevated air pollution concentrations as the result of the built environment that comprises shacks or slums in contrast to the formal house. That is, there is a gap in the South African literature that covers the exposure to poor indoor and outdoor air quality as the result of dwelling in a poorly built household infrastructure in a low-income neighbourhood. Although multiple studies emphasize the role of the built environment as an

Table 1. The most influential countries in terms of quantity (number of documents) and quality (number of citations) of research in the field "Influence of Outdoor Exposure Concentration on Indoor Air Quality" using the VOSViewer tool and Web of Science database.

Country	Documents	Citations
USA	77	4188
China	61	1615
England	16	1174
Canada	17	1163
Germany	11	759
Sweden	6	599
South Korea	11	594
Denmark	6	537
Australia	14	512
Spain	12	447
Portugal	17	430
India	12	369
Czech Republic	7	271
Italy	15	267
France	10	196
Vietnam	6	169
Poland	15	154
Greece	10	148
Taiwan	9	146
Malaysia	8	143
Iran	6	139
Finland	6	138
Brazil	5	83

enabler of indoor exposure concentrations (Shrestha et al., 2019; Agbo et al., 2021; Mendoza et al., 2021; Chakraborty et al., 2022). Therefore, given this observation, the current study attempted to assess the vulnerability of shacks or slum dwellers within the informal settlements of urban neighbourhoods to indoor and outdoor air pollution exposure in contrast to formal housing dwellers.

In light of the above literature, this research study went a step further to illustrate the lack of research that is being conducted in African countries including South Africa, and to depict the current structure of research and the trends in the field of indoor and outdoor air quality. Using the key term "Influence of Outdoor Exposure Concentration on Indoor Air Quality" in web of science database 304 publications were retrieved and analyzed. This analysis was performed using the specialized software VOSViewer. The results showed that the USA, China, England, and Canada are the most influential countries in terms of quantity and quality of research in the field and there are no African countries in this list. This reflects the lack of relevant publications in South Africa and across the continent in this prestigious scientific database.

Furthermore, regarding the structure of research in the Web of Science database, the results using VOSViewer show that exposure, particulate matter, indoor air quality, personal exposure, ventilation, and pollutants are the hottest topics the most occurring in this field (Figure 1a). The findings show also an increasing trend in research on topics including fine particulate matter, urban, infiltration, size, black carbon, source apportionment, elemental composition, and cooking (Figure 1b).

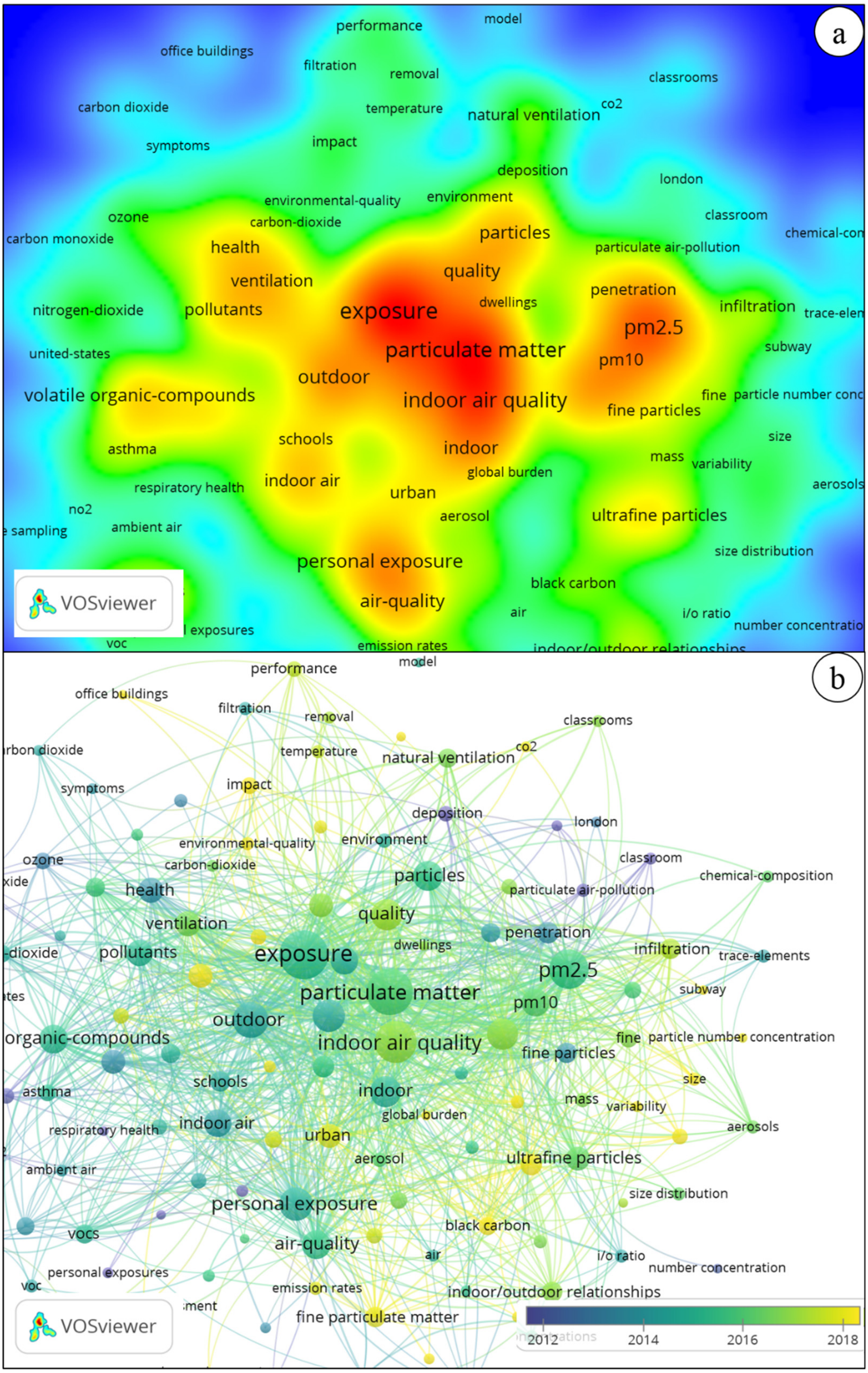

Fig. 1. Structure of research in web of Science using VOSViewer tool. (a) Density analysis (b) trending analysis

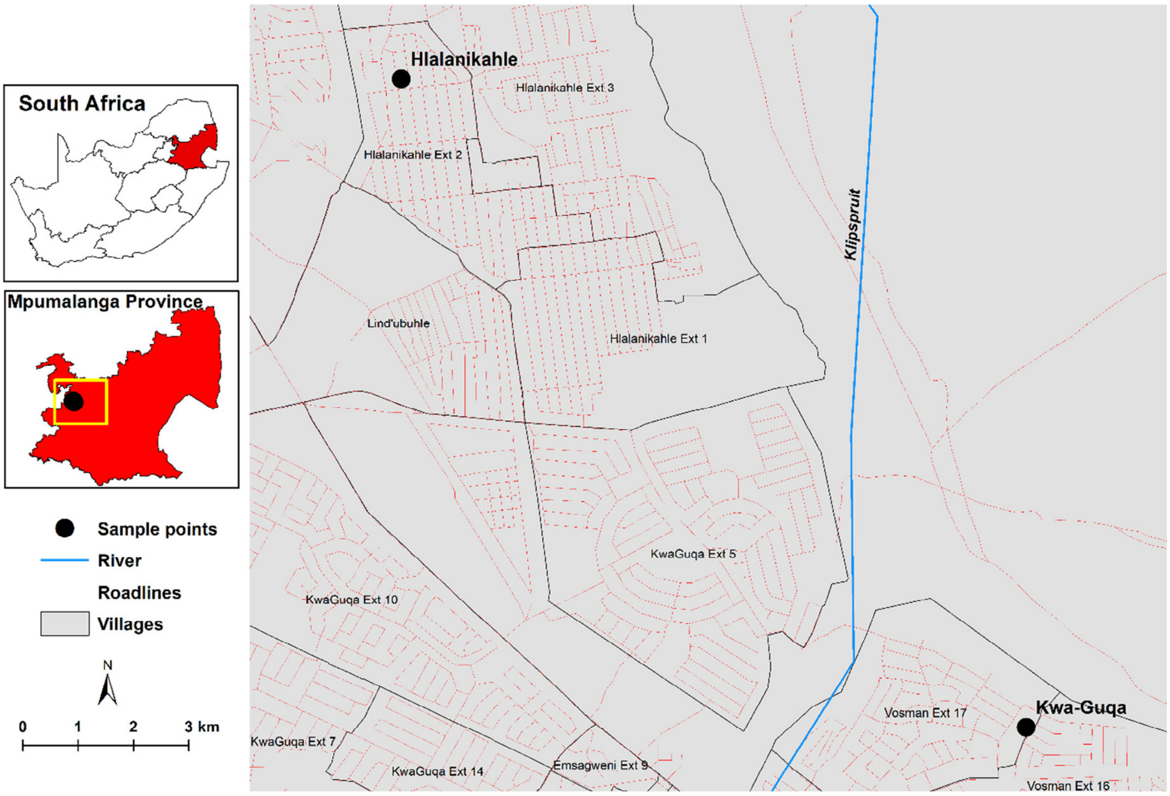

Fig. 2. shows the study areas of Hlalanikahle and Kwa-Guqa at Emalahleni Local Municipality, Mpumalanga , South Africa.

MATERIALS AND METHODS

Description of the study areas

The current study was conducted in the highveld of Emalahleni Local Municipality, Mpumalanga Province, South Africa within two distinct neighbourhoods of Hlalanikahle (34.0414° S, 18.6714° E) and Kwa-Guqa (33.9572° S, 22.4485° E) as shown in Figure 2. The exposure concentrations of indoor and outdoor particulate matter and nitrogen dioxide pollutants were measured during the summer and winter seasons in these two low-cost neighbourhoods of Hlalanikahle and Kwa-Guqa. Low-cost neighbourhoods are characterised by a lack of basic services which exacerbates ambient air pollution concentrations (Newton et al., 2022). In these neighbourhoods, the period for summer extends from December to March. Whilst the winter season lasts from June to late August. Hlalanikahle is a South African township characterised by numerous informal settlements located in close proximity to a number of coal mines and industrial sites, which are widely recognized as significant contributors to air pollution. The existence of coal mining and processing sectors can lead to the emission of particulate matter and nitrogen dioxide. Moreover, due to industrial activies vehicle traffic is one of the main sources of air pollution in this neighbourhood, along with the combustion of solid fuels and household waste in the informal settlements which significantly decreases air quality. Vehicle traffic is aggravated by the fact that the informal is connected to Emalahleni and other nearby places by a network of roadways that experience heavy traffic congestionas a result of coal transportation that leads to air quality emissions. Thus, there is a risk exposure to excessive elevated concentrations of particulate matter nitrogen dioxide that might exceeds safe prescribed limits in the area. Likewise, Kwa-Guqa, similar to Hlalanikahle, showcases a combination of industrial and residential zones. Industrial activities, such as mining and manufacturing characterises this neighbourhood. The only difference is contrasts to Hlalanikahle is that this neighbourhood consists of formal housing where household structures are constructed of bricks. These are government-built houses provided to beneficiaries who are considered to be poor. The two neighbourhoods present different household structures as one is constructed from bricks and mortar (Kwa-Guqa), whilst the latter (Hlalanikahle) predominantly uses informal material to construct shacks or what is known as the slum. The selection of these neighbourhoods was purposive given their distinction in household infrastructural construction.

Pollutants data collection and analysis

Indoor and outdoor air quality sampling

To investigate the exposure concentrations of particulate matter smaller than 2.5 µm ($PM_{2.5}$) and nitrogen dioxide (NO_2) in Hlalanikahle and Kwa-Guqa study areas on every 4th day of the week exposure readings for both pollutants were collected. To this end, measurements of nitrogen dioxide and the mass concentration of particles smaller than 2.5 µm were monitored in these two neighbourhoods of comparable geographic characteristics. On a google earth map, households that would optimize the indoor and outdoor spatial distribution of these two pollutants of concern were identified and located in both neighbourhoods. Through Google Earth map aid, the selected household considered to optimize indoor and outdoor exposure to pollutants had to meet the criterion that considered the density of buildings as well as informal housing structure within proximity to highway. Subsequently, Hlalanikahle at Emalahleni Local Municipality in the highveld of Mpualanga Province met this criterion of a dense informal settlement that contained the infrastructure constructed from corrugated iron and other scavenged materials. Additionally, the monitored households considered in the current study were within the range of less than fifty meters from the main road (Muttoo et al., 2018). Similarly, households monitored for air quality exposure concentration levels in Kwa-Guqa were within similar proximity to the main road. Contrary to being heavily populated, these structures consist of traditional brick dwellings. Furthermore, households between these two areas that met the criterion for selection were stratified using Google Earth map.

Consequently, from the selected strata of household's convenience non-probability sampling techniques were used to sample NO_2 and $PM_{2.5}$. The sampling train of NO_2 and $PM_{2.5}$ was attached right above the roof structure of the selected household for ambient air monitoring. Whilst during the indoor air quality monitoring the sampling train was attached closely to the roof using a tripod. In this process, the $PM_{2.5}$ concentration was determined through the use of Zefon International 37 mm (2 µm pore size) PTFE membrane filters and a GilAir Plus air sample pump. The Zefon international, PTFE, 2.0, 37 MM filters were utilized in leak-free filter cassettes comprised of three PCS. At the University of Forthare, the filters were pre-sampled, and their weights were determined with the assistance of a Mettler UMX2 microbalance and a custom-made weighing chamber. The sampling of pollutants was conducted for a duration of six months. The sampling was designed such that the duration of six months extends throughout the summer and winter seasons. The GilAir Plus air sampling pump was configured to run for 72 hours at a rate of 15 minutes/hour to avoid overloading the filters as a result of the lengthy sampling duration. While NO_2 gases were sampled using passive diffusion samplers. These passive diffusion samplers are designed to capture integrated concentration with the same average time as exposure time (Madonsela et al., 2022).

Quality control

Field blanks and duplicate samples were deployed as part of the exposure monitoring exercise to maintain quality control compliance and to ensure that the actual result of the experiment is representative and comparable as prescribed by Williams et al. (2021). At the sampling field, field blanks were exposed in the sampling environment for a few seconds. Moreover, in the sampling environment, the original samplers' duplicates were deployed for the same period as the original samplers. Diffusive passive samplers and filter cassettes were refrigerated at 4°C to maintain the cold chain at the University of Forthare Laboratory before sampling. This was done in accordance with the manufacturer's instructions. Furthermore, a Gillibrator-2 was used to calibrate the GilAir personal air sampler pumps at the laboratory . In this case, a mild soap solution was used to form a bubble inside an interior chamber of a Gillibrator-2 primary calibrator. The airflow provided by the sample pump pulls the bubble from the bottom of the chamber to the top. The Gillibrator-2 times the bubble, and the flow rate is estimated by the time it takes the bubble to travel from the bottom of the chamber to the top (Madonsela et al., 2019; Zinke et al., 2023).

Before going out into the field, Laboratory-based rotameters were used to confirm the correct pump flow rate of 4 per miunter (Liter/minute) in the laboratory after calibration. As the the flow rate of the GilAir pump is suppose to be 4 Liter/minute. 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 cool down the samples.

Data analysis of $PM_{2.5}$ and NO_2 parameters

Postexposure assessment in the sampling field, Teflon filters were again weighed on a microbalance at the University of Forthare using a custom-made weighing chamber and a Mettler UMX2 microbalance to analyse the mass for $PM_{2.5}$. It is important to note that the mass analysis for $PM_{2.5}$ followed procedures prescribed by the Environmental Protection Agency (EPA, 1998). The weighing facility's specifications have already been published elsewhere (Allen et al., 2001) During this procedure, it was observed that for at least 24 hours before weighing, filters were conditioned to the weighing room's temperature (20–23 °C ± 2 °C) and relative humidity (30–40% ± 5%). Whilst, on the other hand, in contrast to mass analysis for particulate matter, NO_2 gases were measured using passive diffusion samplers and analysed at the scientific laboratory accredited by the South African National Accreditation Systems where the collected NO_2 exposure concentrations were analysed photospectrometrically using the Saltzmann method (Madonsela et al., 2022).

Statistical analysis

All statistical analyses were performed using Microsoft Excel 2019 and Python (Version 3.8) Spyder. Descriptive univariate statistics were generated for the total sample distribution that includes indoor and outdoor parameters of $PM_{2.5}$ and NO_2. Subsequently, seasonal exposure plots were used to illustrate the seasonal data distribution depicting the minimum and maxim values of exposure. Moreover, the seasonal exposure fluctuations indoors and outdoors in each neighbourhood were explained through a paired t-test. A t-test is a statistical analysis test that may be used to compare the means of two samples to evaluate whether there is a significant difference between the sample means (Mcdowell, 2009, Valsamakis, 2015, Francis & Jakicic, 2023). Furthermore, the t-test in the current study generated a p-value that shows the likelihood that there is a seasonal difference between the mean concentration of pollutants samples indoors and outdoors. Hence, the paired t-test analysis was used to compare the summer and winter mean NO_2 and $PM_{2.5}$ concentrations in Hlalanikahle and Kwa-Guqa. In conclusion, for this parameter, the South African Department of Health (DoH) domestic indoor air quality levels were employed to contextualize the exposure risks associated with the concentrations in these neighbourhoods. In a nutshell, domestic indoor air quality standards are used to determine

Table 2. Indoor air quality guidelines

Air quality standards			
Pollutant	**Averaging time & limit value**		**Reference**
$PM_{2.5}$ (µg/m^3)	Annual	5	**(DoH, 2019)**
	24-hour	10	
NO_2 (µg/m^3)	Annual	10	**(DoH, 2019)**
	1-hour	200	

the permissible maximum concentration of air quality substances that might be safe in a given environment for a certain duration. Moreover, these standards provide a guideline for highlighting the difference between a contaminated and a safe environment. To this extent, table 2 below outlines the guidelines limit values for permissible exposure indoors. Even though exposure to these exposure concentrations is considered unsafe (DoH, 2019). To quantify the impact of outdoor air and indoor sources on indoor air quality, indoor/outdoor ratios were calculated using the fomular below:

$$I/O = C_{indoor} \div C_{outdoor}$$

Where *Cindoor* = outdoor air concentration [µg/m^3]
Coutdoor = indoor air concentration [µg/m^3]
I/O = indoor-outdoor ratio [-]

RESULTS & DISCUSSION

Summer indoor and outdoor nitrogen dioxide exposure levels

Numerous exposure factors are attributed to high air pollution exposure levels within urban settings. To this end, Mutahi et al., (2021) cite several issues that range from inadequate air pollution control policies to increased population. In addition to these sources is the poor structural infrastructure that could easily permeate ambient pollutants indoors that embodies most of the urban area's informal settlements. Thus, the Hlalanikahle neighborhood just like other urban informal settlements is at high risk of experiencing this phenomenon of outdoor pollutants influencing indoor exposure levels. As accentuated by Leung (2015) and Shrestha et al. (2019). Given that, the households are constructed from poor infrastructural materials such as wood. Moreover, there is a direct relationship between seasonal variation and the accumulation of pollutants in the atmosphere. That is, there is a correlation between the unique weather patterns and the observations of the prevalence of higher exposure values of air pollution within certain seasons. It is for this reason that in order to understand the seasonal variation of particulate matter and nitrogen dioxide their behavior was classified according to seasons. In line with this viewpoint, Figure 3 below depicts in microgram per cubic meter (µg/m^3) the indoor and outdoor summer seasonal behaviour of nitrogen dioxide pollutants. Figure 3 demonstrates the seasonal difference in the exposure levels of indoor and outdoor air pollutants in each neighbourhood. The data suggest that summer NO_2 concentrations in Kwa-Guqa were slightly above 10 µg/m3 in both instances of indoors and outdoors with the calculated Indoor/Outdoor (I/O) ratios of 0.7. The results were slightly comparable as indoor exposure concentrations values were recorded to be between (4 and 13 µg/m^3), whilst the outdoor concentration ranged between (6 and 11 µg/m^3). A similar concentration observation of nitrogen dioxide pollutants behaviour was detected in the Hlalanikahle neighbourhood. As the highest pollutants values were clustered between (17 µg/m^3) and (19 µg/m^3) indoors and

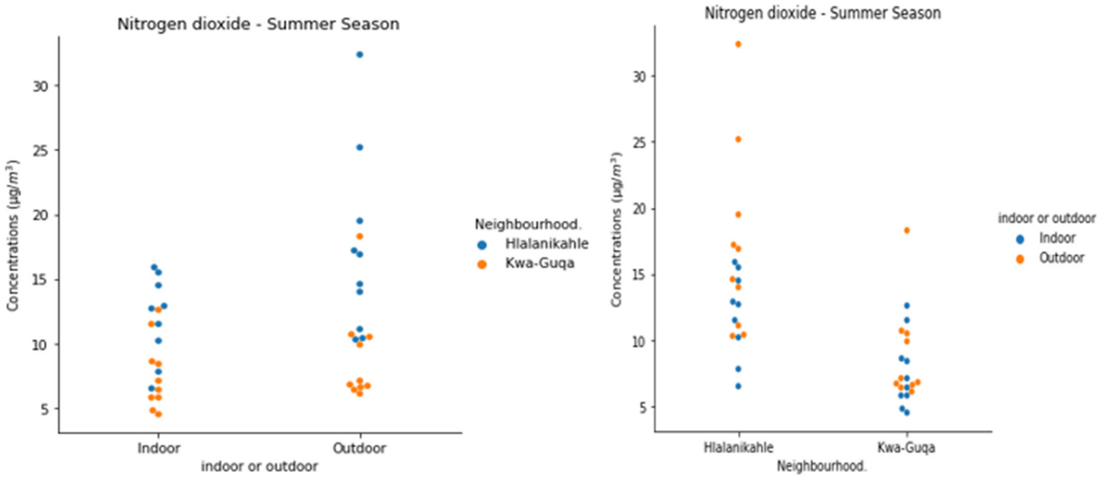

Fig. 3. Indoor and outdoor nitrogen dioxide exposure concentrations in Kwa-Guqa (Kwa-Guqa) and Hlalanikahle precinct

outdoors respectively. To this effect, the summer results indicate that exposure to air pollution that informs indoor and outdoor levels in Hlalanikahle is relatively comparable as observed in Figure 3 . Furthermore, the comparability between indoor and outdoor exposure concentrations of each neighbourhood was clearly concluded by the statistical inferences which highlighted that the exposure values of indoor and outdoor were not significant (p=0.06) for Hlalanikahle neighbourhood as well as Kwa-Guqa (p=0.37). These results, however, are congruent with the findings of Dėdelė and Miškinytė (2016) who discovered a similar observation for nitrogen dioxide indoors and outdoors. In the observation, Dėdelė and Miškinytė (2016) conclude that outdoor air quality influences indoor concentrations. Moreover, Huo and Zao (2020) elaborate that the indoor NO_2 concentration is significantly influenced by the outdoor NO_2 concentration due to the ability of the air to flow indoors and outdoors. Therefore, in this case, there is no significant difference between the indoor and outdoor exposure concentrations. That is, in principle, the exposure levels are similar between indoors and outdoors.

Winter indoor and outdoor seasonal concentrations of nitrogen dioxide

The plots were created to illustrate the nitrogen dioxide visuals of the indoor and outdoor summer and winter seasonal exposure concentrations (Figure 4). The figures below depict the difference in exposure concentrations levels of NO_2 in each neighbourhood of Kwa-Guqa and Hlalanikahle measured in micrograms per cubic meter shown using the graphical technique. According to the data observations in winter Hlalanikahle neighbourhood exposure concentrations were clustered between (30 and 40 µg/m^3) outdoor. Whilst during a similar season the indoor exposure concentrations were limited between (2 and 12 µg/m^3). A similar trend associated with the outdoor winter pollutants behaviour was similarly observed during the winter period at Hlalanikahle precinct whereby the ambient concentrations were clustered between (30 and 40 µg/m^3). However, the indoor concentrations conversely differed as they ranged between (8 and 38 µg/m^3). Similarly to summer, the average Indoor/Outdoor NO_2 ratio it remained less than 1(0.84).

Furthermore, in Kwa-Guqa the winter indoor exposure concentrations (2 and 22 µg/m^3) were higher than overall levels recorded outdoor (2 and 12 µg/m^3) in the similar season. Interestingly, the statistical difference indicates that overall there was no significant difference between indoor

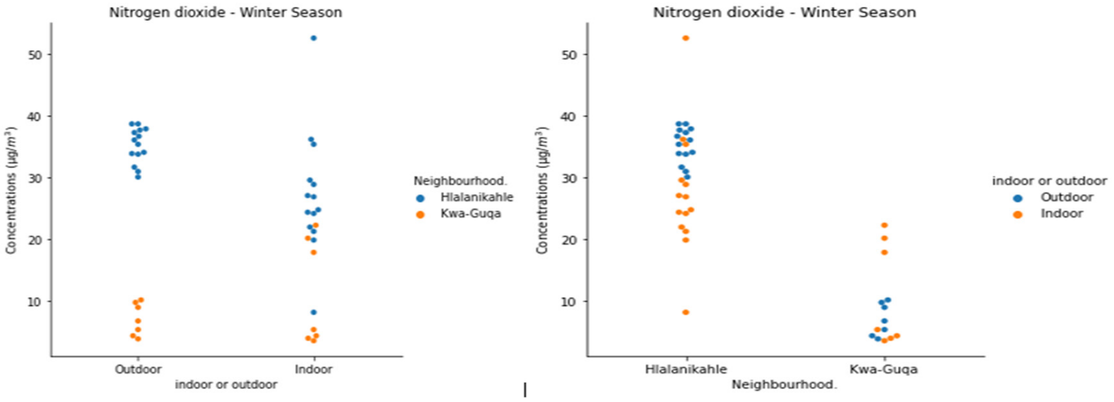

Fig. 4. Visualization of indoor and outdoor NO_2 winter levels

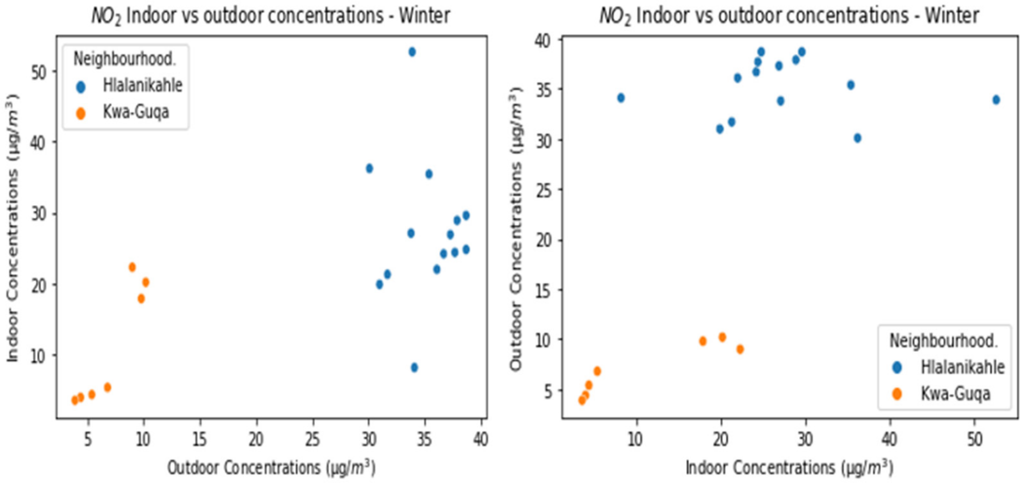

Fig. 5. The nitrogen dioxide exposure relationship between indoor and outdoor levels

and outdoor exposure levels in Kwa-Guqa (p=0.27).

The association between indoor and outdoor levels of nitrogen dioxide exposure

Generally, there is a perception that indoor exposure concentrations exceed ambient air pollutants levels. Based on this background, the premise was subsequently tested in Hlalanikahle and Kwa-Guqa. Thus, figure 5 below illustrates the relationship between indoor and outdoor exposure levels of nitrogen dioxide.

Figure 5 shows the winter season comparison of indoor and outdoor levels of nitrogen dioxide exposure. The results above indicate that indoor in Kwa-Guqa doubled (23 µg/m^3) the exposure concentrations that were observed outdoors (11 µg/m^3). Whilst in contrast at Hlalanikahle ambient air exposure concentrations (38 µg/m^3) exceeded the indoor exposure levels. This is evidence that in this neighbourhood of Hlalanikahle, according to the current discoveries there is no association between indoor and outdoor exposure concentrations. This finding was further concluded by the statistical results which showed that the result was significant at p=0.01 for Hlalanikahle.

This observation is incongruent from the summer season articulated in Figure 3. As the winter observations in Hlalanikahle proved to be significant (p=0.01). With higher concentrations recorded indoors instead of outdoors. A similar observation was spotted and communicated

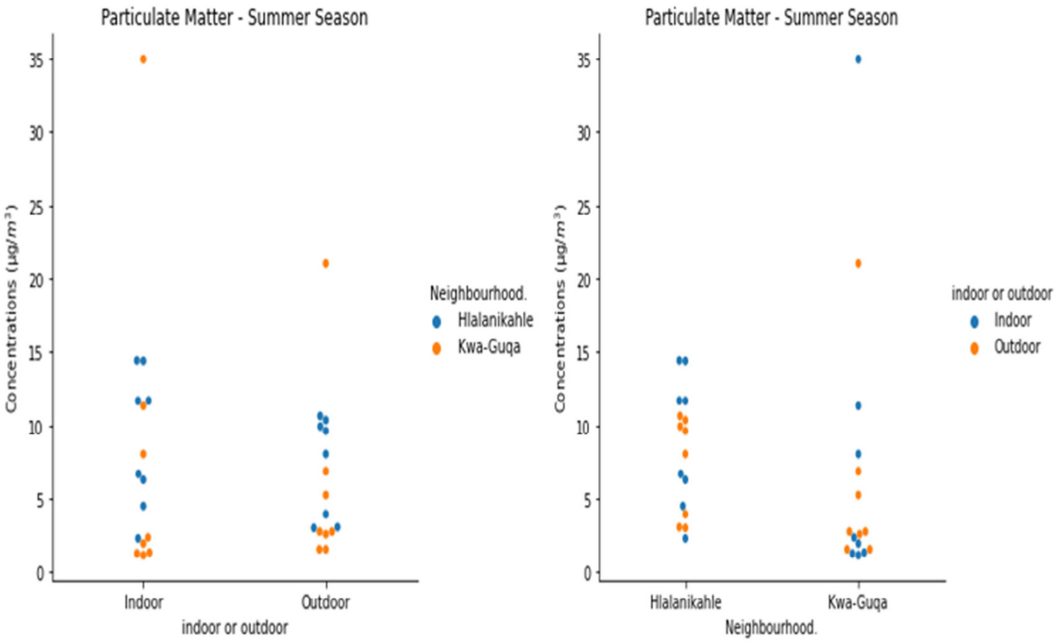

Fig. 6. $PM_{2.5}$ exposure levels for summer indoor and outdoor in Hlalanikahle and Kwa-Guqa (Kwa-Guqa) neighbourhoods

by Abdel-Salam (2021) during winter periods. Nevertheless, this observation is not startling as during winter seasons there is a relatively low air exchange rate between indoor and outdoor exposure concentration. Especially, within the Mpumalanga Province where climatic conditions that favour strong air circulation are recorded during the summer seasons (Ndletyana et al., 2023). This phenomenon is experienced due to the air circulation that increases the air exchange rate as the result of the increase of south-easterly winds (Jury, 2020). Therefore, any combustion that encourages emissions of pollutants that transpires indoors during the winter is less likely to be driven outdoors due to insignificant natural cross-ventilation as a result of low airflow circulation. For instance, to demonstrate better this phenomenon, even the usage of solid fuels as a medium of cooking in a household with poor cross ventilation may explain why the indoor concentration variable may be higher (Fullerton et al., 2009; Van Vliet et al., 2013).

Summer indoor and outdoor particulate matter exposure levels

Figure 6 below illustrates the concentration results for indoor and outdoor particulate matter. Particulate matter concentrations have indicated that observed values of 14 µg/m^3 indoors and 12 µg/m^3 outdoors are by virtue comparable levels that are relatively not far off from each other. Furthermore, the comparability of the variables of indoor and outdoor concentrations in terms of being relatively comparable is validated by the statistical significance of independent variables. The statistical significance indicated that there is no difference between indoor and outdoor exposure concentrations in Hlalanikahle since the p-value (0.43) is greater than the level of significance (0.05). However, in Kwa-Guqa, the exposure concentrations between indoors and outdoors were incomparable. For instance, the exposure levels indoors were about 12 µg/m^3 whilst the ambient concentrations were limited to 8 µg/m^3. Thus, the average I/O ratio was above 1 (1.3). However, be as it may statistical significance similarly indicated that the indoor and outdoor exposure concentrations are the same (p=0.64).

Winter exposure concentrations

According to the demonstrations below (Figure 7) the levels of particulate matter ambient

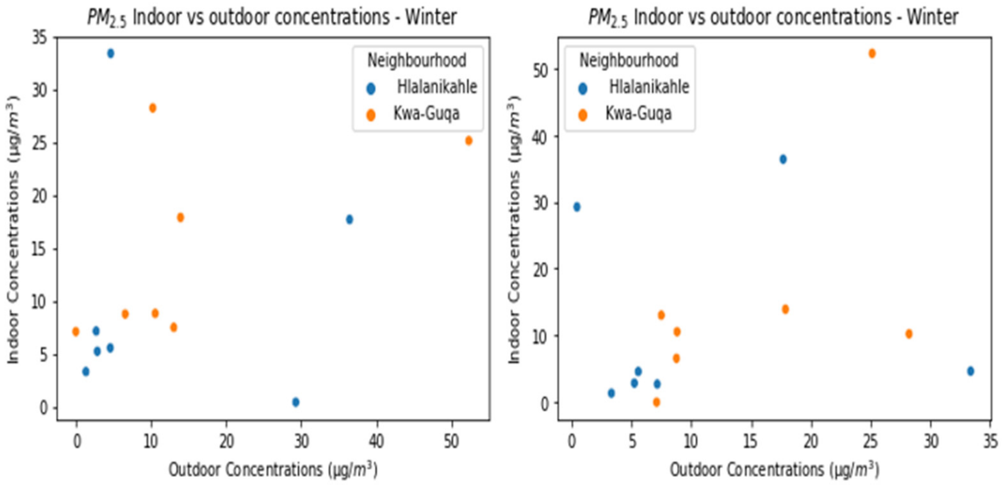

Fig. 7. Indoor and outdoor behaviour of winter particulate matter

air concentration appear to be slightly higher (38 μg/m^3) than the concentrations recorded indoors (34 μg/m^3) in Hlalanikahle neighbourhood. While in Kwa-Guqa a dissimilar trend was recorded. In this neighbourhood, the particulate matter behaviour during winter indicated that more than double the exposure concentration of the pollutants of concern was indoors (28 μg/m^3). While ambient levels were relatively low (12 μg/m^3). However, despite some differences in terms of levels of exposure in both neighbourhoods of Kwa-Guqa and Hlalanikahle, the statistical significance highlights that there is no significant difference between indoor and outdoor exposure levels for particulate matter. That is the exposure levels of particulate matter and nitrogen dioxide indoors and outdoors are relatively the same. Furthermore, similarly to the summer seasons the calculated Indoor/Outdoor ratio was well above 1 (1.08) indicating that indoor air quality is influened by ambient air pollution sources.

In addition, indeed in Kwa-Guqa, elevated exposure concentrations of particulate matter were reported indoors to be double in value in juxtaposition to the outdoor exposure levels during the winter season. This behaviour of particulate matter pollutants is not foreign as a similar trend has been reported elsewhere by Agbo et al. (2021). Consequently, Agbo et al. (2021) allude that "this is expected and attributable to dilution occasioned by dispersion and mixing of air pollutants in the atmosphere and by the emission intensity of indoor sources". Likewise, the seasonal contrasting elevated ambient air concentration documented in these neighbourhoods of particulate matter and nitrogen dioxide during winter could be attributed to the abundance of vehicular traffic emissions as well as other indoor anthropogenic activities associated with the combustion of fuels. However, the absence of documenting the source types of indoor and outdoor exposure is some of the numerous limitations that have been identified in this pilot study. In addition to the limitations is the lack of quantification practices that measure the airflow circulation between indoors and outdoors which greatly influences the exposure levels. Despite these limitations, it is essential to note that overall, indoor exposure level concentrations of Hlalanikahle and Kwa-Guqa do not pose any health risks when compared to the indoor air quality guidelines in Table 2.

CONCLUSION

The current study has discovered that in many instances despite the weather seasons the statistical significance highlights that there is no significant difference between indoor and outdoor exposure levels of pollutants between Hlalanikahle and Kwa-Guqa neighbourhoods.

However, this was not always the case throughout the entire seasons. As in some instances, observations proved to be significant indoors and outdoors, especially during winter seasons. This could be attributed to a relatively low air exchange rate between indoor and outdoor exposure concentration. Especially within the Highveld in Mpumalanga province where climatic conditions that favour strong air circulation are recorded during summer seasons. Furthermore, it is important to note that given the number of limitations associated with the current study such as the failure to quantify the fuel types as well as the airflow exchange rates within the monitored households, it is difficult to conclude if outdoor exposure concentrations of formal and informal structural households influence indoor air quality. Thus, having laid a foundation, the current study calls for future holistic studies that will cover this gap.

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CONFLICTS OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

INSTITUTIONAL REVIEW BOARD STATEMENT

This paper does not contain any studies involving human participants or animals performed by any of the authors.

INFORMED CONSENT STATEMENT

Not applicable.

DATA AVAILABILITY STATEMENT

The data presented in this study is available on request from the corresponding author.

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