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Contents

2019 Annual Conference of the National Association for Clean Air

Save the Dates and Call for Papers

Date 3 - 4 October 2019

Venue Protea Hotel Marriott Stellenbosch Technopark Western Cape

The 2019 Conference of the National Association for Clean Air will again be held back-to-back with the Department of Environmental Affairs' Air Quality Governance Lekgotla.

The 2019 Annual NACA Conference will start with the joint DEA and NACA Multi-Stakeholder Workshop on Thursday morning, followed by lunch.

After lunch, the NACA Conference will continue with an opening address by the NACA President, feedback from the 14th Air Quality Governance Lekgotla and the presentations of reviewed papers. The day will end with the traditional NACA Braai, overlooking the picturesque Stellenbosch vineyards and Hottentots Holland Mountains.

Day two of the conference will get off to an early start and is expected to end at five o'clock on Friday afternoon.

2018 Conference Rates

NACA Member Early Bird Fee Until and due by 1 September 2019	R5 000.00 (Excl. 15% VAT)
Government Rate Early Bird Fee Until and due by 1 September 2019	R5 000.00 (Excl. 15% VAT)
Non-NACA Member Early Bird Fee Until and due by 1 September 2019	R6 000.00 (Excl. 15% VAT)
* Student Fee Until and due by 1 September 2019	R3 500.00 (Excl. 15% VAT)
Standard Conference Fee From 2 September 2019 onwards Due before the start of the conference	R6 500.00 (Excl. 15% VAT)

* Note on Student Fee: Any person registered at a recognised South African University or University of Technology qualifies for the Student Fee. A copy of a valid student card must be loaded to the registration system or e-mailed to the organisers to qualify for this rate.

CALL FOR PAPERS

The Organising Committee of the 2019 NACA Conference invites submissions of papers for the annual conference. Presenters are requested to register and submit their abstracts on the electronic submission and evaluation system. Guidelines for papers and posters will be made available on the conference page of the NACA website.

Abstract submission
6 May 2019

Notification of acceptance of abstracts
10 May 2019

Full papers due
15 July 2019

Notification of acceptance and comments on papers
29 July 2019

Authors resubmit papers if required indicating how reviewers' comments were addressed
12 August 2019

Reviewers indicate whether comments were sufficiently addressed
19 August 2019

Submission of final papers for inclusion in the electronic conference proceedings
26 August 2019

Exhibitions

The 2019 NACA Conference will again feature an exhibition. The opening of the exhibition will coincide with the opening of DEA's 14th Air Quality Governance Lekgotla on Tuesday, 1 October 2019. All NACA members will be advised as soon as the Exhibition Prospectus is available.

CONFERENCE WEBSITE & REGISTRATION OPENS MONDAY 29 APRIL 2019
www.naca.org.za

Editorial
Celebration of the 80th Issue

Gregor Feig, Rebecca Garland, Kristy Langerman, Caradee Y. Wright, Gerrit Kornelius
Editors and former Editors

https://doi.org/10.17159/2410-972X/2019/v29n1a9

In celebration of the 80th issue of the Clean Air Journal (CAJ) it is worth looking back on where the Journal started and where it provides value to the African air quality research, and air quality management communities.

The first issue of the CAJ was published in 1971 when air quality management was governed in South Africa by the newly promulgated Air Pollution Prevention Act (APPA) of 1965. The first articles published largely focused on the difficulties of coming to terms and complying with a new regime of air quality management. The lead article by the Chief Air Pollution Control Officer (Boegman, 1971) described the difficulties in implementing the APPA. Difficulties in the implementation of smoke control programmes were discussed (Tucker, 1971) while the occupational health concerns of air pollution in South African industrial settings were discussed by the State Health Department (van Rooyen, 1971). On a more optimistic note, the manager of the Vegetation Unit of the Chamber of Mines opined on how the covering of the mine dumps around Johannesburg would provide valuable open space for recreation and other activities (Cook, 1971). These themes of implementing an air quality management regime, addressing the technical aspects of means of reducing air pollution, and the health and environmental impacts of air pollution have continued through the last 80 issues.

The CAJ has in 80 issues (over nearly 50 years) provided a space to engage with the major air quality management issues in South Africa, and has served as a vehicle for the air quality research and management communities to discuss their findings, raise questions and build their knowledge. The CAJ has been able to maintain a high quality of publications from its earliest editions. This has all been done through the voluntary work of a small number of editors, the efforts of the research and management communities, and the dedication of reviewers.

We have recently focused on increasing the visibility and number of articles published, and on ensuring the quality of the articles published. This has been done through improving the publication procedures and has been rewarded through recognition by SCOPUS, SciELO-SA and the DHET. These are achievements of which we are immensely proud.

Moving forward, the scope of the CAJ has broadened to a continental focus. Across the continent, there is a tremendous amount of development with high rates of economic growth and rapid urbanisation. This presents an opportunity for a Journal that is based in Africa and that is focused on the air quality concerns and needs of the African continent.

References

Boegman, N. (1971) 'Problems in the application of Part II of the Atmospheric Pollution Prevention Act (45), 1965', *Clean Air Journal*, 1(1), pp. 9–11.

Cook, B. (1971) 'Growing vegetation on mine residue dumps', *Clean Air Journal = Tydskrif vir Skoon Lug*, 1(1), pp. 21–26.

Rooyen, V. (1971) 'Atmospheric Pollution in special Environments', *Clean Air Journal = Tydskrif vir Skoon Lug*, 1(1), pp. 27–33.

Tucker, L. E. (1971) 'Practical difficulties in implementing a smoke control programme', *Clean Air Journal*, 1(1), pp. 12–20.


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Generation Division

Message

Message from the NACA President

Prof Stuart Piketh

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https://doi.org/10.17159/2410-972X/2019/v29n1a5

In 2018 NACA celebrated its 50th anniversary. During this period, NACA has contributed in a significant way to promote clean air in communities around South Africa. This has not always been an easy task. The passing of the National Environmental Management: Air Quality Act in 2004 has seen a step change in air quality management. NACA provided insightful inputs to the legislation setting process, subsequent amendments and revisions as well as the implementation of this legislation.

An important function of NACA is to ensure that stakeholders in air quality have access to relevant information, and education and training opportunities. To this end, NACA has five important activities that actively strive to create an environment of informed and engaged dialogue in South Africa. The activities include: 1) the National Association for Clean Air annual conference, 2) on-going workshops and seminars around the country organised by our regional branches and council, 3) outreach programs, 4) training courses in aspects related to air pollution and air quality management, and finally 5) the publication of the Clean Air Journal.

The annual conference was held in Vanderbijlpark in 2018 (30 October – 1 November 2018). As we have come to expect we had a successful conference at which 29 papers of high quality were presented in themes that included air pollution policy and legislation, dust and other related topics, modelling, and emissions and air pollution monitoring. The conference was well supported by delegates from government, industry and academia as well as exhibitors and provided a fabulous forum for discussion and debate. In 2019 the conference will be held in Stellenbosch (3-4 October 2019) in conjunction with the Department of Environmental Affairs annual Lekgotla. It is our objective for this year to ensure that all stakeholders are represented at this conference.

Workshops and seminars remain an important forum for engaging with interested and affected communities. This will continue in 2019. The first seminar was held in Cape Town and a joint workshop with DEA was hosted in Johannesburg on 11 April 2019 – Emission reduction options relevant to South Africa. NACA will embark on an outreach program to schools in South Africa in 2019. The outreach material is in the process of being developed. It is envisaged that NACA members will host information sessions at selected schools in different provinces. Details will be announced on the NACA website (www.naca.org.za).

Training air pollution practitioners has been a key focus of the Association over the past decade. In 2019 courses will focus on introduction to air pollution and dispersion modelling courses. Details of these courses can also be found on the website.

The Clean Air Journal is the premier place to publish air pollution-related research in South Africa and is actively expanding its focus to the entire continent. The journal has an independent editorial board which NACA will continue to support to ensure a high-quality publication.

News

First WHO Global Conference on Air Pollution and Health: A Brief Report

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The subject conference (documented in www.who.int) was organized by WHO in collaboration with WMO, CCAC, UNFCC, UNECE, The World Bank, UN-DESA and EU-DEVCO in Geneva, Switzerland from 30 October to 01 November 2018. The conference focus was Saving Lives through improvement of Air Quality and Combatting Climate Change. This was motivated by the voluminous and scientifically informed global evidence on the negative impact on human health that is contributed by air pollution and climate variability.

The conference was organised in ten Plenary Sessions, three Parallel Sessions composed of nine sub-sessions and two Side Events of six sub-events. The pace of the conference was set in Plenary Session I where presentations on scientific evidence on ambient and household air pollution and the connection to climate change were articulated. A moving evidence was delivered in Plenary V by Professor Arvid Kumar, Chairman of Centre for Chest Surgery, Director of the Institute of Robotic Surgery at Sir Ganga Ram Hospital, Founder Trustee of Lung Care Foundation in New Delhi and President Elect of the Association of Surgeons of India. In his presentation titled “Doctors as active advocates for clean air” he graphically presented a comparable condition of a lung from a non-smoker to one of a smoker as convincing evidence of the impact of air pollution in New Delhi, India.

The Parallel Sessions had topics covering air quality, health effects, air pollution and climate change links; engagement of global stakeholders; and action with a health focus. Three of the major highlights were: (1) the impact of ambient and household air pollution on children, and how interventions to clean the air can support child health and development; (2) air pollution as a major risk factor for cancers and why its mitigation can reduce the epidemic non-communicable diseases; and (3) the high threat to the lives of urban populations considering that currently 50% of the global population lives in cities and this will increase to 70% by 2050. The main highlights of the side events were: (1) major household pollutants besides particulate matter; (2) critical need for improved energy access in sub-Saharan Africa; and (3) the scale and relative severity of the health and economic impacts of local air pollution.

Apparently in Plenary Session X and during the “Roundtable and the launch of new initiatives/pledges/partnerships and commitments by countries, cities and organizations”, while there were strong commitments and substantial pledges from the North, the commitments from the Africa region were only from Egypt, Morocco, Mozambique and Uganda. However, Ethiopia, Burundi, Ghana, Kenya, Nigeria, South Africa, Sudan and Uganda participated in presentations.

The author encourages regional air quality stakeholders and policymakers to visit www.who.int and read the documented information.

Acknowledgements

The International Science Programme, at Uppsala University in Sweden, is appreciated for helping with travel grant.

News

Marine atmospheric chemistry research on the South African ice-breaker, the R/V *SA Agulhas II*

Katye Altieri[1,2] and Shantelle Smith[1]

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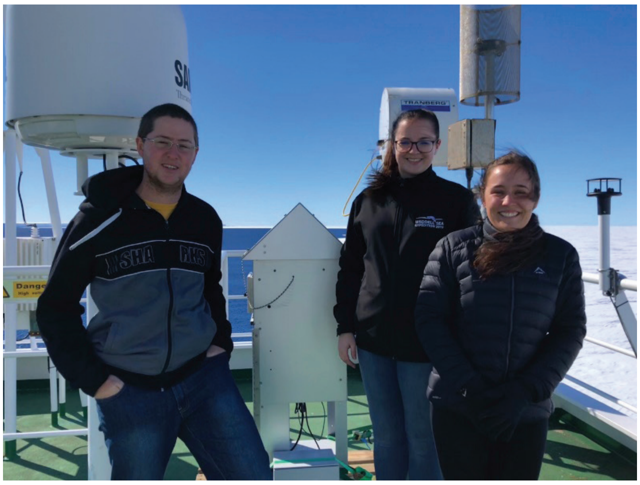
https://doi.org/10.17159/2410-972X/2019/v29n1a6



UCT postgraduate students Kurt Spence, Shantelle Smith, and Jessica Burger (left to right) next to the size-segregated aerosol sampler aboard the R/V SA Agulhas II *in the Southern Ocean.*

South Africa has a unique geographic advantage that affords regular access to the Southern Ocean, as well as a technical advantage in the Department of Environmental Affairs-owned state-of-the-art ice-breaker, the R/V *SA Agulhas II*, as an integrated research and training platform. Atmospheric chemistry research in South Africa has the potential to leverage these advantages and make significant contributions to the rapidly integrating Earth systems science (terrestrial-atmospheric-oceanic-ice) and climate change research space.

Recently, a group of University of Cape Town (UCT) postgraduate students studying Oceanography and Atmospheric Sciences had the opportunity to participate in the 58th South African National Antarctic Expedition (SANAE 58) and the international 2019 Weddell Sea Expedition (WSE) (https://weddellseaexpedition.org). The R/V *SA Agulhas II* left Cape Town on December 6, 2018, voyaged 11 000 km, and returned on March 15, 2019. M.Sc. students Kurt Spence and Shantelle Smith and Ph.D. student Jessica Burger, members of Dr. Katye Altieri's marine atmosphere biogeochemistry research group at UCT, led the atmospheric chemistry research campaign on the ship. Size-segregated aerosol samples were collected daily using a cascade impactor, while an Ambient Ion Monitor-Ion Chromatograph (AIM-IC) system measured hourly gas-phase (ammonia, nitric acid, sulfuric acid) and aerosol-phase (sodium, chloride, nitrate, sulfate, ammonium) concentrations. The students returned with ~220 aerosol filters to extract and analyze, and 600 hours of AIM-IC data to process.

This campaign was just the first of many atmospheric chemistry research opportunities afforded by the R/V *SA Agulhas II* and the NRF's South African National Antarctic Programme (SANAP). The Southern Ocean Seasonal Experiment (SCALE; www.scale.org.za), funded by the Department of Science and Technology, will take place in 2019 with dedicated science cruises planned for winter and spring, and SANAE 59 is scheduled for the summer of 2019/2020. In addition to Dr. Altieri's research group from UCT, these cruises will include international partners from Plymouth Marine Laboratory and GEOMAR measuring volatile organic compounds, dimethylsulfide, isoprene, and other trace gases. There are opportunities to join the exciting atmospheric chemistry research happening on the R/V *SA Agulhas II* through SCALE or future research cruises.

Contact Dr. Katye Altieri at UCT (katye.altieri@uct.ac.za) if you are interested in learning more. Also check out SOLAS (the international surface ocean lower atmosphere study; www.solas-int.org) and CATCH (the cryosphere and atmospheric chemistry; www.igacproject.org/activities/CATCH) for information on summer schools, workshops, and more.

News

Sixth Global Environmental Outlook report calls for scaling up environmental protection

Caradee Y. Wright
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https://doi.org/10.17159/2410-972X/2019/v29n1a3

GEO-6 authors who wrote a case study on the circular economy for Chapter 17 (page 439) of the GEO-6 report including Dr Caradee Wright (far left) and Dr Linda Godfrey (far right) from South Africa.

On the 13 March 2019, the United Nations Environment Programme released the sixth Global Environmental Outlook (GEO-6) report in Nairobi, Kenya. After 5 years of hard work by 250 scientists from more than 70 countries, the comprehensive assessment was launched as the latest evidence on 'the environment under review'.

The theme of GEO-6 is 'Healthy Planet, Healthy People' and the report warns that 'human health is in dire straits if urgent actions are not made to protect the environment'. Water pollution, air pollution, food waste and plastic pollution in the oceans were among many of the pressing challenges identified in the report. An innovative way of thinking was proposed that shifts the current model of 'grow now, clean up after' to a 'near-zero-waste economy by 2050' model if the world is to achieve the Sustainable Development Goals.

Several South African scientists, including Caradee Wright (South African Medical Research Council), Linda Godfrey and Nadia Sitas (Council for Scientific and Industrial Research), Babatunde Abiodun (University of Cape Town), Pali Lehohla (Pan African Institute for Evidence), Rowena Hay (Umvoto), and Laura Pereira (Stellenbosch University) contributed as authors to the GEO-6 report. South Africa case studies also appear in the GEO-6 report including rhinoceros poaching as an example of overexploitation, and acid mine drainage as an impact of mining.

Writing meetings were held annually in different countries where authors gathered to pull together the evidence on five environmental themes, namely, air, biodiversity, oceans and coasts, land and soil and freshwater. Part A of the report describes the current state of the global environment by these environmental themes followed by Part B that analyses the effectiveness of policies, goals, objectives and environmental governance in relation to the same environmental themes. Part C then looks forward to what is required for a Health Planet with People and emphasizes future data and knowledge needs.

South Africa can garner important learnings from the GEO-6 report. Environmental resources and ecosystems are key to public health and we must find ways to use science, technology and finance to move along a sustainable development pathway. This requires support from communities, business and governments. Furthermore, South Africa needs to collect environmental statistics to help advance knowledge using big data and work collaboratively between public and private partners to find solutions.

The GEO-6 report is available online: www.unenvironment.org/resources/global-environment-outlook-6

Book review

Gary Lackmann's book *Midlatitude Synoptic Meteorology: Dynamics, Analysis* and *Forecasting and Synoptic-Dynamic Meteorology Lab Manual*, by Gary M. Lackmann, Brian E. Mapes and Kevin R. Tyle

Willem Landman
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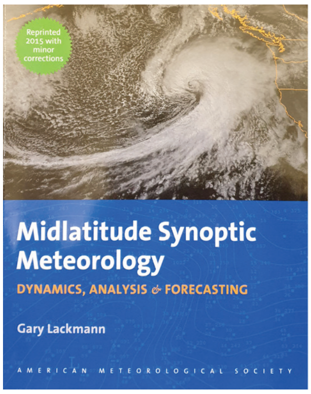
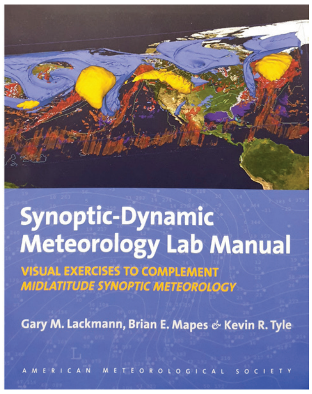
https://doi.org/10.17159/2410-972X/2019/v29n1a11

The study of atmospheric motions as solutions of the fundamental equations of hydrodynamics, or better known by students in the atmospheric sciences as dynamic meteorology, is a complex and challenging theoretical subject. The book by Lackmann is primarily on synoptic analysis, including manual analysis, and on weather forecasting with a target audience of anyone interested to find out more about the dynamics of atmospheric motion. However, an undergraduate level knowledge of meteorology and mathematics will come in handy. This book certainly is not the only good one on synoptic analysis and forecasting, but what makes it quite different from most other such books is the emphasis put on *application* of theoretical concepts and the human weather forecast process. There is also a technical manual that presents visual exercises and introduces powerful visualization capabilities through open source, free software that can run on all contemporary computer operating systems.

The Lackmann book primarily attempts to bridge the gap between text book theory and weather analysis and forecasting. After an introductory chapter on the basic concepts of dynamic meteorology, the book covers topics that are often enjoyed by meteorology students such as the quasi-geostrophic theory. In addition to case study examples, the book also emphasizes practical weather forecasting and how to best apply numerical weather prediction models in a forecast process. Through discussion of sophisticated numerical weather prediction models, experiments are presented, and data assimilation and ensemble prediction are introduced. A chapter on an atmospheric process analysis tool that has only fairly recently become popular among dynamic meteorologists called potential vorticity is comprehensively addressed in a dedicated chapter. Detailed discussions, always accompanied by real observed and/or model data, on synoptically driven mesoscale phenomena, extra-tropical cyclones, frontogenesis and types of fronts, and baroclinic instability (arising from the existence of a meridional temperature gradient) are all well presented.

The book and its manual only cover mid-latitude synoptic-dynamic meteorology and do not cover tropical meteorology.





Although there are strong interactions between tropical and extra-tropical circulation systems, tropical systems can be less often dealt with using, for example, the quasi-geostrophic techniques presented in the two books. The books also focus entirely on the Northern Hemisphere. From a southern African perspective, the books have limited application for areas where weather systems are of a predominantly tropical nature. Moreover, students and the broader atmospheric science community of the region will have to make the conversion to Southern Hemisphere circulation first to obtain maximum benefit from these wonderful books.

Research brief
South African Highveld concentrations of outdoor Total Gaseous Mercury

Belelie MD[1], Piketh SJ[1], Burger RP[1], Naidoo M[2]
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It is well-known that the Highveld is one of the country's poorest air quality regions. This is due to the abundance of anthropogenic activities such as coal-fired power plants, mining, and cement production among others. The formerly mentioned source is regarded globally and has been extensively studied as the leading source of ambient mercury. Mercury is recurrently oxidized and reduced between its environmental forms. Methyl-mercury poses adverse effects on humans if inhaled/consumed in excessive amounts. In this research, the authors conducted a first-ever characterization of total gaseous mercury (TGM) concentrations over the Highveld region.

We evaluated concentrations of the pollutant at three characteristically different sites (Balfour, Middelburg, and Standerton). Datasets spanning 2009–2013 for each site were obtained from the Mpumalanga Department of Agriculture, Rural Development, and Land and Environmental Affairs. For data investigation and manipulation purposes, we only considered data pertaining to 2009.

In general, measured concentrations were within the Northern Hemisphere range of 1.5–1.7 ng/m^3 and 1.2-1.4 ng/m^3 observed at Cape Point, South Africa. The seasonal variation between sites suggests that meteorology had a profound influence on TGM concentrations. Diurnally, no profound variations were observed at Balfour and Middelburg and this may be ascribed to sparse regional sources. At Standerton, however, the observed diurnal variation suggests a significant influence from local domestic coal combustion.

Coal-fired power plants, the foremost source of TGM, appeared to have little to no effect on measured concentrations. This does not imply that it should be discarded as the leading source of the pollutant in the country, but rather highlights the importance of meteorology in regulating spatial and temporal change in concentrations. Additional studies in the immediate vicinity of coal-fired power plants are needed in order to quantify the specific contribution from this source. This study aims to serve as a baseline from which future changes can be measured.

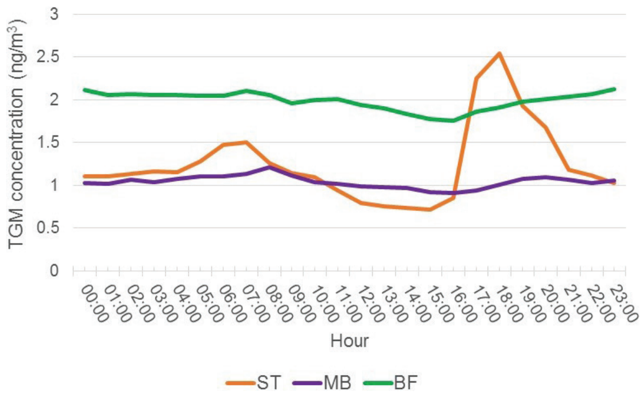

Figure 1: *Mean diurnal variation in TGM concentrations (ng/m^3) at Balfour (BF), Middelburg (MB), and Standerton (ST) during 2009.*

Reference

Belelie MD, Piketh SJ, Burger RP and Naidoo M. Characterisation of ambient Total Gaseous Mercury concentration over the South African Highveld. Atmospheric Pollution Research 2019;10:12-23.


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Research brief

Indoor Particulate Matter Concentration Variations and Associations with Indoor/Outdoor Temperature in Rural Limpopo

Thandi Kapwata*[1], Brigitte Language[2], Stuart Piketh[2] and Caradee Y. Wright[3,4]

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The World Health Organization (WHO) reports that, worldwide, approximately 50% of all households and 90% of rural households burn solid fuels as a primary source of energy. In South Africa, data collected during a national census showed that a high proportion of the population use wood, coal or animal dung as fuel for cooking and space heating, the majority of whom reside in rural areas. During the combustion of solid fuels indoors, high concentrations of particulate matter (PM) are released inside the dwellings. Therefore, occupants are exposed to significant health risks that result from personal exposure to PM. This study assessed indoor air quality in rural Giyani, situated in the Limpopo province of South Africa, by monitoring indoor PM_4 concentrations, temperature and relative humidity. These were recorded daily in summer (February), spring (September) and winter (July).

Measured PM_4 concentrations displayed seasonal variation with concentrations being higher in winter compared to spring and summer (Figure 1). Increased burning/heating activities during winter periods leads to increased ambient concentrations that are contributing to increased levels of PM exposure indoors. Reduced ventilation by closing windows and doors to keep warm during winter also likely trapped PM_4 inside thus increasing the indoor concentrations. Daily indoor PM in winter and spring exceeded concentration standards and guidelines, namely South Africa's National Ambient Air Quality Standards (NAAQS) and those of the WHO. A distinct diurnal pattern in PM concentrations was observed during the study period with peaks occurring in the early mornings and evenings. These coincided with the times of the day during which combustion for cooking and space heating usually occurred. Results also showed that measured indoor temperatures were extremely high. Household occupants are therefore vulnerable to heat-related illnesses due to exposure to elevated temperature.

Our results suggested a strong seasonal variability in PM_4, with diurnal variability being highest in winter. Also, exposure to peak PM_4 values largely occurred during winter due to the high indoor PM_4 concentrations. Conversely, during summer, indoor temperatures exceeded thresholds recommended by epidemiological studies therefore occupants were at risk of negative health effects caused by high temperatures. These include the onset of heat-related illnesses as well exacerbation of existing chronic health conditions. Study findings suggest that intervention is required to reduce the use of biofuels indoors as well as community-level policies, education programmes and other relevant initiatives relating to awareness of heat-health outcomes.

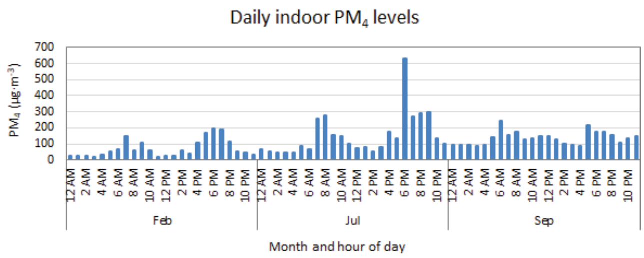

Figure 1: *Averages of hourly indoor concentrations of PM_4 during summer, winter and spring.*

Reference

Kapwata T, Language B, Piketh S and Wright CY. Variation of indoor particulate matter concentrations and association with indoor/outdoor temperature: a case study in rural Limpopo, South Africa. Int J Environ Res and Pub Health 2018, 9: 124.

Research brief
Summary of research paper published in Journal of Atmospheric Chemistry titled: Assessment of polar organic aerosols at a regional background site in southern Africa

Wanda Booyens[1], Johan P. Beukes[1], Pieter G. Van Zyl[1], Jose Ruiz-Jimenez[2], Matias Kopperi[2], Marja-Liisa Riekkola[2], Miroslav Josipovic[1], Ville Vakkari[3], Lauri Laakso[1,3]
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A recent paper reported GCxGC-TOFMS analysis used for the first time in southern Africa to tentatively characterise and semi-quantify ~1 000 organic compounds in aerosols at Welgegund – a regional background atmospheric monitoring station (Booyens et al., 2015). This was considered to be the largest number of ambient organic compounds tentatively characterised in atmospheric samples utilising GCxGC-TOFMS. In this new paper, ambient polar organic aerosols characterised are further explored in terms of temporal variations, as well as the influence of meteorology and sources. Organic aerosols in southern Africa are affected by globally important sources, which include (primary and secondary) biomass burning aerosols.

No distinct seasonal pattern was observed for the total number of polar organic compounds tentatively characterised and their corresponding semi-quantified concentrations (sum of the normalised response factors, ∑NRFs). However, the total number of polar organic compounds and ∑NRFs between late spring and early autumn seemed relatively lower compared to the period from mid-autumn to mid-winter, while there was a period during late winter and early spring with significantly lower total number of polar organic compounds and ∑NRFs. Relatively lower total number of polar organic compounds and corresponding ∑NRFs were associated with fresher plumes from a source region relatively close to Welgegund. Meteorological parameters indicated that wet removal during late spring to early autumn also contributed to lower total numbers of polar organics and associated ∑NRFs. Increased anticyclonic recirculation and more pronounced inversion layers contributed to higher total numbers of polar organic species and ∑NRFs from mid-autumn to mid-winter, while the influence of regional biomass burning during this period was also evident. The period with significantly lower total number of polar organic compounds and ∑NRFs was attributed to fresh open biomass burning plumes occurring within proximity of Welgegund, consisting mainly of volatile organic compounds and non-polar hydrocarbons.

Temporal variations observed could not be related to a specific influencing factor, but rather seemed to depend on a combination of the influences of source regions and meteorology. Multiple linear regression analysis substantiated that the total numbers of polar organic compounds and associated semi-quantified concentrations were related to a combination of the influence of these factors and the occurrence of wild fires within close proximity of Welgegund.

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Research article

The potential for domestic thermal insulation retrofits on the South African Highveld

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Abstract

The South African Highveld is a portion on the inland plateau characterized by low winter ambient temperatures. Studies done in several climatic regions around the world have found a positive relationship between inadequate housing and low indoor temperatures during the winter season. Prolonged exposure to low indoor temperature is a threat to human physical health. This study characterizes indoor human thermal comfort conditions in typical low-income residential dwellings during the winter season. Mapping indoor human thermal comfort can assist in exploring the potential for domestic thermal insulation retrofits interventions. In-situ temperature measurements were done in 2014, 2016 and 2017 across three Highveld settlements of kwaZamokuhle, kwaDela, and Jouberton. The sample included a mixture of old (pre-1994), post 1994 Reconstruction and Development Programme (RDP) as well as non-RDP structures. Findings were that 88% of sampled dwellings in Jouberton 2016, 86% in Jouberton 2017, 62% in kwaDela and 58% in kwaZamokuhle had daily mean temperatures below the WHO guideline of 18°C. These low indoor temperatures indicate poor insulation in these sampled dwellings. Across all settlements, insulated dwellings had higher daily mean indoor temperatures than non-insulated dwellings. These findings indicate the potential to use thermal insulation retrofits in improving indoor thermal conditions as the majority of dwellings are non-insulated thereby exposing occupants to low indoor temperatures.

Keywords

Low-income, human indoor thermal comfort, ambient temperature, indoor temperature, solid fuels, retrofits, thermal insulation, inadequate housing

Introduction

Studies conducted in different climatic regions across the world have found a positive relationship between inadequate housing and poor indoor human thermal conditions (WHO, 2011). Wright et al., (2005), Summerfield et al., (2007) and Sakka et al., (2008) are some of the indoor human thermal comfort studies done in the European region. In South Africa one study by Naicker et al., (2017) was identified. The study focused on five low-income settlements in the city of Johannesburg. It was limited to summer months while this current study focuses on winter months. The current study fills the knowledge gap that exists in the field of human indoor thermal conditions during winter seasons. Human indoor thermal comfort is a subjective measure of peoples' satisfaction with indoor temperatures. It varies across cultures, individuals and geographical regions (Toe & Kubota, 2013; ASHRAE, 2010).

A successful house is one which is able to regulate indoor temperatures (Nicol and Humphreys, 2010). Inadequate housing has a profound negative impact on indoor human thermal comfort as well as increasing health risk exposure to occupants (Indraganti, 2010). Asthma, cross infections, respiratory infections, and excess winter mortality are some of the physical health threats that result from low indoor temperature exposure

(Anderson et al., 2012, Hui & Jie, 2014). In Europe alone, it is estimated that there are about one-quarter of a million winter deaths each year as a result of human low indoor temperature exposure (WHO, 2011). Furthermore, seasonal morbidity and mortality have been found to increase in low-income housing due to cold temperatures (Paravantis & Santamouris, 2015).

Thermally efficient housing is also a key element to dwelling energy consumption (Raja et al., 2001, Indraganti, 2010, Ponni & Baskar, 2015). Poor insulation hampers effective space heating in low-income dwellings. Indoor solid fuel burning for space heating remains a major source of household air pollution in South Africa (Nkosi et al., 2018).

Sites for this study are located on the South African Highveld where coal is abundantly used for space heating (Nkosi et al., 2017, Nkosi et al., 2018). Household coal burning causes degradation of both ambient and indoor air quality, thus posing a health risk to human beings (Smith et al., 2013, Language et al., 2016).

The purpose of this paper is to characterize indoor human thermal comfort environments of typical low-income residential dwellings on the South African Highveld during the winter season in accordance with WHO guidelines. Mapping indoor human thermal comfort can help establish the potential to use thermal insulation retrofits as an intervention strategy to improve low-income housing stock thermal performance. Section 2 discusses the materials and methodology used during the study.

Material and methods

Study area

Figure 1 represents the sampling sites where indoor temperature measurements were done. kwaZamokuhle and kwaDela are located in Mpumalanga province and fall under the Highveld Priority Area (HPA). The HPA is a region on the Highveld identified for high air pollution from both domestic and industrial sources. (Department of Environmental Affairs (DEA), 2011). Domestic solid fuel burning remains a significant source of fine particulate matter on the HPA (DEA, 2011). Jourbeton (located in North-West province) is situated on the Highveld region but is not under the priority area jurisdiction. Winters on the Highveld are mild and dry, but cold at night when frost may occur (DEA, 2011). Cold nights motivate households to use solid fuels for space heating contributing to the deterioration of both indoor and ambient air quality.

Instrumentation and data collection procedure

Indoor and ambient air temperature measurements were done using Thermochorn iButton DS1922L sensor loggers. In order to complement the study ambient air temperature measurements, extra data were obtained from the nearest South African Weather Service weather stations. (Jouberton, Klerksdorp station, kwaDela, Ermelo station and kwaZamokuhle, Ermelo station).

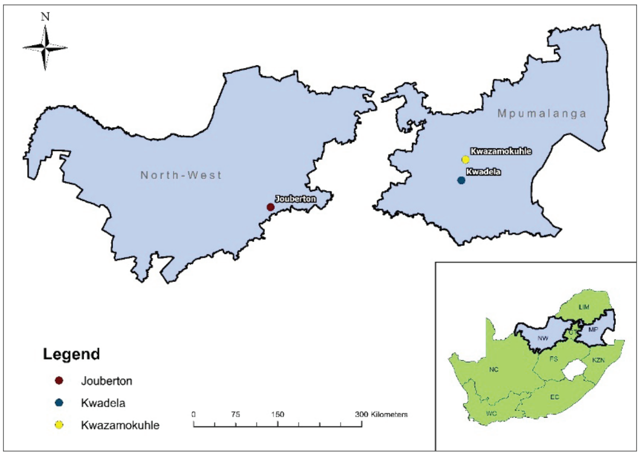


Figure 1: *Study sites in Mpumalanga and North West Provinces of South Africa*

Loggers were programmed to collect data over a 24hr period at 30-minute intervals. Monitoring periods are highlighted in Table 1. DS1922L sensors measure a temperature range of -40°C to +85°C at a resolution of ±0.5°C and are tested for accuracy in the laboratory by the manufacturer. Dwellings at each study site were disaggregated as follows; kwaDela winter survey - 13, Jouberton 2016 winter survey - 23, Jouberton 2017 winter survey - 8, and kwaZamokuhle winter survey– 24. Two winter surveys were done in Jouberton in 2016 and 2017 respectively in order to allow comparison over space and time. The sample included RDP government subsidy houses and non-RDP dwellings constructed pre-1994 and post 1994. The study used indoor temperatures as a proxy for determining indoor human thermal comfort levels while the relationship between ambient and indoor temperatures was used as a proxy for the level of thermal insulation.

Thermal comfort parameters

Indoor human thermal comfort is calculated using the following environmental parameters;

1. Indoor air temperature (*Ti*): Temperature surrounding the human occupants.
2. Outdoor Temperature (*To*): Average temperature of surfaces surrounding the occupant.

If indoor air temperature conditions correlate strongly with ambient temperatures, it becomes a good indicator of indoor personal exposure to occupants (Nguyen et al., 2014).

Location of temperature loggers

Indoor sensors were placed in the living room. The living room was chosen as a representative of the whole dwelling, assuming that occupants spend a considerable amount of time occupying this space. Indoor loggers were placed at approximately 1.5m above ground in accordance with ASHRAE 55-2005 and ISO 7730-2010 standards (Gallordo et al., 2016). This height was chosen in order to avoid human interruptions with the sensors.

Ambient sensors were deployed on the outside southern walls of a select number of dwellings across the settlements. The northern outside walls were avoided as these receive the majority of direct solar radiation during the day. Prolonged sensor direct sun exposure negatively influences measurements. The collected data were analysed on a daily basis for indoor variations throughout the monitoring period. Furthermore, indoor and ambient temperatures were correlated to gauge the influence of ambient temperature on the indoor temperature in order to establish the functionality of insulation material. Results of the study are discussed in section 3

Sampling was done in the winter months of June, July, and August as indicated in Table 1. These are the coldest times of the year on the South African Highveld. Winter indoor monitoring was chosen as this is the season where low-temperature exposure can be experienced.

Table 1: *Winter indoor temperature monitoring times*

Location	Year	Period	Insulated	Non-insulted	Total	Number of monitoring days
Jouberton	2017	1June - 5 July 2017	1	7	8	33
kwa-Zamokuhle	2017	17 July - 28 August 2017	10	14	24	40
Jouberton	2016	15 July - 23 August 2016	3	20	23	37
kwaDela	2014	10 July - 30 August 2014	5	8	13	19

Results

This section gives an account of the results and findings.

Indoor and ambient temperatures during the survey

Table 2 shows the daily instantaneous minimum, maximum temperature values for both indoor and ambient temperature during the surveys. The lowest ambient temperature across all study sites was recorded in Jourbeton 2017 at -3°C, while an ambient maximum of 27.5°C was recorded in Jourbeton during 2016. The lowest indoor temperature was recorded at -2°C in Jouberton in 2016 while the highest indoor temperature was recorded in kwaZamokuhle at 39°C.

Figure 2 shows daily mean indoor temperatures of all sampled dwellings for the three settlements comparing insulated and non-insulated structures. The trend established was that insulated dwellings had higher mean daily indoor temperatures than non-insulated structures across all settlements.

In kwaDela, the lowest daily mean indoor temperature recorded was 4°C in non-insulated dwellings while the highest temperature was 17°C. The lower quartile and upper quartile temperatures

Table 2: *Daily minimum and maximum instantaneous indoor and ambient temperatures*

Location	Year	Minimum °C	Maximum °C
kwaDela (n=13)	2014		
Ambient		-2	22
Indoor		4	38
Jouberton (n=23)	2016		
Ambient		-1.3	27.5
Indoor		-2	36
Jouberton (n=8)	2017		
Ambient		-3	26.5
Indoor		0.5	31
kwaZamokuhle (n=24)	2017		
Ambient		-3	22
Indoor		-1	39

were 11°C and 13°C respectively giving an interquartile range of 2°C with a median temperature of 12.5°C. On the other hand, insulated structures had the lowest indoor temperature of 17°C with the highest temperature of 23°C. The recorded lower quartile and upper quartile temperatures were19°C and 22°C respectively giving an interquartile range of 3°C.while the median temperature was 20°C.

In Jouberton 2016, the lowest indoor daily mean temperature recorded was 11°C in non-insulated dwellings and the highest mean daily temperature being 19°C. The lower and upper quartile temperatures of 15°C and 17.5°C respectively were recorded giving an interquartile range of 2.5°C with a median temperature of 16°C. For insulated dwellings, the lowest temperature was recorded at 15°C and highest at 23°C. Lower quartile was 16°C with an upper quartile of 19°C giving an interquartile range of 3°C. The median temperature was 18°C.

From the Jourbeton 2017 survey, the lowest mean indoor temperature in non-insulated dwellings was 13°C with the highest temperature of 17.5°C. The lower quartile temperature was recorded at 15°C, while the upper quartile temperature was recorded at 16°C giving an interquartile range of 1°C with a median of 15.5°C. On the other hand in insulated dwellings, the lowest temperature was 16°C and highest at 21°C. The upper quartile temperature was 19.8°C with lower quartile temperature at 18.5°C giving an interquartile range of 1.3°C. The median temperature was 18.7°C.

In kwaZamokuhle 2017, the lowest and highest mean daily temperature in non-insulated dwellings recorded was 13°C and

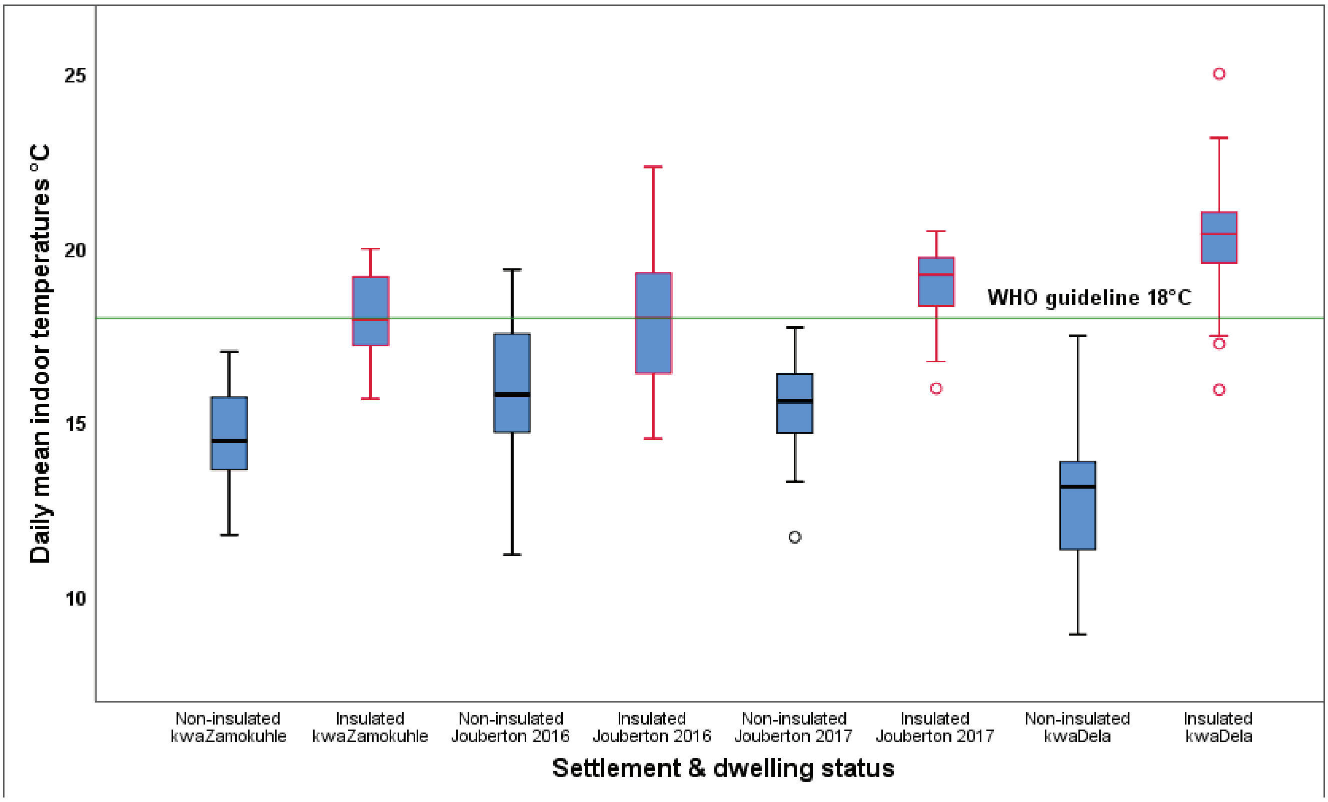


Figure 2: *Daily mean indoor temperatures across all settlements during the monitoring surveys*

17°C respectively. The upper quartile temperature recorded was 16°C and a lower quartile value of 14°C giving an interquartile range of 2°C. The median temperature was recorded at 14°C. The lowest temperature in insulated dwellings was observed at 16°C and highest temperature at 19°C. The upper quartile temperature was recorded at 19°C with a lower quartile of 17°C giving an interquartile range of 2°C. The median temperature was recorded at 18°C.

Table 3 shows a scatter plot representation of the indoor and ambient temperature relationship across the three settlements in non-insulated and insulated dwellings. For both surveys in Jouberton 2016 and 2017 non-insulated and insulated dwellings showed a strong positive correlation between ambient temperature and indoor temperature. Non insulated dwellings had a correlation of (r=0.61) and (r=0.65) for 2016 and 2017. Insulated dwellings also had strong positive correlation for both years of surveys (r=0.77) and (r=75) in 2016 and 2017 respectively.

In kwaDela, the ambient and the indoor temperature had a weak positive correlation relationship for both non-insulated and insulated dwellings. Non-insulated dwellings had a correlation of (r=0.10) while insulated dwellings had a correlation of (r=0.12).

In kwaZamokuhle, non-insulated dwellings showed a strong positive correlation between ambient and indoor temperature at (r=0.92) while a weak correlation was shown for insulated dwellings at (r=0.02).

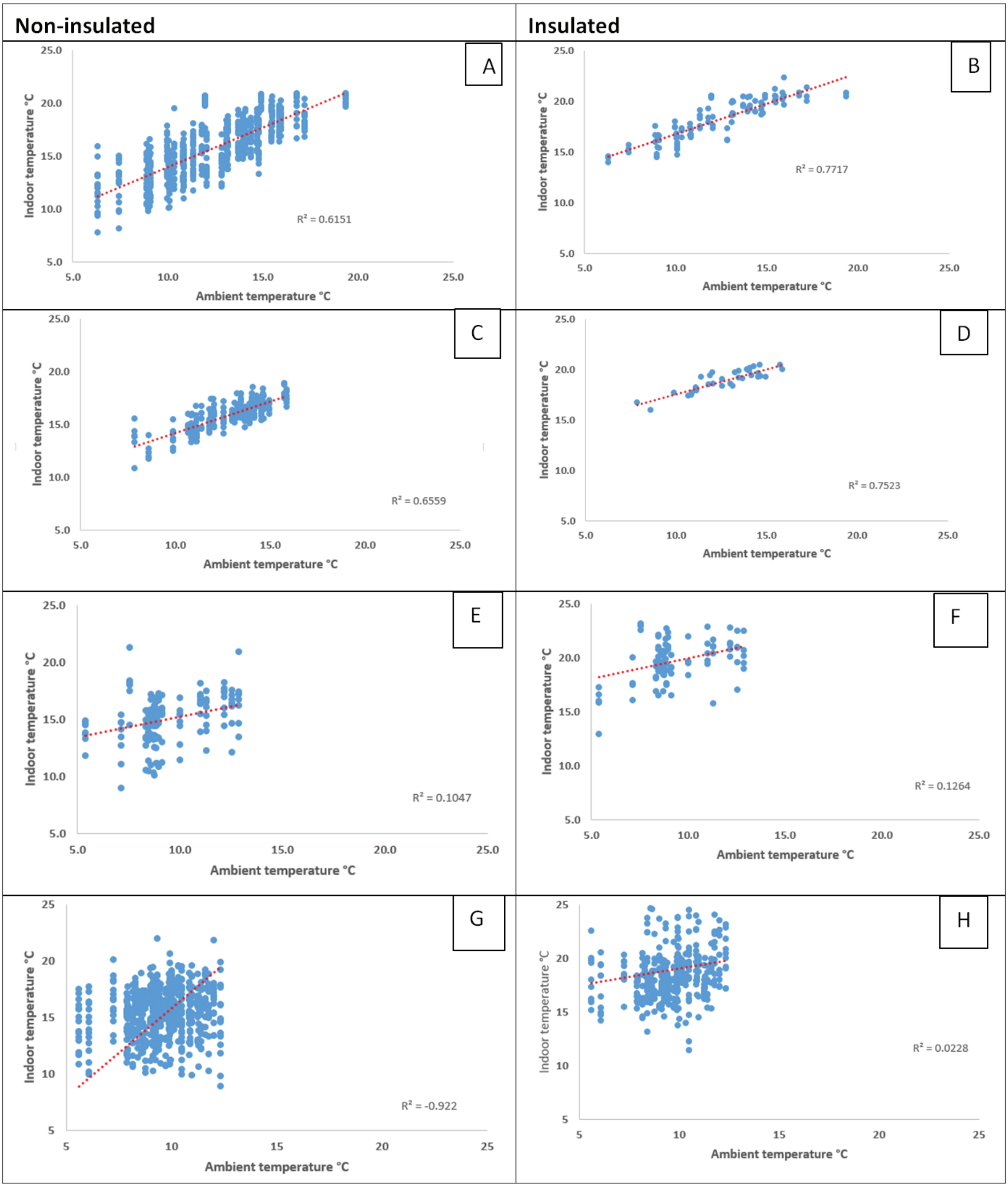
Table 4 shows the percentage representation of sampled dwellings which had mean daily indoor temperatures falling below the WHO guideline of 18°C throughout the monitoring period. The highest percentage of structures which fell below the 18°C minimum threshold was in Jourberton with 88% and 86% for 2016 and 2017 respectively. kwaZamokuhle had the least number of dwellings falling below the WHO minimum threshold of 18°C at 58% of the dwellings not meeting the prescribed guideline. From Table 3, it can be inferred that Jouberton structures are poorly insulated as compared to those in kwaDela and kwaZamokuhle.

Discussion

The study found that all non-insulated dwellings daily mean indoor temperatures fell below the WHO standard guideline of 18°C while insulated structures managed to maintain or were above 18°C. Furthermore, scatter plots correlations indicated that indoor temperature in kwaZamokuhle and Jouberton is strongly influenced by ambient temperature changes regardless of whether they are insulated or non-insulated. A comparison between insulated and non-insulated structures also found that insulated structures had warmer interiors than non-insulated at all times of the day. The ability of insulated structures to maintain higher indoor temperatures throughout the monitoring period can be attributed to their better capacity to retain internally generated heat as well as being able to retain solar heat gain during the day.

Indoor temperature recordings indicated that temperatures peaked during afternoon monitoring (10am-1pm). In free running buildings indoor temperatures are a consequence of heat gained

Table 3: *Scatter plot showing indoor and ambient temperature relationship for non-insulated and insulated dwellings*



***A**-non-insulated (Jouberton 2016)*
***C**-insulated (Jouberton 2017)*
***E**-non-insulated (kwaDela)*
***G**-non-insulated (kwaZamokuhle)*

***B**-insulated (Jouberton 2016)*
***D**-insulated (Jouberton 2017)*
***D**-insulated (Jouberton 2017)*
***H**-insulated (kwaZamokuhle)*

***Table 4:** Percentage number of dwellings with daily mean indoor temperatures of < 18°C*

Site-survey	Total (n)	% < 18°C
Jouberton winter 2016	24	86
Jourbeton winter 2017	7	88
KwaZamokuhle winter 2017	26	58
kwaDela winter 2014	14	62

from solar heating (Yohanis and Mondol, 2010). On the other hand lowest indoor temperatures were recorded during early mornings (between 1am-6am). The trend was similar for both non-insulated and insulated dwellings. Differences were however noted that the insulated structures retained higher indoor temperatures at night times compared to non-insulated structures. This is can be attributed to that non-insulated structures tend to lose heat relatively faster as compared to insulated structures.

Subsidy government RDP structures built post-1994 are single brick walled and lack plaster making heat retention difficult (Naicker et al.,2017). Significantly, the study found that indoor temperatures for dwellings in Jouberton (2016)- 88%,Jouberton (2017)-86%, kwaDela-62% and kwaZamokuhle -58% experienced mean daily temperatures of less than 18°C throughout the monitoring period. Prolonged exposure to such indoor temperatures poses a threat to human thermal comfort and physical health wellbeing especially the elderly, children and others with underlying medical conditions.

Previous studies have confirmed that exposure to low indoor temperatures increases the risk of respiratory infections and asthma attacks. In Northern Ireland, Yohanis & Mondol (2010) found that at least 80% of monitored dwellings had winter internal temperatures ranging from 15-20°C. Alevizos et al., (2013) found that winter average indoor temperatures in Greece varied between 11.7°C and 21.11°C. Minimum indoor temperatures were found to be between 5.2°C and 18.1°C. Oreszcyn et al. (2006), monitored 1600 low-income houses in low-income dwellings of England and found median temperatures of 19.1°C in living rooms during the day. Two studies in Ireland and Switzerland estimated that home retrofitting resulted in energy savings as well as positive health outcomes for occupants (Chapman et al., 2007, Chapman et al., 2009).

The three mentioned studies focused on low-income households. These findings estimate high exposure levels to low indoor temperatures that occupants of low-income dwellings in Europe experience during winter seasons. It is important to note that even though similar findings were obtained in the European studies, climatic conditions differ to those of South Africa where winter ambient temperatures do not get as low as those experienced in Greece and Northern Ireland. The common element is that the poor are exposed to low indoor especially where their dwellings are not insulated. Prolonged low-indoor temperature exposure increases the risk of respiratory infections as well as other related ailments especially for the elderly and young children.

Findings from Jouberton and kwaZamokuhle are similar to Naicker et al., (2017), which reported that RDP dwellings in Bramscheville are highly sensitive to outside temperature changes during the summer season. These are structures similar to the majority of structures sampled in this study.

The main limitation in this study is that human indoor thermal comfort is also influenced by other environmental factors such as wind speed and human factors such as clothing, age, metabolic rates, and occupant ventilation behavior practices also influence thermal comfort which was not taken into account.

Conclusions

Out of the three sites located on the Highveld, 88% of dwellings in Jouberton in 2016, 86% in 2017, 64% in kwaDela and 61% in kwaZamokuhle of sampled dwellings had indoor temperatures of less than 18°C. Such low indoor temperatures expose occupants to human health risks such as respiratory infections and asthma attacks especially young children and the elderly.

High level of dwelling sensitiveness to low ambient temperature changes was particularly observed in Jouberton and kwaZamokuhle for both insulated and none-insulated structures. Dwellings in kwaDela had a weak correlation between ambient and indoor temperatures. Low indoor temperatures in non-insulated dwellings translate to households using more energy for space heating especially solid fuels that result in air quality deterioration. The study confirmed the value of insulation in improving indoor thermal conditions in residential housing as shown by the ability of sampled insulated dwellings to maintain comfortable indoor temperatures throughout the monitoring period, as spelled by WHO standards.

All through the monitoring period insulated dwellings had higher indoor temperatures hence achieving the WHO human indoor thermal comfort guidelines while uninsulated dwellings did not meet the WHO standards. These findings suggest that there is potential for thermal insulation retrofits interventions on the South African Highveld in order to improve the indoor thermal conditions of low-income dwellings housing stock. Retrofit interventions can reduce household reliance on solid fuels for space heating consequently reducing emissions as well as yielding physical health co-benefits for occupants.

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Author contributions

Newton R. Matandirotya wrote the manuscript with support from Dirk P. Cilliers and Roloef P.Burger. Christian Pauw and Stuart J. Piketh conceived the idea for the study as well as editing the report. Bridgette Language carried out the experiment for the study and edited the manuscript.

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Research article

Assessing the impact of Eskom power plant emissions on ambient air quality over KwaZamokuhle

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Abstract

Coal-fired power plants are considered a major source of criteria air pollutants. The existence of such activities close to densely populated areas has an impact on human health and more generally on the environment. The impact of a pollutant typically depends on its residence time and the existence of background concentration levels. This study evaluates the dispersion of $PM_{2.5}$, SO_2 and NO_X emissions from Eskom power plants (Arnot, Hendrina, and Komati) located close to KwaZamokuhle Township. AERMOD was used to assess the contribution of each plant to the air quality of the township. This steady-state dispersion model was used to simulate surface concentrations (1-hour, 24-hour and annual average concentrations) on a 50km domain for 2015-2017. The modelled results together with data obtained from Eskom's KwaZamokuhle monitoring site were used to estimate the extent to which these power plants contribute to the ambient air quality of KwaZamokuhle Township. The results confirm that the power plants do contribute to concentrations of $PM_{2.5}$, SO_2, and NO_x in the ambient air of the township. However, based on a comparison between the modelled and monitored data, it was inferred that power plants are not the only significant source of these criteria pollutants. Evidence from temporal variations in the monitored data shows that domestic burning is likely the major contributor since the variability is more closely associated with burning habits. It is therefore likely that existing regulatory strategies that focus mostly on the industrial sector may not be successful in improving ambient air quality in low-income settlements like KwaZamokuhle.

Keywords

Coal-fired power plants, emissions, AERMOD, atmospheric dispersion modelling, $PM_{2.5}$, SO_2, NO_X

Introduction

Natural processes and anthropogenic activities release pollutants into the atmosphere which can be hazardous to the health of humans and the environment alike (Patrick et al. 2015). Although emissions occur at a local scale, it is possible for the impact to be observed globally; for example, emissions of carbon dioxide (CO_2). This makes atmospheric emissions an important concern that requires attention from the local to the global scale (Pretorius 2015). Emitted pollutants are exposed to different processes in the atmosphere (turbulence caused by convection and stability, wind speed and direction, mixing height and temperature) that control their dispersion and transportation. Finally, the pollutants are transformed over time in the atmosphere to form secondary pollutants. Ultimately, the surface concentration of these trace gases and particulates determine the local air quality of an area (Hunter et al. 2002).

Emissions of criteria pollutants from South Africa's coal-fired power plants are considered significant on a global scale (SA. DEA 2016; Pretorius 2015). This is ascribed to the country's heavy dependence on coal as it has several large coal reserves (Zhou et al. 2009). Von Blottnitz (2006) compared emissions from South Africa's power plants to those in Europe and established that the total emissions of criteria pollutants from South Africa's coal-fired power plants are higher than all the European countries considered.

About 80% of the country's coal reserves are located in the Highveld area; the industrial epicentre of the country. This area houses 11 of the 13 Eskom coal-fired owned power plants as well as other anthropogenic activities (a large petrochemical plant, mining and steel and metal processing facilities) (SA. DEA 2011; Muthige, 2014; Language et al. 2016). The combined impact of these activities degrades local air quality hence why the region was declared as an Air-shed priority area under the National Environmental Management: Air Quality Act (NEM: AQA) (Act no. 39 of 2004).

The impacts of poor ambient air quality are mostly experienced in low-income settlements (Hersey et al., 2014). These settlements are usually associated with high levels of poverty, poor service delivery and lack of resources (Language et al. 2016). Furthermore, they often experience a double burden, which includes poor living conditions as well as exposure to poor ambient air quality levels due to indoor and outdoor air pollution from various sources (John and Sonali 2012). This is since the majority of the people in these settlements do not earn enough to afford clean energy options, so they settle for the affordable and readily available options, for instance, wood, paraffin fuel and coal (Language et al. 2016). Additionally, these settlements are usually located in areas directly impacted by major sources of emission (SA. DEA 2016).

Pressure on the industry from governmental institutions and civil community to reduce air pollution and its carbon footprint are steadily growing (ITA 2018). This includes the emission standards as set in terms of the Air Quality Act, the carbon tax bill that will be implemented at the beginning of 2019 and the alternative energy strategies implemented by the Department of Energy to control industrial emissions (SA. DEA 2016). SA. DEA (2011) acknowledges that various studies agree that the local sources, notably domestic coal burning is responsible for high concentrations of ambient air pollution but this specific contribution has not been adequately addressed nor fully been understood.

The aim of this research is to model the dispersion of emissions of sulphur dioxide (SO_2), nitrogen oxides (NO_X) and fine particulate matter ($PM_{2.5}$), originating from three Eskom power plants, and to evaluate their possible impact on air quality of KwaZamokuhle Township. Air quality assessment is enhanced by using monitoring and modelling to evaluate the most effective emissions mitigation strategies. Therefore, a combination of AERMOD dispersion modelling and ambient air quality monitoring data have been used to achieve the aforementioned aim of this study.

Methodology

Study area

KwaZamokuhle Township is a low-income settlement located on the Highveld (26.1346S, 29.7317E) in the Mpumalanga province within the Highveld priority area. The township has three Eskom power plants within 50km; Arnot (22.5km SSE), Komati (27.3km ESE) and Hendrina (18.3km SE) (Figure 1).

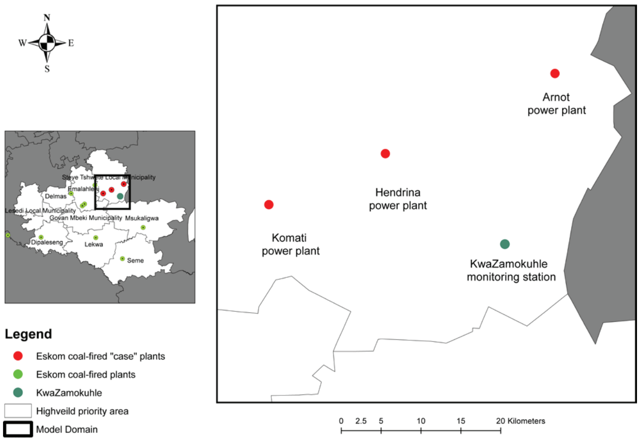

Figure 1: *Study area map showing the location of the domain, power plants and receptor used in the modelling system.*

The average monthly income of KwaZamokuhle Township is approximately R1 965 per household with an unemployment rate of 45% (STATS SA 2011). The Township is characterised by a fairly young population with a median age of 24 years (STATS SA 2011). The most common energy source used in KwaZamokuhle Township is coal with approximately 74% of the households depending on it as a primary source of energy. On average, each household uses between 141kg of coal in summer and 246kg in winter (Langerman et al. 2016).

AERMOD

Dispersion modelling is the standard method for analysing the impact of emissions from air pollution sources (Cora and Hung 2003; US EPA 2005). The model consists of a mathematical expression of the dispersion and chemical transformation of pollutants in the atmosphere (Cora and Hung 2003). This is done by estimating downwind air pollution concentrations for a given time frame, at potential receptor sites (Mtiya 2013).

AERMOD is a steady-state plume dispersion model, which uses a Gaussian and bi-Gaussian approach (US EPA 2002; Touma et al. 2007). It is applicable to near-source emissions and up to least 50 km (US EPA 2002). The model has proved to be an effective tool in modelling the dispersion of tall stack emissions (Perry et al. 2005; Buthelezi 2010; Mtiya 2013). There are three main types of data input required in AERMOD, i.e., information on the source (including emission rates, heights and locations), meteorological data and the local topography of the area of interest.

AERMET

AERMET provides a meteorological pre-processor for consolidating available meteorological data into a fixed planetary boundary layer (PBL) format appropriate for use in AERMOD. This is achieved by computing distinctive surface parameters and meteorological measurements (US EPA 2016a). Wind speed and direction, ambient pressure and temperature, albedo, Bowen ratios and cloud cover were used as input data. Hourly dataset containing the aforementioned parameters was obtained from Lakes Environmental Software, Canada for the period 2015-2017 and used as input of the AERMET pre-processor. The modelled data included hourly surface and upper air meteorology data in a processed grid cell format, with 26.6484 S, 27.9256 E as the grid cell centre.

AERMAP

AERMAP allows for the processing of terrain data, including a layout of the receptor sites and sources (Touma et al. 2007). It can process several standardised data formats, which makes it possible to produce terrain base elevations for specific receptors and sources as well as a hill height scale value for each respective receptor (US EPA 2016b). To calculate the terrain height scale for the receptor location, AERMAP uses gridded data that makes it possible to calculate the divided streamline height.

The topographic data required by AERMAP was obtained from SRTM1 (Shuttle Radar Topography Mission), whereas, the land cover data was attained from (WebGIS), with a resolution of (~30m). Studies have shown that SRTM datasets have limitations– large outliers and voids exists in the dataset; the accuracy of the data decreases with an increase in elevation and slope; and it shows features like buildings and forests which can increase the error bar in studies like this (Karwel and Ewiak 2008; Gorokhovich and Voustianiouk 2006). The WGS84 projection datum was used, with the terrain data calculated based on the UTM coordinate system (35 South). The receptors' grid was set at 2000m by 2000m with 2500 points. KwaZamokuhle Township monitoring station was added as a sensitive discrete receptor in order to evaluate the simulated concentrations at the settlement.

Emission sources as model inputs

Arnot, Hendrina and Komati power plants were considered as the emission sources in this study due to their proximity to the low-income settlement in question (Figure 1). The stack parameters used to run the model are shown in Table 1. These parameters were obtained from studies by Pretorius (2015) and Belelie (2017). The source characteristics and emission factors (calculated as an annual average from 2011-2013) used in these studies were obtained directly from Eskom. Emission rates used were converted from $t.yr^{-1}$ to $g.s^{-1}$ and were assumed to be constant over the study. The source characteristics and emission factors (calculated as an annual average from 2011-2013) used in these studies were obtained directly from Eskom Research, Testing and Development (RT&D).

AERMOD was run for an area of 50km x 50km using the configuration co-efficient for rural dispersion and elevated terrain. Upon completion of the model run, output plots of $PM_{2.5}$, NO_x and SO_2 maximum concentrations were obtained for 1-hour, 24-hour and annual averages for the three year period, to allow for the comparison with the ambient air quality standards. Likewise, hourly-generated concentration exceedance output files were generated, which were then related to the measured data drawn from the same location as the discrete receptor in the model.

Ambient monitored data

Monitored air quality data for the period 2015-2017 from KwaZamokuhle Township monitoring site used in the study was obtained from Eskom Research Testing and Development's Climate Change, Air Quality and Ecosystems Management department's database. Clustered columns were used to show the ratio to which the modelled results compare to the measured data.

Table 1: *Stack parameters used as source inputs in AERMOD.*

Power plant		Arnot	Hendrina	Komati
Location	**Latitude**	-25.944	-26.031	-26.091
	Longitude	29.792	29.601	29.422
Generating capacity		2100MW	2000MW	1000MW
Stack height		195m	155m	220m
Stack exit temperature		418k	411k	418k
Effective stack diameter		16m	16m	17m
Stack exit velocity		25 $m.s^{-1}$	22 $m.s^{-1}$	10 $m.s^{-1}$
Base elevation		1692m	1656m	1617m
Total annual emission rate	**SO_2**	2363 $g.s^{-1}$	3019 $g.s^{-1}$	967 $g.s^{-1}$
	NO_x	1664 $g.s^{-1}$	1258 $g.s^{-1}$	790 $g.s^{-1}$
	$PM_{2.5}$	23 $g.s^{-1}$	29 $g.s^{-1}$	66 $g.s^{-1}$

Results and Discussion

Modelled SO_2 concentrations

Figures 2 through 4 show the 1-hour, 24-hour and annual average modelled contributions of SO_2 found within 50km of KwaZamokuhle Township. The model predicted the hourly average concentrations from the power plants to be above the national ambient air quality standards (NAAQS) with a maximum of 654 $\mu g.m^{-3}$ simulated (Table 2). However, the simulated 24-hour and annual concentrations from the three power plants fall within the average standards i.e. 111 $\mu g.m^{-3}$ and 14.2 $\mu g.m^{-3}$, respectively. The simulations show that KwaZamokuhle Township receives hourly average concentrations in the range of 300-400 $\mu g.m^{-3}$, 24-hour averages between 30-50 $\mu g.m^{-3}$ and around 7-8 $\mu g.m^{-3}$ for the annual averages as a result of the power plants emissions.

Table 2: *National ambient air quality standards for SO_2, NO_x and $PM_{2.5}$ and the observed exceedances from the monitored (Mon) and modelled (Mod) datasets for the period 2015 to 2017 (SA DEA 2006*; SA DEA 2016).*

Pollutants	Maximum Averaging Period	Concentrations	Allowed Exceedance per year	Observed Exceedances for (2014-2017)		99th percentile concentration (μg.m^{-3})	
				Mon	Mod	Mon	Mod
Sulphur dioxide (SO_2)	1-hour	350 μg.m^{-3}	88	166	2	317	70
	24-hour	125 μg.m^{-3}	4	20	0	208	20
	Annual	50 μgm^{-3}	0	1	0	-	-
Nitrogen dioxides (NO_2)	1-hourly	200 μg.m^{-3}	88	243	0	258	37
	*24-hour	188 μg.m^{-3}	-	2	0	160	11
	Annual	40 μg.m^{-3}	0	0	0	-	-
Particulate Matter ($PM_{2.5}$)	24-hour	40 μg.m^{-3}	4	121	0	21	0.3
	Annual	20 μg. m^{-3}	0	0	0	-	-

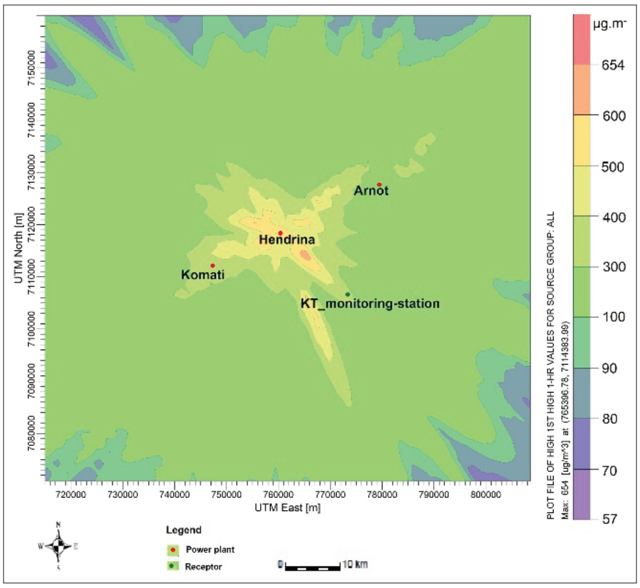

Figure 2: *Maximum 1-hour average contributions of modelled SO_2 due to the power plants for the year 2015-2017 as simulated by AERMOD.*

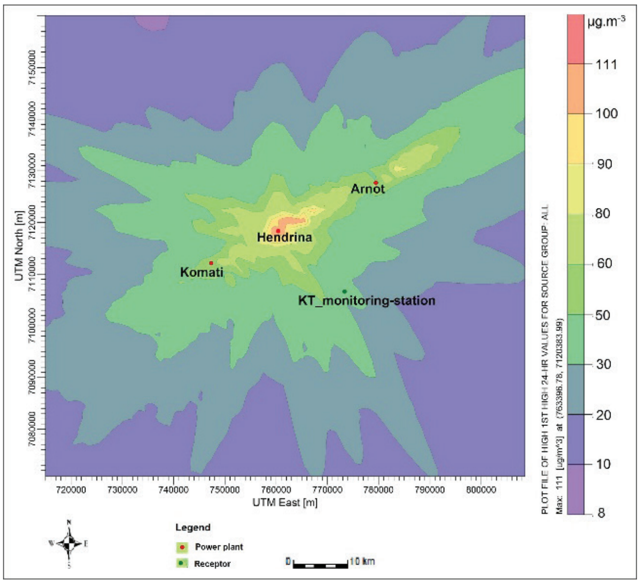

Figure 3: *Maximum 24-hour average contributions of modelled SO_2 due to the power plants for the year 2015-2017 as simulated by AERMOD.*

Table 2 displays the national ambient air quality standards and observed exceedances from the two datasets used in the study. The monitored data demonstrates how poor the ambient air in the Township is, for instance, monitored SO_2 exceeds the NAAQS for the 24-hour and annual averages. On the other hand, the modelled data only show exceedances 2 times conveying the small contribution from power plants to the ambient concentrations in the township. The same can be said for NO_x where exceedances are observed for the monitored 1-hour and 24-hour averages with annual averages showing adherences, while modelled data do not contribute concentrations that exceed the NAAQS in all averaging times. Lastly, monitored 24-hour $PM_{2.5}$ exceeds the standard 121 times; about 30 times more than the allowed four exceedances but does not exceed the annual standards. These exceedances in the monitored data convey a possible health risk to the residents of the Township.

Modelled NO_x concentrations

The maximum 1-hour average NO_x concentration simulations for the three power plants exceeds the South African standards, while the maximums for the 24-hour and the annual averages comply with the standards (Table 2). The model simulated maximum contributions of 263 μg.m^{-3}, 57.8 μg.m^{-3} and 6.40 μg.m^{-3} for the averaging periods, respectively (Figures 5 to 7). The average NO_x contribution of the three power plants towards the Township was observed to be in the ranges of between 100-200 μg.m^{-3}, 10-20 μg.m^{-3} and 3-4 μg.m^{-3} for each averaging period, respectively.

Modelled $PM_{2.5}$ concentrations

The modelling results show that the power plants contribute very small amounts of primary particulate matter concentrations to the ambient environment in KwaZamokuhle. The results

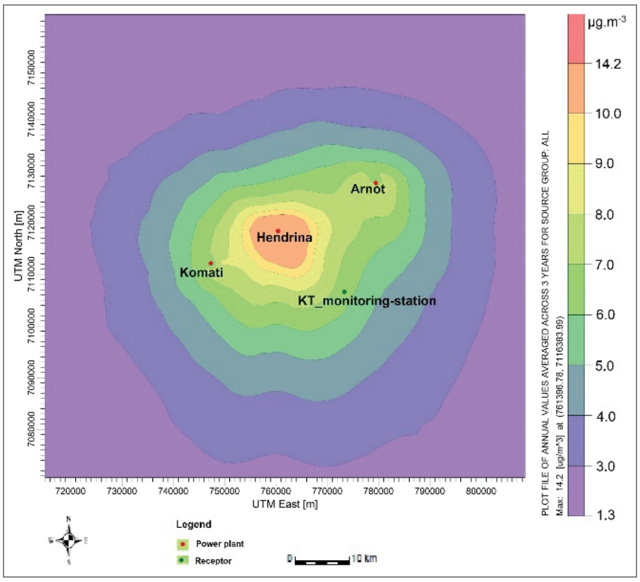

Figure 4: *Maximum annual average contributions of modelled SO_2 due to the power plants for the year 2015-2017 as simulated by AERMOD.*

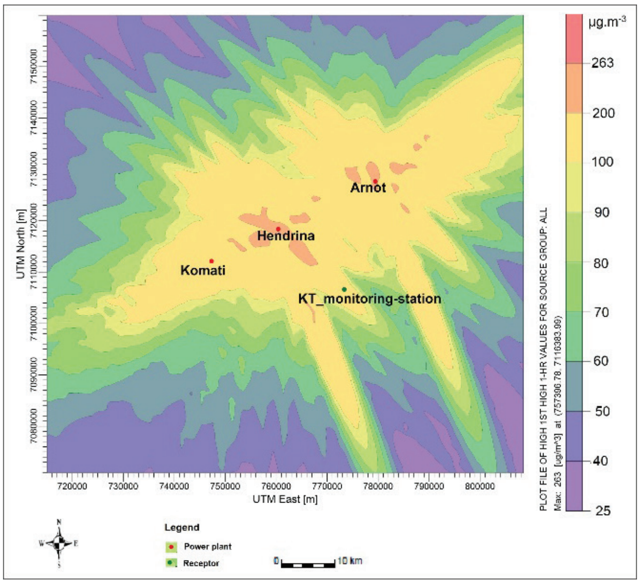

Figure 5: *Maximum 1-hour average concentrations of modelled NO_x due to the power plants for the years 2015-2017 as simulated by AERMOD.*

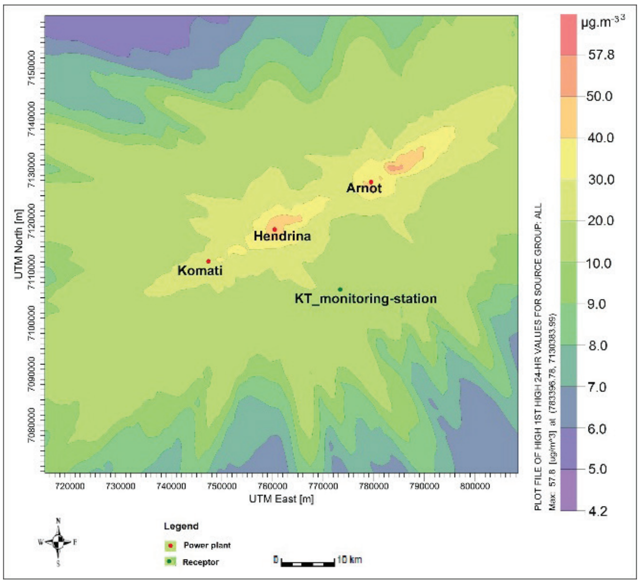

Figure 6: *Maximum 24-hour average concentrations of modelled NO_x due to the power plants for the years 2015-2017 as simulated by AERMOD.*

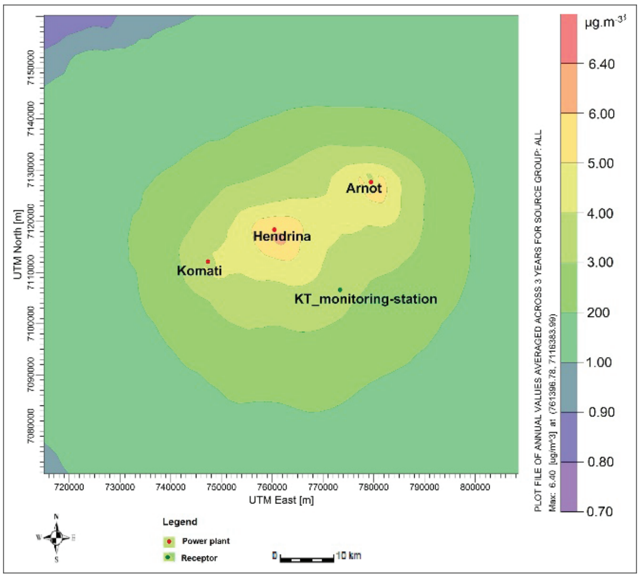

Figure 7: *Maximum annual average concentrations of modelled NO_x due to the power plants for the years 2015-2017 as simulated by AERMOD.*

also illustrate that at the discrete receptor at the township, maximum contributions ranging between 2-3 µg.m^{-3} for the hourly average, 0.5-0.6 µg.m^{-3} for the 24-hour average, and 0.09-0.1 µg.m^{-3} for the annual average are observed. Relatively small emissions were observed near the power plants for the daily and annual averages (Figure 8 and 9).

Monthly averages of modelled against monitored SO_2, NO_X and $PM_{2.5}$

Figures 10 to 12 show the seasonal average concentration contributions of each power plant at KwaZamokuhle Township, the average for the combined power plants, and the measured data at the monitoring site. A general trend observed is that the monitoring site shows high concentration in winter for the three species. The modelled data though does not show the expected seasonal signature for all the three species which is most likely due to the fact that the emission rates were kept at constant throughout the year.

As simulated by the AERMOD, power plants contribute an average of about 6 µg.m^{-3} of the 50 µg.m^{-3} monitored SO_2, which is approximately 13%. Figure 10 shows that Komati is contributing the least with an average of 0.3 µg.m^{-3} (0.6%) of the average observed concentrations. Arnot and Hendrina contribute 1.8 µg.m^{-3} (3.6%) and 4.3 µg.m^{-3} (8.7%) respectively.

Of the criteria pollutants assessed, NO_X has the highest relative contribution to the measured KwaZamokuhle Township levels, i.e., 3.4 µg.m^{-3} (16.9%). Similar to SO_2 Komati is the smallest contributor of NO_X, with an average contribution of 0.28 µg.m^{-3}

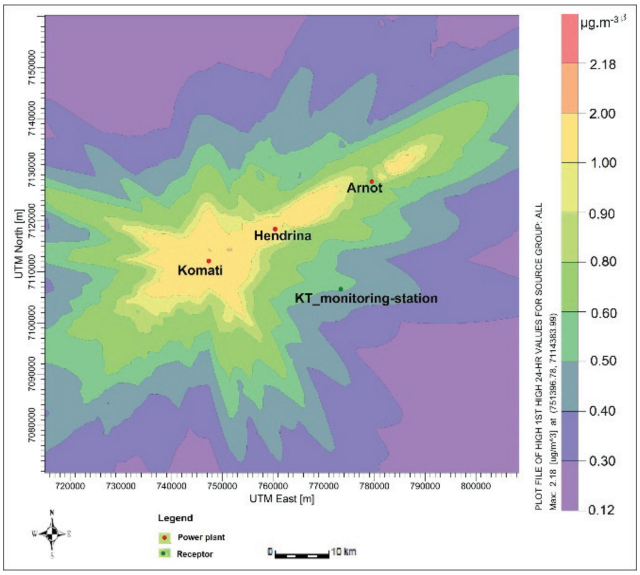

Figure 8: Maximum 24-hour average concentrations of modelled $PM_{2.5}$ due to the power plants for the years 2015-2017 as simulated by AERMOD.

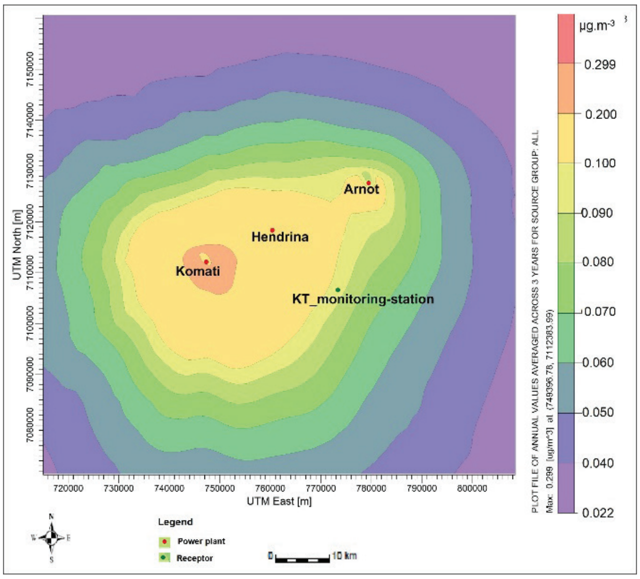

Figure 9: Maximum annual average concentrations of modelled $PM_{2.5}$ due to the power plants for the years 2015-2017 as simulated by AERMOD.

(1.4%) of the total, whereas Arnot and Hendrina contributed 1.47 µg.m^{-3} (7.2%) and 1.7 µg.m^{-3} (8.4%) of the total 20.35 µg.m^{-3} measured NO_x concentrations.

The contribution of $PM_{2.5}$ is much lower compared to SO_2 and NO_x. As depicted in Figure 12 the average concentrations for the three power plants combined are approximately 0.095 µg.m^{-3}, which is 0.2% of 48.6 µg.m^{-3}, measured at KwaZamokuhle Township monitoring site. The highest simulated values were observed at Komati, which had an average of 0.04 µg.m^{-3}, i.e., 0.08% of the average monitored $PM_{2.5}$. Arnot contributes to an average prediction of 0.04%. The model simulated an average of 0.03 µg.m^{-3} at Hendrina, which translate to 0.06% of the measured concentrations.

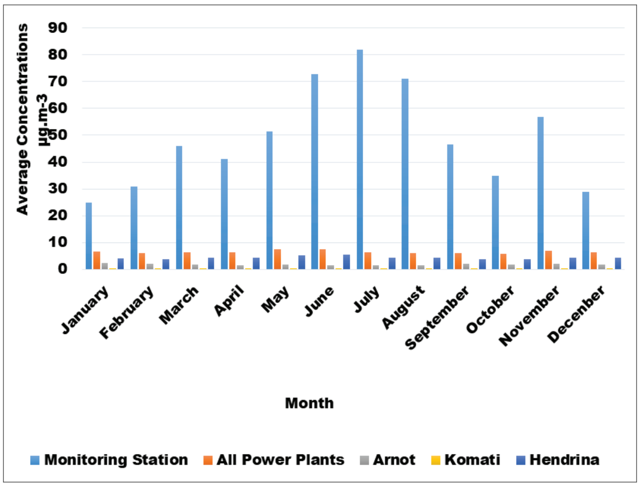

Figure 10: Modelled SO_2 concentrations for individual power plants and all the power plants modelled simultaneously compared to the monitored data collected at KwaZamokuhle Township monitoring station.

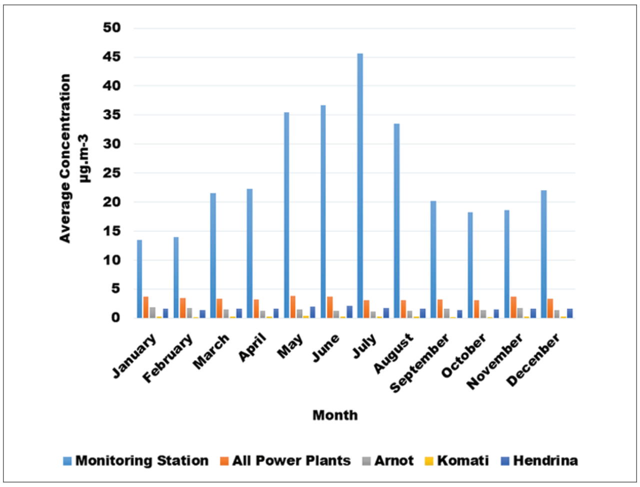

Figure 11: Modelled NO_x concentrations for individual power plants and all the power plants modelled simultaneously compared to the monitored data collected at KwaZamokuhle Township monitoring station.

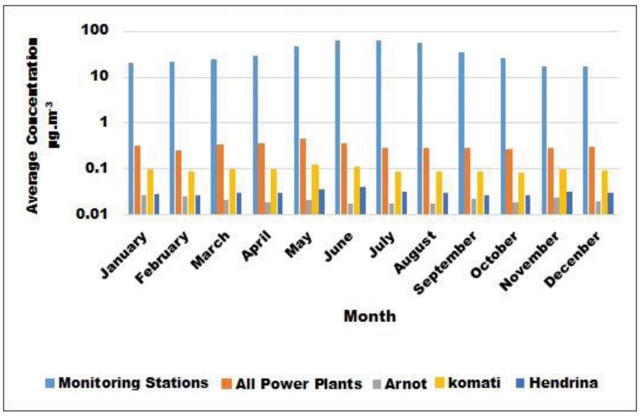

Figure 12: Modelled $PM_{2.5}$ concentrations for individual power plants and all the power plants modelled simultaneously compared to the monitored data collected at KwaZamokuhle Township monitoring station.

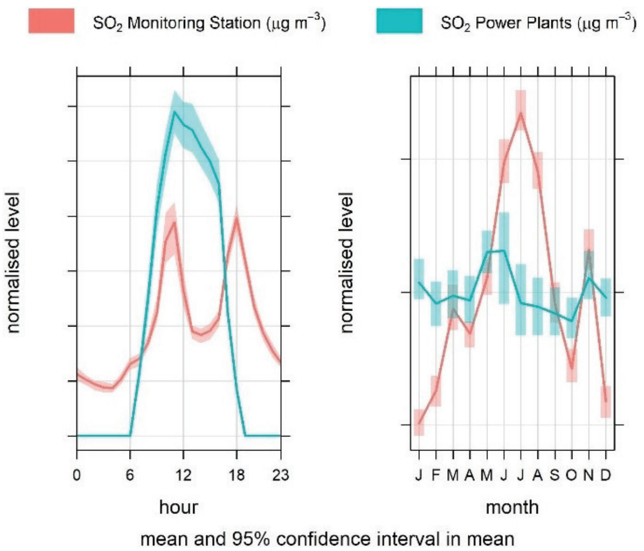

Figure 13: *Plot of the temporal variation of SO_2 concentrations ($\mu g.m^{-3}$) of the three power plants and the monitoring site for the duration of the study.*

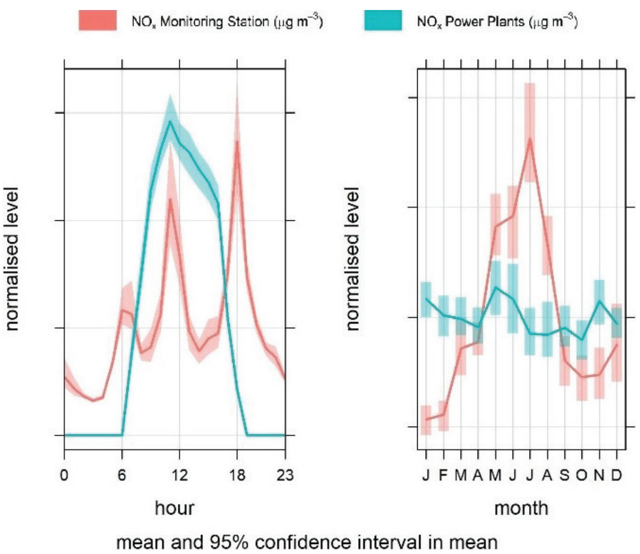

Figure 14: *Plot of the temporal variation of NO_x concentrations ($\mu g.m^{-3}$) of the three power plants and the monitoring site for the entirety of the observational period.*

Comparison of the temporal variations in the modelled and monitored data

According to Carslaw (2015), variations of pollutions by time can be useful in revealing the likely sources. Figures 13 to 15 show the normalized diurnal and monthly patterns of the modelled contributions (power plants) in comparison to the variations in the measured data from the KwaZamokuhle Township monitoring site. The plots were generated at 95% confident interval in the mean, applying the normalised option. Normalisation is adjusting values with different scales to an estimated common one (Carslaw 2015) which is useful in comparing the patterns of the two (modelled and monitored) datasets that had distinct ranges in concentrations. The simulations showed that the model did not agree with the measurements during the night-time in all instances, i.e., between 18:00 and 6:00 the graphs

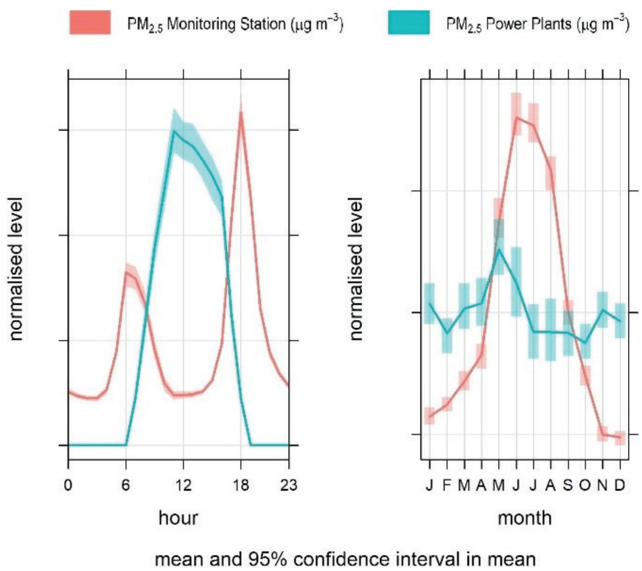

Figure 15: *Plot of the temporal variation of $PM_{2.5}$ concentrations ($\mu g.m^{-3}$) of the three power plants and the monitoring site for the entirety of the observational period.*

show low values. AERMOD neglects the residual plumes and it lacks the ability to approximate secondary formation of pollutants such as sulphates and nitrates produced during the day that impact on the ambient air quality during the stable night-time periods (US EPA 2005).

The diurnal plot of the modelled concentrations shows a peak at around mid-day due to the break-up of the inversion layer and downward mixing, which occurs at the same time as one of the two peaks observed for the monitoring data (Figure 13). The early evening peaks can likely be attributed to other local sources other than the power stations. Nkosi (2018) reported that low-cost fuels (wood, coal and dung) are the main sources of energy in low-income settlements on the Highveld, with burning events dominant between 16:00 and 19:00.

Measured values show distinct seasonal patterns which can be attributed to the variation in burning events. In winter the events are less variable than in the summertime hence the peak in winter (Nkosi 2018). Modelled data does not show much variation throughout the year, with little changes as a result of meteorological conditions, for instance, a dip observed around June and July is most possibly due to stable winter conditions.

In the case of NO_x (Figure 14), three peaks were observed for the monitored data, with the early morning and the evening peaks typical of low-level sources. A study by Nkosi (2018), observed that there are two common burning events i.e. morning and evening burning. The third peak observed around 10 am, which is mutual for the modelled and monitored data can be attributed to the downward mixing of tall-stack emissions. For the monthly variations, a peak is observed in the winter due to increased burning events since apart from cooking space heating is intensified. A drop is observed for the modelled data in winter due to calm conditions experienced during this time.

Low-level sources typically show a bimodal distribution with higher peaks observed in the early morning and evening, which was observed from the monitoring data. Like the other species, simulated $PM^{2.5}$ peaks around mid-day (Muthige 2014). This can be related to the breakup of inversion layers and downward mixing of the tall stack emissions. Nonetheless, unlike the previous two species, its peak coincides with a dip in the monitored concentrations. This together with the two peaks observed during the morning and evening times indicate that there are other major sources besides power plants, with domestic combustion the most probable. Nkosi (2018) substantiate the assumption by affirming that domestic burning is a major source of $PM^{2.5}$. The monthly trend is the same as the previous species with a maximum being observed in winter for the monitored data and not much variation for the modelled.

Conclusion

In this study, the possible impact of Eskom coal-fired power plants on the ambient air quality in KwaZamokuhle Township was evaluated through modelling with AERMOD. This was investigated by comparing simulated and monitored data for the period 2015-2017. Three power plants were considered with $PM_{2.5}$, NO_X and SO_2 being analysed as the criteria pollutants. Secondary particulate formation, detailed meteorological effects were not modelled by AERMOD and the peak short-term impacts were under estimated by the model when simulating annual average concentrations and these were perceived as limitations of this study.

The results showed that the contribution of the power plants as compared to the measured data is small. It may be concluded that poor ambient air quality in the community is not solely attributable to emissions from the surrounding power plants but may be originating from other sources as well. It is evident that local sources, specifically domestic burning, may be the dominant contributor to poor air quality over KwaZamokuhle. The frequency in exceedance of the NAAQS suggests that the residents of the low-income settlement may be susceptible to health risks associated with these criteria pollutants. Temporal variations in the measured data supports this argument in that daily peaks were observed during the morning and evening–a diurnal variation pattern commonly associated with low-level sources like domestic combustion.

Therefore, existing strategies that focus predominantly on the industrial sector may not be successful in improving ambient air quality. Local sources like solid fuel burning, waste burning, dust, and vehicles, should be included in order to come up with reduction mechanisms. This is important as these sources are located at ground level and in close proximity to humans.

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Authors' Contributions

P. Chidhindi developed the theory and wrote the manuscript. S. Piketh and R. Burger conceived of the original idea, devised the project and the main conceptual ideas. M. Belelie and P. Chidhindi were involved in the modelling of the emissions and the analysis of the results while S. Piketh, R. Burger and G. Mkhatshwa verified the analytical methods. R. Burger and M. Belelie developed the normalised graphs while S. Piketh and P. Chidhindi computed the clustered columns. S. Piketh, R. Burger and G. Mkhatshwa provided data and supervised the project. All authors were involved in the discussion of the results and commented on the manuscript.

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