



Spatial planning solutions to mitigate poor air quality in South African dense, low-income areas

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“It was bitter work, but the results were worth it.” – Avatar Roku

ABSTRACT

Poor air quality is considered as among the most significant environmental health risks globally. Spatial planning is intrinsically linked to poor air quality within urban areas, since land use changes dictate the location of significant poor air quality sources, influence the urban form and guide future development. The notion is further exacerbated by the segregated land use patterns left by the previous regime, resulting in incessant urban sprawl of dense, low-income where air quality is particularly poor. This research aimed to investigate whether spatial planning may well be implemented as a possible solution to mitigate poor air quality within South African dense, low-income areas. In doing so, the research employed an exploratory sequential research design by collecting literature, analyse the results, create an assessment tool and subsequently employ it to a case study for testing. Literature was investigated to identify contributing drivers of poor air quality within South African urban areas. The research further explored contemporary spatial planning approaches and their implementation to limit poor air quality in urban areas. Through a process of coding, reconstructed data of the contributing drivers were progressed into an assessment matrix to identify the most significant sectors of poor air quality in Sasolburg-Zamdela. Subsequently, a similar process was used to progress the contemporary spatial planning approaches into “urban development principles” that were employed in the compilation of three distinct development models (realistic, extreme and spatial inclusion) for Sasolburg-Zamdela. In exploring the feasibility of contemporary spatial planning approaches to address poor air quality, AERMOD was used to calculate the emission concentrations of each development model. The analysis demonstrated that the implementation of the “urban development principles” reduced PM_{2.5} concentrations in all three development models. In relation to the baseline model, the overall predicted 99th percentile emission concentrations were reduced in the realistic development model by 13.7%, in the extreme development model by 89.6% and in the spatial inclusion development model by 49.9%. These development models incorporated more compact development by locating high density, mixed-land use development in proximity to transit orientated developments and high order transportation corridors, resulting in agglomeration of land uses that curb incessant urban sprawl. The research revealed that the identified “urban development principles” may well be implemented as spatial planning solutions to mitigate poor air quality within South African dense, low-income areas. It highlighted that in facilitating the mitigation of poor air quality, a collective impact approach should be followed by implementing various spatial planning solutions, inter alia; compact urban development that promotes densification, mixed land use development that is adequately integrated with transit-orientated development and effective green infrastructure; especially surrounding high pollution areas.

Keywords: Air Quality Management, Contemporary Spatial Planning Approaches, Air Quality Management Plans, AERMOD Model, Spatial Planning Solutions

LIST OF ACRONYMS

TERM	DEFINITION
ADDAS	Airborne Dust Dispersion model from Area Sources
AERMOD	Atmospheric Dispersion Modelling System
APPA	Atmospheric Pollution Prevention Act
AQA	National Environment Management: Air Quality Act
AQM	Air Quality Management
AQMP	Air Quality Management Plan
BRT	Buss Rapid Transit
CBD	Central Business District
CLRTAP	Convention on Long Range Transboundary Air Pollution
CO ₂	Carbon Dioxide
CSIR	Council for Scientific and Industrial Research
DEA	Department of Environmental Affairs
DEAT	Department of Environmental Affairs and Tourism
DFFE	Department of Forestry, Fisheries and the Environment
EMP	Environmental Management Plan
DPLG	Department of Provincial and Local Government
DPME	Department of Planning, Monitoring and Evaluation
DRDLR	Department of Rural Development and Land Reform
DRMP	Disaster Risk Management Plan
DWEA	Department of Water and Environmental Affairs
EDP	Economic Development Plan
GHG	Greenhouse Gas
GIS	Geographic Information System
HPA	Highveld Priority Area
HSP	Housing Sector Plan
IDP	Integrated Development Plan
IEA	International Environmental Agreements
IEP	Integrated Energy Plan

TERM	DEFINITION
IA	Impact Assessment
ITP	Integrated Transport Plan
IUDF	Integrated Urban Development Framework
IWMP	Integrated Waste Management Plan
LGDSs	Low Greenhouse Gas Emission Development Strategies
LGTA	Local Government Transition Act
MSA	Municipal Systems Act
MTSF	Medium-Term Strategic Framework
NATMAP	National Transport Master Plan
NDC	Nationally Determined Contribution
NDP	National Development Plan
NEMA	National Environment Management Act
NLTsf	National Land Transport Strategic Framework
NO _x	Nitrogen Oxide
NSDF	National Spatial Development Framework
PM	Particulate Matter
SACN	South African Cities Network
SALGA	South African Local Government Association
SDF	Spatial Development Framework
SO ₂	Sulphur Dioxide
SPLUMA	Spatial Planning and Land Use Management Act
TOD	Transit-Orientated Development
UK	United Kingdom
UNFCCC	United Nations Framework Convention on Climate Change
USA	United States of America
UTM	Universal Transverse Mercator
VOCs	Volatile Organic Compound
VTAPA	Vaal Triangle Airshed Priority Area
WPA	Waterberg Priority Area
WSDP	Water Services Development Plan

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Chapter 1 Introduction

This chapter encapsulates the background and problem statement of the research (Section 1.1), followed by the research aim and objectives in guiding the research and the respective chapters (Section 1.2). Section 1.3 presents the structure of the research; linking the research objectives with the relevant research methods applied in each chapter. The chapter concludes in section 1.4, identifying the limitations of this research.

1.1 Background

Poor air quality is considered among the most pressing environmental and public health challenge globally. A comparative risk assessment for burden of disease and injury conducted by Lim *et al.* (2012:11) highlights that household air pollution is considered the greatest global environmental risk. This notion is supported by Burnett *et al.* (2014:402), indicating that exposure to fine PM is associated with an increase in respiratory illness, cardiovascular disease, lung cancer and premature deaths. It is considered that anthropogenic activities are the primary source of PM; especially within urban areas owing to increase in global population, high levels of urbanisation and economic growth (Karagulian *et al.*, 2015:476). In reference to the latter, Lelieveld *et al.* (2015:367) identify six anthropogenic source categories responsible for particulate matter (PM), namely; residential and commercial energy use, power generation, mining and industry, biomass burning, transportation and agriculture. While PM poses significant risks to human health, it also contributes to climate change through the absorption of solar energy that result in higher atmospheric temperatures (Ivanova, 2020:3058). The preceding is supported by Rosenzweig and Neofotis (2013:126), indicating that land use changes, geological processes, pollution, management practices and change in human demographics may affect climate systems both directly or indirectly. The authors further reiterate that land use changes directly influence climate change through clearing of land for agricultural activities, increase poor air quality in urban areas and modify local climate systems by changing the albedo.

As a consequence of the fragmented nature and inefficient land use patterns in urban areas, South Africa comprises among the most carbon intensive economies for middle-income countries globally, with elevated levels of sulphur dioxide (SO₂), nitrogen oxide (NO_x), PM_{2.5} and ozone (Cairncross *et al.*, 2018:328). As a consequence, poor air quality is particularly severe in large portions of the country where multiple regions experience continuous exceedances of national ambient air quality standards; especially in urban areas and industrialised regions (Altieri & Keen, 2019:611). With a growing concern of poor air quality in industrialised areas, specific regions have been declared as air quality priority areas in an attempt to address poor air quality, namely; Vaal Triangle Priority Area (VTAPA), Highveld Priority Area (HPA) and Waterberg-Bojona Priority Area (WBPA) (Feig *et al.*, 2019:1). However, it is evident that urban areas experience high levels

of poor air quality from various anthropogenic sources, for instance; domestic fuel burning, mine tailings, transportation and power generation (Feig *et al.*, 2019:3). The impact thereof is exacerbated within dense, low-income areas that accommodate a large portion of the South African population (Turok, 2012:21). In expanding the latter, Hersey *et al.* (2015:4271-4273) identified that household air quality within dense, low-income areas are regarded as the worst with the most significant impact to human health. These areas are generally located in close proximity to pollution sources, inter alia; major transportation corridors, landfill sites, industrial zones and unregulated small-scale enterprises (Matooane *et al.*, 2014:2). Owing to a lack of investment and the inefficient provision of infrastructure and services, poor air quality within high density, low-income areas is intensified through the use of dirty fuels for space heating and cooking, domestic waste burning, use of unregulated vehicles and dust from unpaved roads and open areas (Hersey *et al.*, 2015:4271-4273). Moreover, these areas are mostly characterised as unplanned which comprise high densities that further increase cumulative emissions within these compact areas which reduce the dispersion potential of emissions (Chidhindi, 2022:101).

Spatial planning in South Africa, or the lack thereof, plays an imperative role in driving exposure to poor air quality and its associated emissions. Supporting this view, Pieterse (2002:3-37) reaffirms that previous spatial planning legacies located marginalised communities in close proximity to heavy industries and environmentally hazardous locations, generally without adequate infrastructure, services or environmental buffers. Owing to high levels of urbanisation and the absence of coherent spatial planning resulted in the incessant growth of dense, low-income areas in pollution-prone environments, restricting access to clean energy, sanitation or reliable services (Mokoele & Sebola, 2018:579). In addition, Verdini *et al.* (2025:4) lament that despite the good intention of the South African Government to implement strategies in addressing these challenges, recent assessment indicate that new policies reinforce inequality and undermine its impact to mitigate poor air quality and climate change. This may be attributed to the limited integration of air quality management with housing, transportation and industrial development that hinders the overall effectiveness of strategies (Mukwevho *et al.*, 2022:1). In effectively addressing poor air quality in South African urban areas, Van Niekerk *et al.* (2024:88) suggest that South African spatial planning should refrain from traditional, siloed approaches to more integrated, health orientated development.

Robinson *et al.* (2023:2) assert that scholars are increasingly considering the origins of urban vulnerability and how historical influence affected spatial planning, design and management of urban areas and urbanisation. It is argued that traditional spatial planning approaches and contemporary urban forms should be reassessed to include energy saving and low emission remedies that emphasise spatial planning and design which promote slow mobility, walkability and efficient green spaces (Verdini *et al.*, 2025:14). Sharma *et al.* (2018:4) endorse the latter,

reaffirming that spatial planning plays a critical role in ensuring effective infrastructure and service provision, allocate investment towards clean energy and urban mobility and enforcing zoning regulations through cities to mitigate emission at pollution sources and the exposure thereof. In supporting the inclusion of spatial planning into air quality management, the South African Government introduced the “Strategy to Address Air Pollution in Dense Low-Income Settlements: A Burning Issue” (DEA, 2019:1). By doing this, the Strategy highlights the significance of a collaborative, multi-sector approach to establish remedies that focus on pollution reduction mitigation measures in protecting vulnerable communities and ensure long-term sustainable development. When faced with the fact that air quality is a significant and costly challenge, the need to reconsider existing mitigation strategies and approaches, including spatial planning, should be considered. By including air quality considerations in spatial planning practices, future changes and priorities may be changed. The latter prompted the research to investigate the relationship between the urban characteristics and poor air quality in recommending possible spatial planning solutions (strategic and design) that may well be conducive to the mitigation of poor air quality in South African dense, low-income areas.

1.2 Problem statement

Despite numerous interventions implemented by the national government over the past three decades, poor air quality in South African urban areas; especially within in dense, low-income settlements remains a critical concern. These communities face high levels of exposure to poor air quality owing to their proximity to primary sources and reliance on dirty fuels for space heating and cooking. Also, poor air quality is intensified by incessant urban sprawl, unplanned development, lack of sufficient infrastructure or services and historical spatial planning legacies. Therefore, a pressing need is identified to explore whether spatial planning solutions can be implemented to mitigate poor air quality in South African dense, low-income urban areas.

1.3 Research aim and objectives

Referring to the problem statement discussed in Section 1.1 the aim of the research is:

To critically investigate the relationship between poor air quality of South African dense, low-income areas and its mitigation through spatial planning solutions.

The research objectives of the study, necessitated in attaining the preceding research aim, are identified below, namely:

1. To examine specific contributing drivers of poor air quality in South African dense, low-income areas,

2. To examine the level of interface between the South African air quality and spatial planning directives,
3. To examine whether contemporary spatial planning may be conducive to mitigate poor air quality,
4. To examine the implementation of spatial planning solutions to mitigate poor air quality on a municipal level.

1.4 Structure of the research

For a transparent interpretation of the research aim and to demonstrate a clear connection between the research objectives and the employed methodology in attaining the respective objectives, the phases whereby the research are conducted within the respective chapters are ensuing deliberated. In attaining the main research aim of the study (Section 1.2) the research structure is designed to comprise four distinct phases, namely:

1.4.1 Phase 1: Introduction, Literature Review and Methodology

Phase 1 of the research interprets the research and methodological approach in addressing the research objectives and includes the following chapters:

- Chapter 1: Introduction

This chapter presents the research by defining the background and problem statement of the research, followed by the research aim. Thereafter, research objectives are posed in exploring the research aim, ensued by an overview that explains the structure of the research and followed by the limitations of the research.

- Chapter 2: Literature Review

The chapter frames the context of the research by investigating existing literature pertaining to poor air quality within low-income areas, contributing driver of poor air quality in urban areas, spatial planning and environmental justice in South Africa, air quality management in South Africa, the role of spatial planning and its possible solutions in mitigating poor air quality within urban areas and dispersion modelling. This is done to highlight existing knowledge in order to determine possible gaps in the literature.

- Chapter 3: Methodology

This chapter provides a detailed explanation of the research methodology employed in attaining the research aim and objectives (Section 1.2).

1.4.2 Phase 2: Define and Prepare

Phase 2 of the research focusses on research Objective 1, 2 and 3 (Section 1.2.), by reviewing documents in the form of published books, scientific articles and policy directives by considering government policy, repealed and promulgated legislation and supporting guidelines. Phase 2 includes the following chapters:

- Chapter 4 – Investigating the contributing drivers of air quality

This chapter will investigate the comparison and association between recent poor air quality documents and South African Air Quality Management Plans (AQMPs) in determining their relevance towards mitigating poor air quality in South Africa. This is considered a feasible approach considering that local knowledge in relation to poor air quality drivers, even though incomplete, are encapsulated in AQMPs. In doing so, international and local documents pertaining to poor air quality within urban areas will be investigated in determining possible sources of poor air quality within, and surrounding urban areas. Subsequently, the identified sources will be culminated into an assessment matrix to assess the recently prepared national, provincial, district and local AQMPs in South Africa.

- Chapter 5 – (Mis)alignment between spatial planning and air quality policy directives

Chapter 5 explores contemporary international air quality protocols, in addition to national, provincial and local spatial planning directives (policy, legislation and guidelines) in identifying possible references to AQM. Since the National Environment Management: Air Quality Act (AQA) (2004) necessitates the inclusion of an AQMP as a sector plan within the compulsory local municipal IDP, as compelled by the Municipal Systems Act (MSA) (2000), this chapter further explores South African policy directives in identifying the possible alignment measures between AQM and spatial planning in the South African context.

- Chapter 6 – Exploring the contemporary spatial planning approaches conducive to poor air quality

This chapter will examine contemporary spatial planning approaches, in particular, Compact City Development, Transit-Orientated Development (TOD), Smart Growth, New Urbanism and Green Urbanism in identifying spatial planning solutions that may be conducive towards the mitigation of poor air quality. These solutions will be progress into “urban development principles” and subsequently employed (Chapter 7) to establish alternative development models for the purposefully selected case study. The relevance of

the “urban development principles” will be investigated by means of atmospheric dispersion modelling system (AERMOD) to determine whether spatial planning may be conducive to the mitigate poor air quality in the Metsimaholo Local Municipality.

1.4.3 Phase 3: Findings and Analyses

Phase 3 focuses on research Objective 4 (Section 1.2). During this phase of the research, Chapter 7 will employ the “urban development principles” identified in Chapter 6 through AERMOD in determining whether spatial planning solutions may be implemented as possible mitigation strategies to remedy poor air quality. Phase 3 includes the following chapter:

- Chapter 7 – Research finding and case study analyses

As it pertains to this research, the purposefully selected case study is the Metsimaholo Local Municipality that includes Sasolburg as an industrial hub and Zamdela as a dense, low-income areas that are separated by SASOL industry. In investigating whether spatial planning solutions may well be conducive in mitigating poor air quality, the identified “urban development principles” (Chapter 6) will be employed in compiling three development models. The emission rates will be harmonised for each development model and subsequently modelled in AERMOD in order to determine the possible solutions that may be implemented to mitigate poor air quality within South African dense, low-income areas.

1.4.4 Phase 4: Conclude

In the final phase, a summary of the research results will be presented, followed by the overall conclusions in terms of the research results, together with the contribution of the research. This phase includes the following chapter:

- Chapter 8: Conclusion

The final chapter refers to findings gained through the theoretical and empirical investigations, presenting and discussing the results derived from the empirical phase. Conclusions are drawn from the results by underlining the nominated research objectives. Finally, this chapter concludes the research by proposing specific contributions of the research and recommending specific spatial planning solutions that may be employed to mitigate poor air quality, not only in South African dense, low-income areas, but also cities in the global south, representing similar spatial development patterns.

1.5 Limitations of research

Considering the extensive nature of the research topic, limitations are prescribed to constrain the research and to attain the research aim and objectives identified in Section 1.3. Firstly, the research acknowledges that the establishment of a detailed emission inventory for South Africa is an exhaustive methodology that comprises various qualitative and quantitative analyses of diverse databases. The intention of the research is to merely investigate global and local documentation to identify various sources that may contribute to poor air quality within urban areas and not to create a detailed emission inventory of all possible poor air quality sources. As a consequence, the research aims to investigate whether the purposefully selected poor air quality sources identified from the documents are considered in existing South African AQM practices or whether a generic template is used to mitigate poor air quality.

Even though a range of air pollutants are prevalent in urban areas, the research considers it appropriate to only investigate the mitigation of $PM_{2.5}$ through the employment of spatial planning approaches. The reason for this is the significant health impact of $PM_{2.5}$ on urban residents owing to long term exposure, in addition to the association of $PM_{2.5}$ with anthropogenic activities in urban areas. The aim of the research is, therefore, to investigate the manner in which $PM_{2.5}$ may be mitigated when spatial planning solutions are implemented by altering the anthropogenic activities within the case study.

Considering that dispersion modelling may be complex in nature, the research opted to employ a Gaussian plume dispersion model dispersion model, namely; AERMOD comprising simplifying assumptions (building downwash) over a case study. The purposefully selected case study is classified as a type-C urban area which is characterised by low residential densities and limited high-rise buildings, the building downwash effect through the Plume Rise Model Enhancements (PRIME) algorithm is not deemed necessary to include in AERMOD. Apart from certain industrial buildings, the case study mostly comprises single or two storey buildings, limiting the mechanical turbulence. The aim of the analysis is an emergent assessment of the potential impact of spatial planning solutions to reduce poor air quality and not the implementation of an exhaustive assessment. Consequently, the result should be interpreted relative to the various development scenarios, rather than in the absolute sense. In reference to the preceding, only primary PM sources were considered, while excluding regional sources to estimate emission concentration in the case study. The research argues that this approach is sufficient to investigate the impact of spatial planning solution on a municipal level.

1.6 South African air quality management and policy

Air quality management (AQM) in South Africa is governed by the AQA (2004), providing realistic measures for preventing poor air quality and environmental degradation, while ensuring reasonable social and economic development (Engelbrecht & Van der Walt, 2012:408). In doing so, the Act requires the Minister of Environmental Affairs to promulgate a National Framework for Air Quality Management, establishing national norms and standards for pollutants, ambient air quality and monitoring and dispersion modelling (Scorgie, 2012:217). In facilitating the latter, the Act introduced the adoption of an Air Quality Management Plan (AQMP) at the national and provincial levels into Environmental Management Plans and Environmental Implementation Plans as required by the National Environment Management Act (NEMA). The implementation of an AQMP at the local government level is regulated in terms of the MSA (2000) through its inclusion into the Integrated Development Plan (IDP) (Mukwevho *et al.*, 2024:2). Gulia *et al.* (2015:294) suggested that Municipal AQMPs are considered the most effective government level for AQM, identifying the reduction of poor air quality in urban areas through the implementation of successful AQMPs in international cities. However, scholars (Liebenberg-Enslin, 2024:3; Mohlala, 2020:59; Naiker *et al.*, 2012:70; Engelbrecht & Van der Walt, 2012:417; Mukwevho *et al.*, 2024:13) critiqued the progress and effectiveness of AQM on the local government level in South Africa, since the majority of local municipalities do not comprise or are in the process of approving AQMPs. It was argued that social or economic goals were prioritised in local municipalities, resulting in budget constraints to implement AQMPs.

The government acknowledged the decisive role that urban planning has to play in addressing the spatial and environmental challenges (Kihato, 2012:32). The notion is emphasised in the National Development Plan (NDP) (2011:37) and recently promulgated National Spatial Development Framework (NSDF) (2022:51), indicating that future development should minimise poor air quality through effective urban planning and land use management. The NSDF (2022:70) further imposes that the “national spatial development pattern should pursue more compact, concentrated spatial pattern to reduce the number of roads and railway lines to be built and maintained, and more mixed, higher density development to reduce the need for motorised travel”. Retief and Cilliers (2015:563-586) highlighted that local municipalities, through employing the IDP, function as a robust system, ensuring democratic and responsible government for local communities, guaranteeing the provision of services to communities in a sustainable manner, promoting social and economic development and encouraging a safe and healthy living environment. The main function of the IDP is to guide future development of a local municipality through the inclusion of various sectors plans to facilitate inter-departmental cooperation in providing sustainable urban development, underlining the integration of AQM and spatial planning (Tshehla & Wright, 2019:2). In attaining the latter, Joscelyne (2015:47) highlighted that the

municipal Spatial Development Framework (SDF) should incorporate environmental management and bioregional plans to give spatial affect for future urban development.

Van Niekerk *et al.* (2024:88) revealed the lack of alignment between current South African spatial planning and air quality policy directives. The authors argued that this is attributed to the isolated approach by both the spatial planning and air quality fraternity when compiling major policies or sector plans. It is suggested that the lack of integration between AQM and spatial planning is attributed to the fact that the governing legislation, namely; AQA (2004) and Spatial Planning and Land Use Management Act (SPLUMA) (2013) were promulgated in different times periods, during 2004 and 2013, respectively which resulted in the misalignment of their respective missions and objectives. Notwithstanding the legislative foundation provided to facilitate the integration of AQM and spatial planning, Naiker *et al.* (2012:68) disclosed that municipal IDPs showed limited integration between the AQMP, SDF and Integrated Transport Plan (ITP). It was argued that the implementation of IDPs were a compliance exercise for local municipalities, functioning mainly as a budgetary mechanism rather than a long-term planning instrument. Moreover, Engelbrecht and Van der Walt (2012:408) reiterated that local municipalities lack officials comprising technical knowledge or capacity to compile sector plans, resulting in outsourcing the compilation of sector plans to the private sector. As a result, specialists in their respective fields will formulate a particular sector plan that will rarely integrate other sector plans, limiting effective policy alignment.

1.7 Conclusion

This chapter presented the rationale for the research by highlighting the background and problem statement. In addressing the latter the research aim was presented, followed by the research objectives designed to guide the research through the various phases. The chapter concludes by acknowledging intrinsic limitations of the research that defines the parameters wherein the results should be interpreted.

Chapter 2 Literature Review

2.1 Introduction

The ensuing chapter presents an overview of the detrimental impact of poor air quality within South African urban areas, with specific reference to dense, low-income areas. This is attained by investigating the nature and characteristics of existing urban areas in determining significant poor air quality sources and contributing drivers towards poor air quality. By highlighting the link between land use patterns of South African urban areas and poor air quality, existing South Africa policy directives are investigated in identifying possible means for mitigating poor air quality. Moreover, owing to the impact of urban forms on poor air quality, contemporary spatial planning approaches are explored as a possible solution to mitigate poor air quality in South African urban areas.

2.2 Air quality in low-income urban areas

Arku *et al.* (2008:220-229) explored poor air quality within two low-income areas located in Accra, Ghana in identifying the initial levels and spatial patterns of various pollutants. In doing so, the research conducted sampling for PM₁₀, PM_{2.5}, SO₂ and NO₂ to identify the most significant sources of poor air quality. The investigation confirmed that measurements are consistent with similar studies measuring air quality in low-income areas (Engelbrecht *et al.*, 2001:13; Etyemezian *et al.*, 2005:7855), highlighting household combustion, vehicle emissions, fugitive dust and refuse burning as the main sources of poor air quality. While the annual averages within the two neighbourhoods were lower than large cities in Asia and Eastern Mediterranean, it was significantly higher than cities in Latin America and high-income countries. The authors signified that this may be attributed to the lack of available services where residents still rely on biomass fuels. Zimmerman *et al.* (2017:2) in a similar study, investigated the air quality within the informal urban areas located around Nairobi. The authors identified that rapid urbanisation experienced in Nairobi resulted in the establishment of approximately 150 informal urban areas, which lacked adequate housing, access to public facilities, social services and infrastructure. The latter has a major impact on residents residing in these areas, since poor indoor ventilation combined with the prevalent use of dirty fuels and combustion of refuse intensified the exposure to poor air quality. Apart from the aforementioned, another major concern is the location of dense, low-income areas in relation to primary poor air quality sources, namely; transportation corridors, industrial zones or landfill sites (Zimmerman *et al.*, 2017:2).

South African dense, low-income areas, particularly in the VTAPA and HPA, are at risk considering that the majority power plants are located in these regions. Highlighting the significance of proximity, Nkosi *et al.* (2017:6) identified that schools located near to mine dumps

were exposed to higher levels of outdoor and indoor air pollution in relation to those that are located further away. In expanding this notion, research (Scorgie, 2012:44; Muyemeki, 2021:95) affirmed that high levels of PM_{2.5} concentrations are attributed to mine tailings and power generation sources, making industry the most significant source of PM_{2.5} in the northern region of South Africa. However, the author determined that domestic combustion by households was considered the second largest emitter of PM_{2.5}, owing to the number of dense, low-income areas prevalent in the region. The latter is endorsed by the research of Pauw (2020:2), indicating that the majority of households in dense, low-income areas do not have access to adequate infrastructure and services, resulting in reliance of dirty fuels for space heating and cooking. As a result, extreme poor air quality episodes are experienced during morning and evening periods, in addition to winter months. The preceding is confirmed by Moletsane *et al.* (2021:4) through the evaluation of the ambient PM_{2.5} concentrations in KwaZamokuhle. The findings reiterated that extreme PM episodes were experienced during cold months, together with morning and evening peaks as a result of household and community activities. Increase in vehicle traffic; especially during these peak periods, significantly contributed to high levels of PM concentrations in dense, low-income areas. Nkosi *et al.* (2023:116) examined the PM emissions for vehicles in Bokamosa, validating that a strong correlation exists between vehicle traffic per hour and the PM concentrations measured. Also, the authors highlighted that street networks in dense, low-income areas mostly comprise unpaved roads, resulting in resuspension of dust and high PM levels. The latter is supported by a study characterising PM in low-income areas, indicating that trace elements of road dust were observed inside the households. The reason for this is that main roads within these areas are commonly paved, while the minor arterials located between dwelling units are unpaved. As a consequence, the resuspension of dust can infiltrate into households through openings, owing to the poor quality of structures (Language, 2020:229).

Extensive research (Cohen *et al.* 2017; Keen, 2016; Kumar & Rajput, 2022; Landrigan *et al.*, 2016; Lelieveld *et al.*, 2015; Wang *et al.*, 2023) have been conducted on poor air quality and its associated impact on health. Given that the majority research investigated the exposure of PM_{2.5} and respiratory conditions in high-income countries experiencing low concentrations of PM_{2.5}, Hystad *et al.* (2020:242-244) explored the impact in high-income, middle-income and low-income countries. The research found that low-income countries experienced extremely high levels of PM_{2.5} in relation to high-income and middle-income countries, increasing the absolute health burden of respiratory conditions. Frazenburg *et al.* (2025:5-12) investigated poor air quality within “vulnerable populations” in South Africa (dense, low-income areas), confirming that higher exposure to poor air quality within these areas is associated with increase respiratory conditions in children and pregnant women. Owing to the role of women in South African dense, low-income areas, the research suggested that additional research is required, since women spend more time indoors and are exposed to emissions from space heating and cooking. Lindeque *et al.* (2021:10-

12) further highlighted the association by determining that when PM_{2.5} exposure are reduced by 4 ug/m³, a total of 143 premature deaths can be avoided over a 20-year period, calculating to an economic benefit of R370.1 million. Outdoor and indoor exposure to PM of various population groups were investigated in Lebohang by Moletsane (2023:92-99). The research identified that population groups in dense, low-income areas spend excessive periods of time indoors, increasing their risk to poor air quality related health risks. While Moletsane (2023:92) identified that exposure to indoor PM_{2.5} poses a greater health risk, Madonsela *et al.* (2024:477) revealed that indoor air quality is influenced by outdoor poor air quality sources in dense, low-income areas. These findings reinforce the notion that these areas bear a disproportionate burden of poor air quality exposure.

2.3 Sources and contributing drivers of poor air quality within urban areas

Incessant levels of population growth and urbanisation pose considerable challenges for major cities in so far as air quality is concerned (Superczynski & Christopher, 2011:2553). Zhou *et al.* (2018:1) identified that high population densities and economic activities result in a growing number of vehicles, high levels of energy consumption and the loss of green open spaces. Supporting this view, Ozcan and Cubukcu (2016:179) capitulated that low-density land use development, distribution of pollution activities and an increase in privately owned vehicles are considered as among the main drivers of poor air quality in urban areas. For this reason, McCarty and Kaza (2015:177) affirmed that segregated and sprawling urban forms that locate low-density neighbourhoods outside the urban periphery are associated with poor air quality. Numerous studies have identified that urban form has a direct impact on the amount and frequency of emissions (Liu *et al.*, 2018:15555; Yuan *et al.*, 2018:413; Hankey & Marshall, 2017:494). The urban form is characterised by land use patterns, transportation, infrastructure, energy, water and waste services and developments that facilitate the activities of citizens (Marquez & Smith, 1999:542). Clark *et al.* (2011:7028) revealed that the urban form influences the total vehicle kilometres travelled, modal split and trip length. The scholars further suggested that high population densities, grid street network, inefficient public transportation, impervious surfaces, building orientation and distribution of land uses effect urban air quality.

South African cities currently experience the effects of ineffective land use patterns that involve disjointed urban areas associated with fragmented, segregated, distorted, unequal and inefficient land use patterns (Du Plessis & Landman, 2002:4). The land use patterns within these areas generate, inter alia, high transportation demand, energy and resource consumption and pollution (Napier, 2007:19). Following the regime shift in 1994, urban planning policy directives mainly focussed on the pressing need to readdress the spatial inequalities and injustices, through eliminating restrictions on movement, racially based segregated development, curbing urban sprawl through densification programs and infill development and considering alternative urban

forms in restructuring South African cities (Ruhiga, 2014:612). Despite considerable service delivery and development since 1994, Schensul and Heller (2010:79-81) asserted that the post-apartheid era made limited progress to transform the social and economic injustices, resulting in increased inequality and spatial segregation. The claims are supported in the findings of Dewar (1995:407-420), suggesting that South African cities are among the most inefficient worldwide as they continue to reinforce low-density urban sprawl, together with fragmented and separated development. Pieterse (2004:81-104) identified that even though various urban policy directives were introduced since 1994 to support spatial transformation, it appears that South African cities are as fragmented, segregated and unequal as during the previous dispensation. Consequently, considering the spatial patterns of existing South African cities, Turok (2001:2349) proclaimed that urban development since 1994 continued to emphasise spatial segregation by situating low-income areas away from economic activity centres.

These segregated areas, coupled with high levels of urbanisation result in the incessant urban sprawl that continues to disrupt the efficiency of South African cities (Tsoeleng & Shikwambana, 2020:210; Turok & Borel-Saladin, 2014:2). Yuan *et al.* (2018:413) affirmed this notion, indicating that urban areas comprising sprawling neighbourhoods, mono-functional land uses and poor connectivity (lack of fast and affordable public transportation) increase the use of privately owned vehicles, generating high levels of vehicle emissions. Moreover, sprawling urban forms place significant pressure on the delivery of waste services and disposal facilities, since the transportation thereof should be hauled over vast distances (Organisation for Economic Co-operation and Development, 2018:11). As a consequence, many segregated areas lack sufficient waste removal services and result in open refuse burning that contribute to poor air quality. Apart from the aforementioned, Harrison and Todes (2014:15) indicated that previous spatial planning policy directives not only situated dense, low-income areas away from economic and social centres, but also in close proximity to industrial facilities for cheap labour. The residents residing in these areas are more susceptible to poor air quality as the frequency and concentration of emissions are generally higher in the areas surrounding industries (Manisalidis *et al.*, 2020:2). Moreover, Adesina *et al.* (2022:10) identified that even though power plants significantly contribute to exceedances in dense, low-income areas located within close proximity, high levels of pollution concentrations were generated within the community. Additionally, in old industrial areas where activities have been terminated, surrounding areas are exposed to high concentration of windblown dust from unrehabilitated areas (Nkosi *et al.*, 2017:6). Kapwata *et al.* (2018:1) further identified that the lack of reliable energy sources in dense, low-income areas result in the incessant use of dirty fuels for space heating and cooking. Source apportionment conducted by Muyemeki (2021:70) identified that the most significant sources in two low-income areas in VTAPA were industries, household fuel burning, refuse burning and windblown dust.

Apart from the urban form and land use patterns, poor air quality is influenced by diurnal and seasonal tendencies that are considered a function of source activity and meteorological conditions. Chen *et al.* (2020:2) confirmed that, even though anthropogenic emissions are commonly recognised as the leading factor for PM_{2.5} concentrations, meteorological characteristics have a major impact on the long-term PM_{2.5} variations. The research of Nguyen *et al.* (2024:2) further supported these findings, affirming that temperature, precipitation, radiation, relative humidity, air pressure, wind speed and wind direction significantly influence the transportation, dispersion and removal of PM in the atmosphere, impacting the amount that accumulates within a specific area. Research conducted by Wright *et al.* (2025:5) in two South African dense, low-income areas in Gauteng illustrated a positive correlation between source activity and diurnal poor air quality peaks. Across the two case studies, it was identified that peaks occur during the morning (06:00-09:00) and evening (18:00-21:00) when households light fires for cooking. These peaks were further intensified during winter months when household burnt more for heating, together with stable atmospheric conditions that limits dispersion of emissions. While Wright *et al.* (2025:5) only investigated poor air quality within households, similar trends were discovered by Lourens (2012:56) when investigating air quality in Johannesburg and Pretoria. The author identified that over a three month sampling period, morning (06:00-09:00) and evening (18:00-21:00) peaks were observed across all the monitoring station, coinciding with anthropogenic drivers of poor air quality.

2.4 Spatial planning and environmental justice in South Africa

South African cities are considered to comprise among the most inefficient urban forms worldwide that reflect the legacy of urban exclusion, racially separated development and rural deprivation (South African Cities Network (SACN), 2016:10; Turok & Borel-Saladin, 2014:2; Marutlulle, 2022:9). The apartheid legislation, at its core, encouraged spatially segregated development by locating different population groups in particular urban spaces that were generally separated by a buffer zone (Financial & Fiscal Commission, 2012:202). The purpose of these segregated developments was to function as demographic growth poles, situated within daily commuting distances of former white areas that comprised the majority business and work opportunities that were linked with commuting corridors (Turok, 2012:9-11). The research of L'Etang (2013:13-19) verified that this spatial form was designed to racially discriminate against poor communities forcing them to live far from economic opportunities, generally within hazardous environments that lacked efficient services and infrastructure. Ruhiiga (2014:612) further highlighted that the cumulative consequences were wide ranging, ensuring the establishment of urban areas rooted in inequality that are spatially distorted, costly to manage and function poorly. Research conducted by Sithenkosi and Nzewi (2024:16) revealed that existing spatial planning policy directives have failed to attain spatial transformation, demonstrating that South African urban

areas are still entrenched by spatial and social economic segregation which enforce inequality and poverty.

As a consequence, the inclusion of environmental justice into South African spatial planning practices is recently considered as a paradigm shift to address the existing urban challenges. Through an extensive investigation, Ntiwane (2019:54) identified that environmental justice is regarded as the “fair and equitable distribution of environmental resources, services and activities to everyone, regardless of social structure, through recognition and the capability approach of providing equitable access to participate in appropriate procedures with substantive means towards achieving restorative processes and benefits”. While the inclusion of environmental justice into spatial planning is imperative, Ntiwane and Coetzee (2018:94) discovered that existing planning theory does not effectively incorporate environmental justice even though it gained recognition over the past decade. The authors further suggested that planning theory governs planning practices and, therefore, requires advancement to attain environmental justice. Das (2022:170) highlighted the importance of spatial planning in attaining environmental justice, identifying that urban development and zoning regulations are considered imperative components, since land use patterns dictate the provision of social facilities and accessibility. In endorsing the latter, Ntiwane (2019:313) recommended a new approach where environmental justice should be incorporated into spatial planning in addressing the inequalities experienced in existing planning practices. However, Van Zyl *et al.* (2021:130) revealed that even though environmental justice are considered imperative in planning practices, the lack of knowledge hinders its effective implementation.

The persistent environmental injustice experienced in South African dense, low-income areas was expressed by Kekana *et al.* (2023:3722), indicating that inefficient energy provision, high levels of poor air quality, lack of waste management and sanitation services affect the communities. Turok and Borel-Saladin (2014:682) verified that high population growth poses a significant risk for local municipalities to provide infrastructure and adequate housing, resulting in incessant urban sprawl through the establishment informal urban areas on the urban periphery. Research (Musakwa & Van Niekerk, 2014:76) investigating the dimensions of urban sprawl and its impact on sustainable development, revealed that low-density, monofunctional development and leapfrogging developments disconnected from urban centres created a fragmented and unsustainable urban form. As a result, these areas are heavily reliant on the use of privately owned vehicles that increase urban traffic and higher concentrations of poor air quality (Wang *et al.* 2023:2992). Moreover, employment of efficient zoning regulations in order to dictate land use patterns were identified as an imperative tool in facilitating healthier urban areas (Busayo *et al.*, 2019:6). Shikwambana and Tsoeleng (2020:211) observed that not only does effective zoning regulations establish sustainable urban forms that are effectively integrated, but also ensure that

marginalised communities are not situated in close proximity to primary poor air quality sources. While exposure to poor air quality sources should be avoided, Venter *et al.* (2020:8) identified that a major factor exacerbating poor air quality in dense, low-income areas was the lack of adequate green infrastructure. The authors expressed the importance of increasing tree cover to improve air quality and mitigate thermal stress.

2.5 The role of spatial planning in mitigating poor air quality within urban areas

Owing to growing health concerns experienced within global urban areas, spatial planning is continuously considered a solution to mitigate poor air quality within urban areas. Al-Thani and Isaifan (2024:417) identified that notwithstanding the major improvements in urban air quality through technological interventions, spatial planning approaches have performed a critical role in reducing emission concentrations. Compact urban development patterns were introduced as early as 1973 by Dantzig and Saatay in an effort to address fragmented development and urban sprawl. The aim was to implement concentrated development patterns that comprised higher densities to enhance urban resources and provide efficient urban infrastructure. Dadashpoor and Shahhossein (2024:7) investigated urban sprawl through an extensive literature review, defining it as the unsystematic and irregular growth that are characterised by low-density, mono-functional, segregated and transportation dependent development. Development generally occurs on the urban periphery through the change of rural landscapes into built up areas that increase land, soil and energy consumption.

Following the initial implementation of the compact urban development, the approach was augmented by incorporating mixed-land use development, provision of efficient public transportation systems and densification zones (Arbury, 2005:15). In doing so, Newman and Kenworthy (2015:300) demonstrated that the implementation of high density, mixed-land use development will result in the decline of per capita vehicle kilometres travelled, reducing transportation related emission. However, research conducted by Jenks and Jones (2010:6) identified that inefficient compact urban development may result in the loss urban green spaces and higher impervious surfaces. As a consequence, the authors highlighted that urban cooling and ventilation are affected that increase the emission dispersion rate, exposure and energy consumption. In response, Manzueta *et al.* (2024:7) underlined the importance of incorporating green infrastructure within urban areas to function as a buffer for poor air quality sources. The research identified that the employment of urban trees or shrubs adjacent to high order transportation corridors may dilute the emission concentration for pedestrians. However, Venter *et al.* (2024:6) contested this notion, revealing that at a street level urban trees had no significant effect on air quality, yet the increase in urban tree cover resulted in the mitigation of poor air quality at a regional scale. The reason for this was that a specific configuration of large trees can influence airflow and ventilation in urban areas, worsening urban air quality. While the research

of Hamad and Jasim (2024:227) acknowledged the findings of Venter *et al.* (2024:6), the authors argued that urban trees play a pivotal role in reducing poor air quality in urban areas. It was recommended that trees comprising a high poor air quality tolerance index and dust holding capacity should be considered, together with site-specific tree configuration in limiting the impact on airflow.

As discussed in Section 2.2 above, South African urban areas are confronted with significant health and environmental challenges. In response, the South African government introduced the NDP as the principal framework to guide future urban development in a sustainable manner. Albeit not specifically highlighting poor air quality in urban areas, the NDP proposes a paradigm shift by incorporating environmental concerns into spatial planning policy directives to limit energy intensive land use patterns that exaggerate poor air quality (National Planning Commission, 2012:236). Following the implementation of the NDP, the Department of Cooperative Governance and Traditional Affairs (2016:7) presented the Integrated Urban Development Framework (IUDF) to transform South African urban areas. The Framework was the first attempt to provide specific guidelines to address segregated development, recommending that spatial plans should identify areas for housing and services, spatial plans and transportation plans should be aligned and spatial plans should allocate land away from hazardous environments (Van der Berg, 2017:567). Verdini *et al.* (2025:4) underlined that, as a reference point, the IUDF recommended the implementation of the Compact City and TOD approaches to guide future urban development. These approaches were regarded as the most suitable options considering the development of South African urban areas into “tentacle patterns” where segregated areas are located on the urban periphery and connected with the urban centres through high order transportation corridors (Pieterse, 2002:3-37).

Despite its significance recognition by the AQA (2004), it is argued that limited attention is given to poor air quality challenges within South Africa during the development process. Research conducted by Alberts *et al.* (2021:299) identified that social and economic objectives gain precedence over environmental conservation during the development process. In supporting the latter, Baffi *et al.* (2018:311) highlighted that following the democratic dispensation, government addressed previous inequalities by developing subsidiary housing on the urban periphery rather than upgrading existing marginalised communities, resulting in biodiversity loss. While densification and infill development were recently introduced to combat incessant urban sprawl, private developers have not responded to the provision of high-density developments owing to the lack of demand in the existing market (Todes, 2012:163). Moreover, the research conducted by Todes (2017:135) in KwaDukuza demonstrated that private developers generally shape South African urban areas where planning permission for developments were provided in areas in

conflict with local plans. The latter resulted in quick, uncoordinated developments comprising high infrastructure costs that were unsustainable.

Responding to significant influence that private developers play in South African development patterns, Impact Assessment (IA) may well be considered as a contemporary approach in addressing growing South African air quality concerns. Rega and Bonifazi (2013:1343) stated that the objectives of IA are to ensure sustainable development, inclusion of environmental concerns into non-environmental policy sectors and democratic governance. This approach is globally recognised to investigate future consequences of a proposed or existing action that are included in the decision-making process of various government departments, namely; Strategic Environmental Assessment, Environmental Impact Assessment, Social Impact Assessment, Health Impact Assessment (Bond *et al.*, 2022:1), Traffic Impact Assessment (Padma *et al.*, 2020:3187) and Air Quality Impact Assessment (AQA, 2004). Even though IA is entrenched in existing policy directives in conserving South Africa's cultural diversity and natural environment, Retief *et al.* (2021:359) stated that a strategic level assessment instrument is required in guiding strategic-level decision-making within essential sectors in South Africa, inter alia; energy, conservation, transportation and water management.

2.6 Implementation of spatial planning approaches to mitigate poor air quality and verifying the impact

As discussed above, spatial planning has been considered as an additional solution to mitigate poor air quality within urban areas. The earliest solution was the implementation of London's green belt during 1938 in an attempt to curb urban sprawl and employing higher residential densities in close proximity to the urban centre. Even though the emphasis was not placed on air quality, the provision of higher residential development ensured that residents were not reliant on private vehicle use (Amati & Yokohari, 2007:316). While the implementation of the green belt had initial success, London persistently faced high levels of urbanisation that resulted in poor air quality. In response, the Greater London Authority introduced the London Plan that directed residential areas within the existing urban boundaries to conserve green open spaces. The Plan further incorporated higher density and intensification zones that were adequately incorporated with efficient public transportation systems, resulting in a more compact urban form (Fan & Chapman, 2022:11). In addition to the Plan, the Greater London Authority implemented financial policies, inter alia; Congestion Charge (2003), Low Emission Zone (2008) and Toxicity Charge (2017) in order to restrict the use of vehicles inside specific zones to limit transportation related emissions (Prieto-Rodriguez *et al.*, 2022:238).

Another global example is Toyama City in Japan that introduced a compact urban development as a response urban sprawl and associated decline within the centres. In response, the Toyama

City government adopted the Downtown Revitalisation Plan and Public Transport Revitalisation Plan during 2007 to attract residential and business development adjacent to transportation corridors and urban centres, promoting the use of pedestrian orientated development and a light rail transit system. While these plans were not intended to decrease poor air quality in urban areas, the transportation modal shift from private vehicles and busses to light rail transit resulted in the accidental reduction of carbon emissions (Fan & Chapman, 2022:11). Toyama City further introduced amended plans, concentrating urban activities within centres and adjacent transportation corridors through employing residence encouragement zones around public transportation nodes. As a result, residents were financially compensated when opted to move within these zones, promoting the use of pedestrian orientated transportation and the light rail transit system. Moreover, construction companies in Toyama City were subsidised when building eco-friendly houses within the residence encouragement zones, while residents were additionally compensated when purchasing aforementioned houses (Ito, 2019:35).

Similar approaches were adopted in Melbourne, Australia where densification of land uses was focussed within urban growth boundaries; especially surrounding activity centres and transportation nodes. This was done to restructure neighbourhood activity centres into 20-minute walkable neighbourhoods in order to reduce the dependency on vehicles (O'Reilly *et al.*, 2024:2). The Melbourne 2030: Planning for Sustainable Growth strategy was introduced during 2002 as a long-term strategy where compact development was implemented for the first time to guide future growth in a sustainable manner. The strategy identified urban growth boundaries as a means to restrict further urban sprawl, focussing on the development of high-quality activity centres within demarcated zones, while restricting development outside the urban growth boundary (Fan & Chapman, 2022:11). The City additionally implemented future goals in attaining net-zero greenhouse gas emissions by 2050. In doing so, emission reduction methods were incorporated through energy efficient building methods and design of commercial buildings within centres. This was attained by emphasising green buildings within the building approval process, together with renewable energy solutions (Jones, 2012:1256).

While global attention is growing towards the effective implementation of spatial planning solutions to mitigate poor urban air quality, the effectiveness of certain measures is often inconclusive or lacks supporting evidence (Hamad & Jasim, 2024:227; Venter *et al.* 2024:6; Fan & Chapman, 2022:11; Burton, 2000:1974; Schweitzer & Zhou, 2010:365). As a result, research continuously considers simulating the dispersion of urban emissions and air flow in identifying the impact urban characteristics. Research mostly employs computational fluid dynamics simulations, since it accurately incorporates the effect of building morphologies on a site-specific analysis. However, considering the recent progress of computational fluid dynamics research, the simulations remain excessively complex, computationally intensive, require expertise and are

expensive (Badach *et al.*, 2023:1). In addressing these limitations, research conducted by Martín *et al.* (2024:20) identified that Gaussian dispersion models may be considered as an alternative approach for simulating urban characteristic to inform spatial planning. The authors identified that the employment of Gaussian dispersion models show consistent application for simulating emission concentrations when compared to computational fluid dynamics, Lagrangian, and artificial intelligence models.

Gaussian dispersion models, in contrast to computational fluid dynamics simulations, are generally employed for regulatory purposes, since they are inexpensive to implement and are able to simulate various emission concentrations over an urban or regional scale (Patiño *et al.*, 2024:2). These models simulate the concentration of an emission at a specific point through employing the emission rate, meteorological conditions and distance from the poor air quality source. The preparation of the model is grounded on the assumption of normal distribution for horizontal and vertical crosswind dispersion, portraying the emission as a single plume that expands over time (Snoun *et al.*, 2023:222). Gaussian dispersion models simulate steady state conditions where emissions and meteorology stay constant over time. Complex building typologies and terrain characteristics are incorporated in an over simplified manner, while low wind speeds and chemical transformation can be modelled to a limited capacity (Di Nicola *et al.*, 2022:6). However, majority of recent research employs dispersion models to investigate existing processes of urban ventilation and the dispersion of urban emissions, focussing on building typology, transportation systems and urban greening (Badach *et al.*, 2023:11). While this approach may inform building morphology and urban design, it is argued that dispersion models may be employed in spatial planning for scenario simulation to determine the most effective solutions to mitigate poor air quality in urban areas prior to implementation, inter alia; appropriate urban form, densification zones, green infrastructure and TOD.

2.7 Conclusion

The chapter presented the disproportionate burden of poor air quality experienced by residents in South Africa; especially those residing in dense, low-income areas. Evidence from both international and local literature reveal that the most significant contributors to poor air quality include household air pollution, vehicle emissions, industrial activities and the resuspension of dust. Poor air quality episodes are intensified by the spatially segregated and fragmented nature of South African urban areas where dense, low-income areas are generally located on the urban periphery and lack sufficient infrastructure or services. As a result, it is considered that poor air quality is linked with spatial planning through land use patterns that increase private car dependency and locating of communities in proximity to primary poor air quality sources. Moreover, poor land use planning and rapid urbanisation exacerbate poor air quality. It is further identified that spatial planning is continuously considered as a possible means to mitigate poor

air quality in urban areas, however, existing South African policy directives struggled to address these complex challenges. As a consequence, the research will investigate whether spatial planning solutions may well be implemented as an alternative approach to mitigate poor air quality in South African dense, low-income areas.

Chapter 3 Methodology

3.1 Introduction

Considering the aim and research objectives identified in Section 1.2, a mixed research method is selected by implementing an exploratory sequential research design to investigate the relationship between poor air quality and South African urban areas. This methodological approach, in principle, involves an initial phase with the collection and analysis of qualitative data that is followed by second phase where quantitative data are collected and analysed to “build” on the initial results of the qualitative phase (Cresswell, 2009:195). Accordingly, the research will initially collect data from specific documents, analyse the results, create a tool or instrument and subsequently employ it to a case study for testing (Creswell & Creswell, 2018:349).

Fundamentally, the aim of the exploratory sequential design is to utilise quantitative data and analysis in an attempt to interpret the qualitative results. As a consequence, the rationalisation of this research design is to explore a phenomenon (Creswell & Plano-Clark, 2018:86). This design is not only suitable for testing components of an emergent theory resultant from the qualitative phase, but also for the generalisation of qualitative findings on different case studies (West, 2011:47). The sequential exploratory research design is generally preferred in instances where an instrument or tool should be developed, owing to the lack or inadequacy of existing instruments. This research design begins by collecting and analysing qualitative data. Based on the insights gained from the qualitative results, quantitative tools or instruments are subsequently developed for quantitatively testing the identified variables and interpreting how the quantitative data generalises and expands upon the qualitative results (Dawadi *et al.*, 2021:31). In doing so, Cresswell (2009:195) suggests that by using the three-phase approach, the researcher firstly employs a qualitative phase by collecting and analysing documents (Phase 1), employing the analysis in developing an instrument (Phase 2), and subsequently applying the instrument to a case study (Phase 3).

3.2 Investigate the manner in which the most significant contributing drivers to poor air quality are managed

In order to conduct the documentation review, the research employs theoretical sampling (Cohen *et al.*, 2018:714-717). This method involves continuously collecting data by adding sample units to the existing theory until saturation of the data is achieved (Cohen *et al.*, 2007:492). In doing so, sampling of qualitative data is conducted through purposefully selecting and identifying relevant information that are related to the research topic (Colon *et al.*, 2018:3). For the purpose of this phase, the collection of data is attained through investigating existing documentation

related to the research topic until data saturation is obtained, signifying that no further additional insights can be described from the data (Blair, 2015:16-18).

In identifying the most significant sectors and associated sources of poor air quality within South African urban areas and evaluating how are they managed within South African AQMPs (research Objective 1), a thematic analysis is used to characterise significant contributing drivers of poor air quality (Xiao & Watson, 2019:101). Following Figure 3-1 presents a flow diagram outlining the process followed for the thematic synthesis.

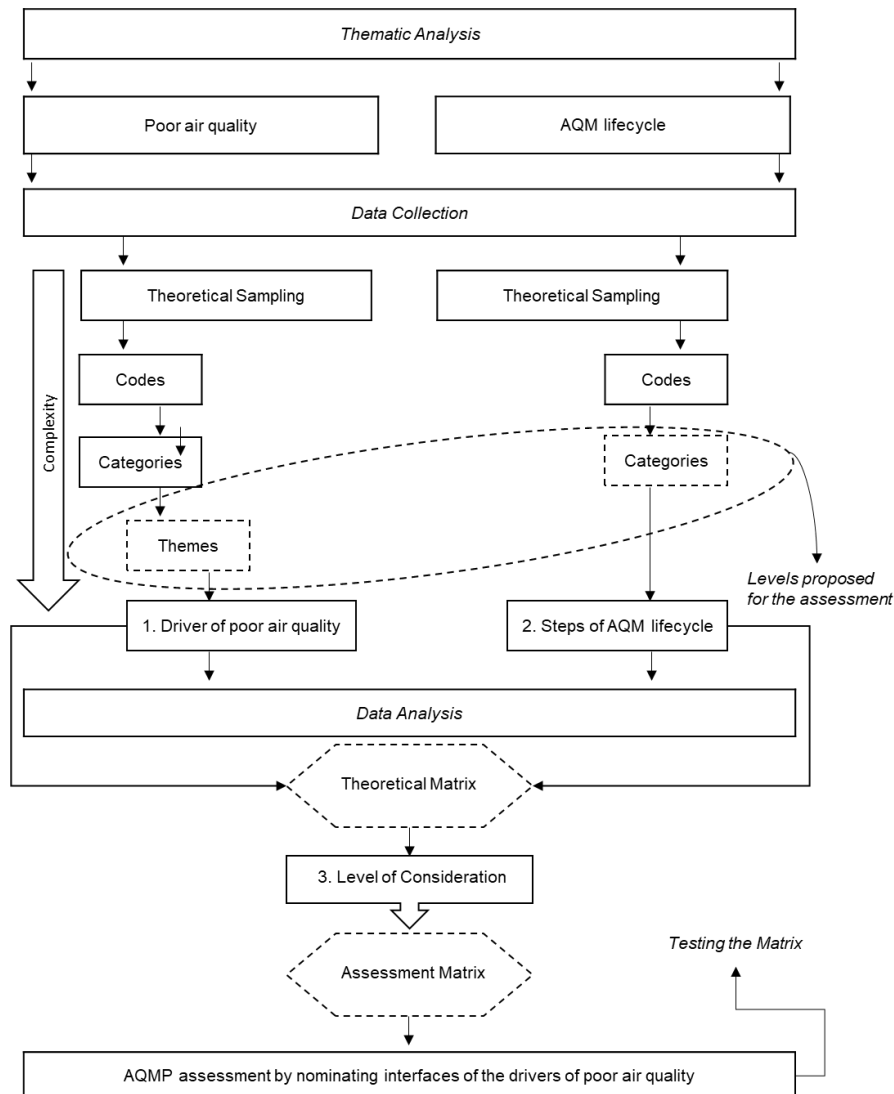


Figure 3-1: Methodology process for research Objective 1

For this purpose, documents relating to poor air quality within urban areas is investigated. This is done by collecting documents from online databases, employing search terms: “air pollution sectors”, “urban air pollution sources”, “sources of air pollution in developed countries”, “sources of air pollution in developing countries”, “sources of air pollution sources in South Africa” and “air pollution sources in South African low-income areas”. The preceding is subsequently analysed by employing close line-by-line reading (Benaquisto, 2008:87) in identifying and deriving as many

sentences and phrases as possible drivers of poor air quality codes. This process is followed until data saturation was attained, signifying that additional information will not provide any new insights (Hancock *et al.*, 2001:22). Subsequently, these codes are organised and reduced by applying a process of coding (Cohen *et al.*, 2018:668), where similar poor air quality drivers are allocated a single code (category) and where complexity of the data suggest progression, these codes (poor air quality drivers) are divided into themes (sectors). This method simplifies the organising or grouping of specific codes, since they comprise comparable attributes that are closely related (Lincoln & Guba, 1985:347; Locke *et al.*, 2023:268). Categories embody the fundamental attribute or topic of the identified text within phrases that illustrate the correlation between various assessment units (Cohen *et al.*, 2007:478). This is attempted to identify the most significant poor air quality sectors and their associated drivers of poor air quality within contemporary urban areas. These drivers of poor air quality (categories) are considered as the first element (rows) in the compilation of an assessment matrix (Averill, 2002:856) to evaluate the recently prepared South African AQMPs on various spheres of government.

3.2.1 Characterising the air quality management lifecycle

Identify an emission source

Similar to the preceding, the second phase constitute a document survey relating to AQM coupled with the current South African AQM directives. The main input phrases used are; “air quality management systems”, “best practice air quality management”, “South African air quality management” and “effective air quality management plans”. During the second phase, the process of coding was not considered as the documents are merely used to identify the most suitable components compulsory in the establishment of AQMPs in facilitating the mitigation of poor air quality. It is important to note that even though the research employs AQMPs to examine the current AQM practices in South Africa, the research does not attempt a document review by investigating the quality of the current AQMPs. The said AQMPs are merely used as an assessment tool to examine the AQM lifecycle of the identified drivers of poor air quality. Gulia *et al.* (2015:288) and Kura *et al.* (2013:5) note that, in order to manage poor air quality sources, a proactive AQM approach has to be followed for reducing the associated emissions effectively. In support, Sivertsen and Bartonova (2012:668) endorse that AQM should be regarded as a continual system that is dependent on a set of technical and analytic steps. While the investigation demonstrates that various steps are considered essential for the mitigation of poor air quality, the research deems it pertinent to exclusively consider the steps that place specific emphasis on the sources of poor air quality, in particular; (i) emission inventory, (ii) air quality standards, (iii) ambient monitoring, (iv) dispersion modelling and (v) mitigation strategies. Figure 3-2 below provides an illustration of the AQM lifecycle which is further clarified in the ensuing section.

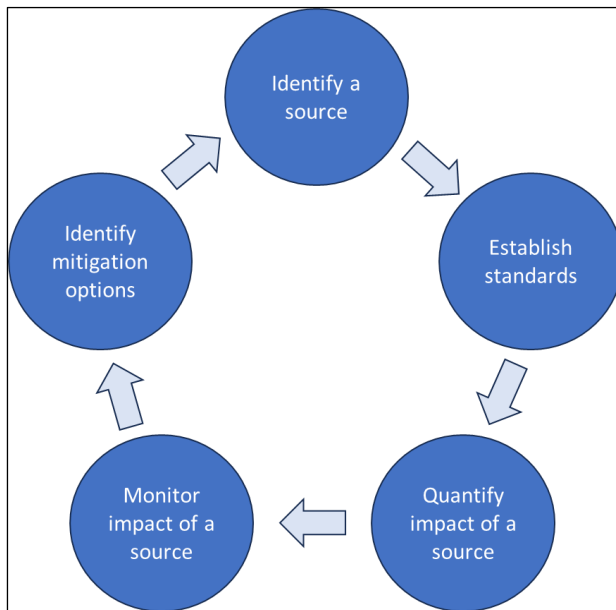


Figure 3-2: Air quality management lifecycle

The focus of this step is to provide a basic assessment of the current air quality status in a specific region in identifying the relevant sectors and activities responsible for poor air quality. This includes an overview of the classes and types of emissions, their contributing sources and characteristics (United Nations, 2016:9). By exploring the characterisation of poor air quality sources in current AQM, the research investigates the baseline assessment and preliminary inventories to identify the significant sources incorporated in AQMPs.

Establish standards

Air quality standards are considered as a benchmark for generating acceptable air quality objectives. The investigation identifies that in order to manage poor air quality effectively, government may consider implementing ambient, emission and technological standards (Field & Olewiler, 2015:2). Standards are deemed an integral step for effective AQM as they link a potential source with associated emissions (DEA, 2005:18). Thus, during the assessment of AQMPs, the research investigates to what extent all three above-mentioned types of standards are incorporated. Even if one of the standards is included in the AQMP, for example national ambient air quality standards, but the source or aspect of a source is not directly incorporated, the research accepts that the municipality do not adequately consider that particular source.

Quantify the impact of a source

Air quality models employ mathematical techniques to investigate the relationship between ambient air quality and emissions. These models aim to predict concentrations at receptor points by combining knowledge of emission sources and meteorological data (DEAT, 2008:26). Dispersion modelling is considered as among the most imperative steps in AQM as it identifies

dominant emission sources, simulate future air quality projections and assess the impact thereof, enabling government authorities to make informed policy decisions (Aggarwal *et al.*, 2014:356). Similar to monitoring, the research explores to what extent the poor air quality sources are dealt with in dispersion modelling. Consequently, when the AQMPs merely modelled specific emissions without linking it to the relevant source, the research assumes that the municipality fails to manage it appropriately.

Monitor the impact of a source

Monitoring networks should be implemented into the AQM process to provide accurate and continuous information regarding the status of air quality in a region. The planning, design and implementation of these networks should be aligned with air quality objectives. Monitoring is considered an essential step as it aids with the evaluation of existing policies and mitigating strategies (Gulia *et al.*, 2015:288). In assessing in the AQMPs, the research investigates the specific sources to determine how it is treated within this specific step. Therefore, when an AQMP only includes the monitoring of specific emissions, but fails to link it with the associated poor air quality source responsible for the emissions, the research presumes that the municipality does not appropriately comprehend this source.

Identify mitigation options

When preparing mitigation strategies, it is essential to focus on maintaining acceptable air quality through implementing appropriate control measures. The preparation of these strategies is generally informed through dispersion modelling. Nonetheless, the health impacts associated with poor air quality, the socio-economic and health costs should be regarded decisive factors when preparing strategies (Gulia *et al.*, 2015:293). In so far as the assessment of mitigation strategies in AQMPs, the research investigates the specific measures implemented for the sources identified in the characterisation step.

As deliberated above, the AQM and its associated steps are introduced as a contemporary approach for mitigating poor air quality through their inclusion into AQMPs. As a result, the research will employ the aforementioned categories by exploring to what extent practitioners and regulators consider poor air quality sources in AQMPs. In doing so, the research will utilise the identified poor air quality sources and AQM steps in the development of an assessment matrix to conduct the analysis. This is considered an appropriate means for investigation, since the AQMPs are expected to reflect the current understanding of poor air quality sources in the current South African AQM system.

3.2.2 Preparing the assessment matrix

As precedingly discussed, the research aims in evaluating the inclusion of the identified poor air quality sources in prepared AQMPs and their consideration throughout the AQM lifecycle. This will be conducted in determining whether all identified poor air quality sources are considered in current AQM practices, together with their level of mitigation. The matrix will be compiled by using the data obtained from the thematic analyses deliberated above. The identified poor air quality sources will be considered as rows in the matrix, while the components necessitated in AQMPs for the effective management of poor air quality sources will be considered as the columns. This will be applied to investigate whether the sources identified in literature are effectively managed in current South African AQM practices. Ensuing Table 3-1 demonstrates the poor air quality sources identified in the literature and documentation review.

Table 3-1: Identified poor air quality sources from documents

Sector	Poor air quality source	Sector	Poor air quality source	Sector	Poor air quality source
Transportation	Vehicle tailpipe emissions	Agriculture	Controlled Burning	Industrial	Machinery
	Motorcycle tailpipe emissions		Ploughing		Mineral Product Manufacturing
	UV tailpipe emissions		Harvesting		Resource Collection
	Taxi tailpipe emissions		Fertiliser		Metallurgical Industry
	Bus tailpipe emissions		Pesticides		Rubber manufacturing
	Freight Transport		Grain Processing		Sugar Manufacturing
	Rail		Livestock Feed Operations		Wood Product Industry
	Airport		Heavy Machinery		Paper Mills
	Port	Mining	Machinery		Oil Refineries
	Driving Cycles (Speed/Trips)(L/I)		Mining		Mechanical Grinding(L/I)
	Non-exhaust emissions(L/I)		Vehicle Entrained Dust		Liquid Storage Tanks
	Traffic Volume		Fugitive Dust		Coating
	Travel Distance		Mine Tailings		Boilers
	Vehicle Age		Mine Drilling		Smelter
	Engine Technology		Mine Blasting		Power Stations
	Vehicle Entrained Dust		Quarrying		Fertiliser and Pesticide Manufacturing
Commercial	Vehicle entrained dust	Construction	Flaring	Natural	Brick Manufacturing
	Dry Cleaning		Coal Mine Fires		Windblown dust
	Print Shops		Demolition		Veld Fires
	Combustion/Cooking		Land Clearing	Other	Military Sources(L/I)
	Food Processing		Material Burning		Deforestation
	Food Preparation		Construction		Storage and Handling Piles
Waste	Meat Product Manufacturing	Household	Construction Materials (Cement)		Municipal Grass Burning
	Building Waste Removal		Space Heating and Cooking		
	Solid Waste Landfills		Cooking Appliance		
	Open Burning		Household Cleaning Products		
	Water Treatment Plants		Smoking		
	Waste Incineration (L/I)		Indoor Gas Stoves(L/I)		
	Medical Waste Incineration		Office Equipment(L/I)		
	E-waste Recycling(L/I)		Diesel Generators(L/I)		
	Domestic Waste Burning		Grass Burning		
	Industrial On-site Burning (Sugar Mills, Wood Residue)		Household Insulation(L/I)		
	Tyre Burning		Pesticides		

The assessment will be conducted by nominating interfaces between the identified poor air quality sources and each respective AQM step mentioned above. In producing an insightful assessment of the AQMPs, the research deems it appropriate to employ the data from the nominated interfaces in a percentage value. This value will be attained by dividing the total nominated interfaces of a poor air quality source in relation to a respective AQM step of all the AQMPs and

subsequently dividing it with the total AQMPs of 21 (n=21). Table 3-2 below illustrates a summarised version of the assessment matrix that will be employed in evaluating the AQMP.

Table 3-2: Assessment Matrix

<u>Purposefully Selected AQM Steps</u> <u>Purposefully Selected Poor Air Quality Sources</u>	Categories				
	AQM Steps				
	Inventory	Standards	Dispersion	Monitoring	Mitigation
<u>Significant Categories</u>					
Vehicle tailpipe emissions					
Vehicle Entrained Dust					
Manufacturing					
Power Stations					
Oil Refineries					
Smelter					
Landfill Sites					
Solid Waste Burning					
Fugitive Dust					
Space Heating and Cooking					
Food Processing					
Controlled Agricultural Burning					
Tillage					
Crop Sprays					
Coal Mine Fires					
Mine Tailings					
Mining					

3.2.3 Selection of South African AQMPs

The assessment of AQMPs is deemed an appropriate means for investigation, since the plans are expected to reflect the current understanding of poor air quality sources within the South African AQM system. It is imperative to note that the research makes no attempt to evaluate or criticise the quality of existing AQMPs, but rather investigates the manner in which the poor air quality sources are treated in facilitating the implementation of effective mitigating strategies.

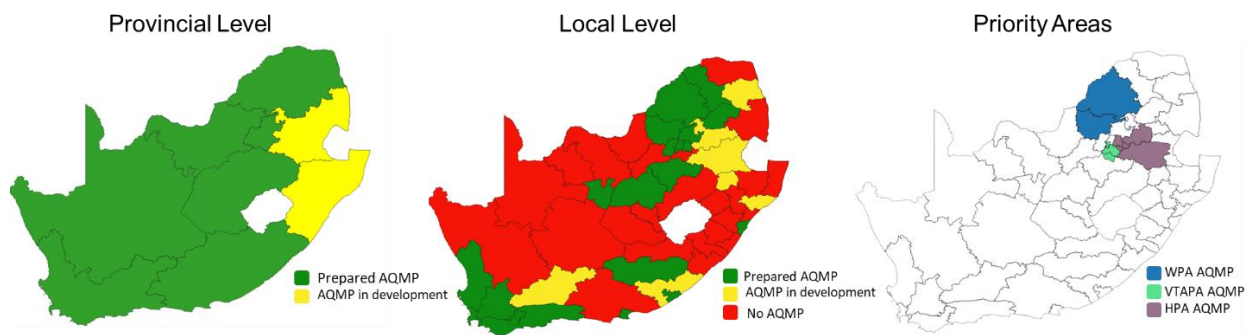


Figure 3-3: South African prepared air quality management plans

Source: South Africa Air Quality Information System

Figure 3-3 above illustrates the locality of the selected AQMPs within their respective Municipal, District, Provincial and Air Quality Priority Areas demarcated areas in South Africa. The purposefully selected AQM steps are all embedded in or should be embedded in the preparation of AQMPs. The AQA (2004) and its associated Framework for Air Quality Management in South Africa (2012) additionally instructs that certain key steps should be considered during the preparation of AQMPs. Consequently, AQMPs is regarded as a decisive instrument in, inter alia, the attainment air quality within urban areas, further endorsing their selection to assess their consideration of poor air quality sources within the AQM steps. The assessment of the identified poor air quality sources within each respective AQM step in determining their consideration during the preparation of the AQMPs will be conducted in Chapter 4.

3.3 Investigating the alignment between spatial planning and air quality policy directives

Similar to the process followed in Section 3.2, the research employs a thematic analysis in investigating the level of interface between the South African air quality and spatial planning directives (research Objective 2). Figure 3-4 below presents a flow diagram outlining the process followed for the thematic synthesis.

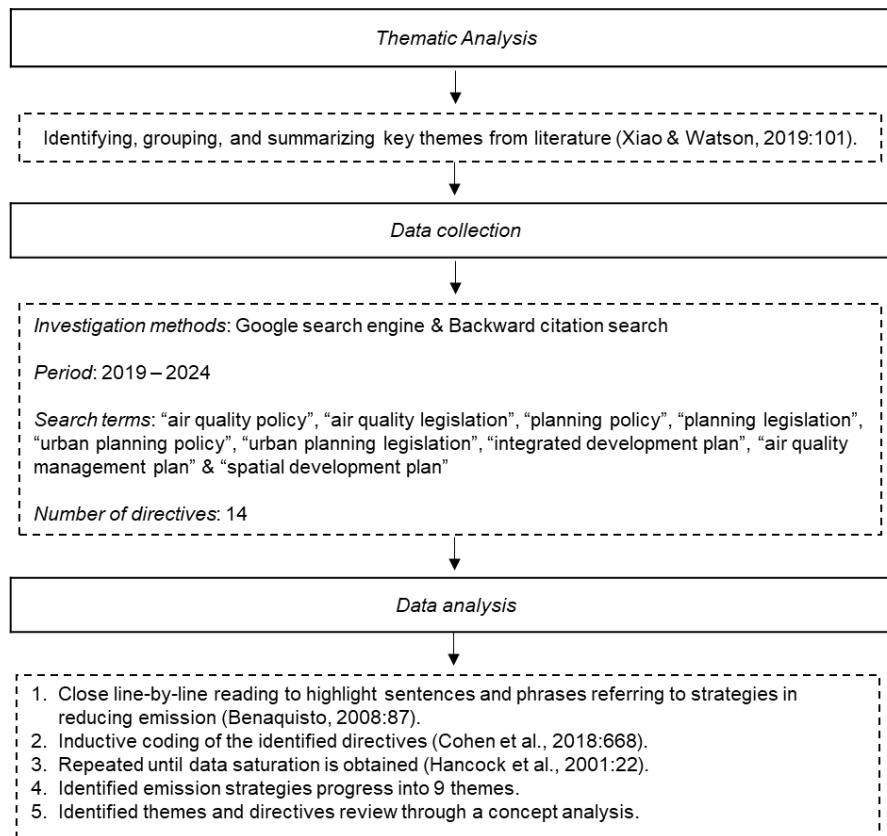


Figure 3-4: Methodology process for research Objective 2

A thematic analysis is conducted to investigate the alignment between existing South African policy, legislation and guidelines (policy directives) governing AQM and spatial planning. The policy directives are collected through a Google search and followed by backward citation searches and cross-references within documents. The search terms included: “South Africa” AND (respectively) “air quality policy”, “air quality legislation”, “planning policy”, “planning legislation”, “urban planning policy”, “urban planning legislation”, “spatial planning policy”, “spatial planning legislation”, “urban planning guidelines”, “spatial planning guidelines”, “integrated development plan”, “air quality management plan”, and “spatial development plan”.

A total of fourteen documents are identified, namely; NDP, Medium-Term Strategic Framework (MTSF), National Transport Master Plan (NATMAP), The National Land Transport Strategic Framework (NLTSP), IUDF, NSDF, SPLUMA, MSA, the Guidelines for Human Settlement Planning and Design, the AQA, National Framework for Air Quality Management, Manual for Air Quality Management and Planning and the Strategy to address poor air quality in dense low-income settlements: a “burning” issue.

The accumulated documents are subsequently reviewed through close line-by-line reading (Benaquisto, 2008:87) to identify sentences and phrases concentrating on strategies or framework recommended for mitigating air quality. The process is followed until saturation of the data was attained (Hancock *et al.* 2001:22). The identified sentences and phrases are

subsequently reduced by applying a process of inductive coding (Cohen *et al.*, 2018:668) where a single code (label) is allocated to similar focus areas, while the selected codes are finally progressed into themes. The nine most prominent themes identified are (i) Air quality Monitoring and Management, (ii) Spatial Planning, (iii) Green Energy, (iv) Low-Carbon Economy, (v) Natural Environment, (vi), Green Economy (vii) Low-Carbon Energy, (viii) Low-Carbon Transportation, and (vi) Sustainability. The aforementioned themes are employed in a concept analysis of the collected directives to investigate the level of alignment of between AQM and spatial planning in South Africa.

3.4 Exploring the contemporary spatial planning approaches that may be conducive to mitigate poor air quality

Similar to the methodological approach used in Section 3.3, the research utilises a thematic analysis to determine the possible contemporary spatial planning approaches that may well improve poor air quality (research Objective 3). Ensuing Figure 3-5 presents a flow diagram summarising the process followed for the thematic synthesis.

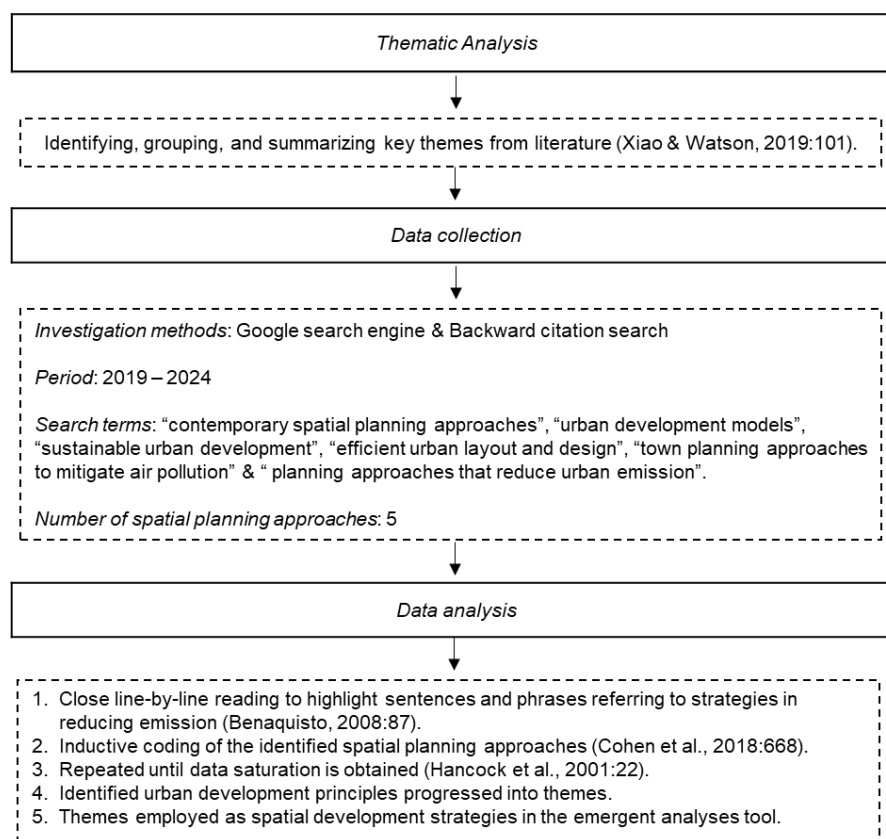


Figure 3-5: Methodology process for research Objective 3

As indicated above, a thematic analysis is followed by exploring contemporary spatial planning approaches that may be conducive in addressing poor air quality within urban areas. The spatial planning approaches are determined by employing a Google search and subsequent backward

citation searches and cross-references within the accumulated documents. In collecting the preceding, the search terms used are: “contemporary spatial planning approaches”, “urban development models”, “sustainable urban development”, “efficient urban layout and design”, “town planning approaches to mitigate poor air quality” and “planning approaches that reduce urban emissions”.

In doing so, five contemporary spatial planning approaches, namely; compact city, TOD, smart growth, new urbanism and green urbanism, are identified that may well be implemented to mitigate poor air quality within urban areas. These documents are then reviewed through a detailed, line-by-line reading process (Benaquisto, 2008:87) to identify sentences and phrases related to “urban development principles” that may be introduced as a response to poor air quality in urban areas. The review continues until data saturation is reached (Hancock *et al.*, 2001:22). The identified sentences and phrases are further refined through inductive coding (Cohen *et al.*, 2018:668), assigning a single code to similar focus areas, which are then developed into themes.

Seven key themes are identified, in particular; (i) Urban Densification, (ii) Urban Integration, (iii) Public Transportation, (iv) Mixed Land use Development, (v) Urban Regeneration, (vi) Green Corridors, (vii) Green Buffer. The aforementioned themes are incorporated as “urban development principles” within the emergent analyses tool to investigate whether it may be implemented as a possible solution in mitigating poor air quality within the purposefully selected case study, namely; Sasolburg-Zamdela.

3.5 Determining whether spatial planning solutions may be implemented to mitigate poor air quality

In investigating the possible spatial planning solutions that may well be implemented on a municipal level to reduce poor air quality (research Objective 4), the research will develop an appropriate analyses tool for a case study. In doing so, the research selects the employment of a dispersion model, namely; AERMOD to investigate the variation of emissions within the purposefully selected case study when applying the “urban development principles” within the dispersion model. For the purpose of the research, AERMOD is considered a suitable analysis tool, since it is utilised for modelling atmospheric dispersion by employing a near-source steady-state Gaussian plume model that is appropriate for diverse locations and is based on contemporary characterisation of atmospheric boundary layer sources, suitable for both complex and flat terrains (Ridzuan *et al.*, 2020:357). AERMOD is mainly utilised for regulatory emissions dispersion modelling that may be applied to various pollution sources, specifically; line, point, volume and area sources (Idris *et al.*, 2019:120). Additionally, the model may be used for the influence of planetary boundary layer variation on vertical dispersion, whereas the stable boundary layer assumes a Gaussian distribution of the plume in both horizontal and vertical

directions. While the horizontal distribution remains Gaussian in the convective boundary layer, the vertical dispersion is represented employing a bi-Gaussian probability density function. Moreover, AERMOD has the capability to incorporate the effects of building wake using the PRIME algorithm (UI Haq *et al.*, 2019:1492). AERMOD is adequate for modelling on a local scale for distances not exceeding 50km that applies urban pollution sources at a small regional sphere, since the model presumes that the meteorological conditions remain uniform within the modelling domain (Langer & Klemm, 2011:640).

AERMOD is considered the main program in the modelling system that comprises two input data processors, namely; AERMET and AERMAP (Langer & Klemm, 2011:641). AERMET software is used to calculate common meteorological conditions (temperature, wind and turbulence profiles) as data inputs in computing the boundary layer based on existing meteorological data. AERMAP software applies geological data by means of gridded terrain parameters to compute terrain height for the modelled domain in determining the ground level altitude for the emission sources and receptors, and subsequently transfers the data to AERMOD (Idris *et al.*, 2019:120). Terrain data may be obtained from online commercial sources in the form of elevation data files in various formats that are imported into AERMAP to generate base elevations for all the pollution sources (US EPA, 2016b:2-9). Figure 3-6 below illustrates the sequence of operations that will be followed in order to develop AERMOD for the case study analyses.

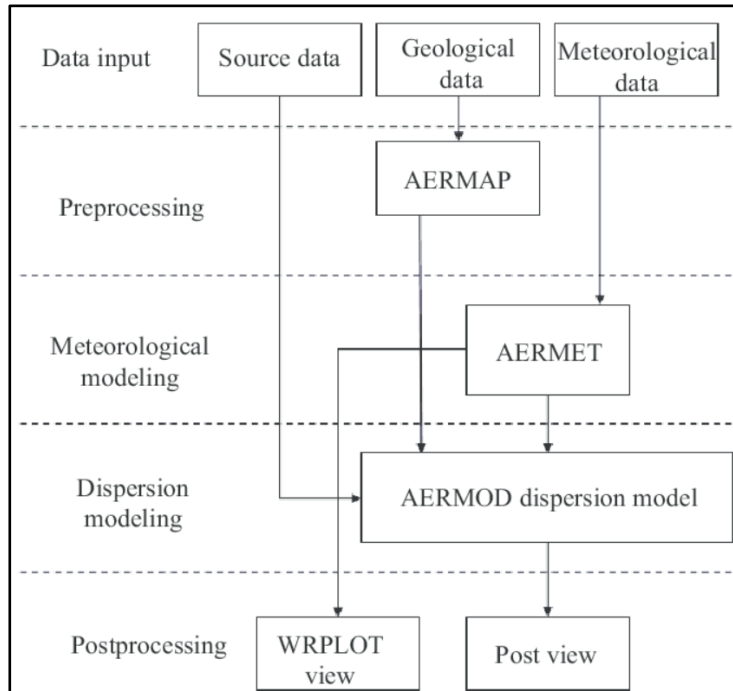


Figure 3-6: Process of the AERMOD modelling system

Source: Seangkiatiyuth *et al.*, 2011:934.

In view of preceding Figure 3-6, the development of the AERMOD Model that will be employed in assessing the implementation of spatial planning solutions to reduce poor air quality through the incorporation of various input data is discussed in the ensuing sections.

3.5.1 Identification of sources and estimation of PM_{2.5} emissions

Gwaze and Mashele (2018:3) elucidate that environmental and government authorities are responsible for measuring air quality at various monitoring stations across South Africa. These stations are generally located in densely populated urban areas in measuring the impact of poor air quality on South African citizens. Even though a limited number of the stations provide reliable data (Tshehla & Wright, 2019:2), the benefit of these stations is their ability to measure a variety of substances over prolonged periods that may be employed for long-term air quality estimations in assessing the effect of interventions (Gwaze & Mashele, 2018:3). For the purpose of the research, PM_{2.5} concentrations for various poor air quality sources will be investigated, since it is regarded as both a “primary pollutant, emitted directly from sources, and secondary pollutant formed in the atmosphere from gaseous precursors”, posing significant health risk for South African citizens (Cairncross, 2016:1).

As discussed in Section 3.2 above, a thematic analysis will be conducted in Chapter 4 to identify all possible poor air quality sources responsible for emitting PM_{2.5} in the study area. A desktop survey will be conducted through Planet GIS and Google Earth to highlight all properties (erven, small holdings and farmland) within the study area and associate poor air quality sources to each respective property relating to its activity. In estimating PM_{2.5}, AERMOD is commonly utilised to simulate proximations derived from measurements of similar source types, since measuring air quality for all the identified activities within the study area are nearly impossible (Watson *et al.*, 2012:146). As a consequence, the research groups the identified activities emitting PM_{2.5} (as identified in Chapter 4) into eight poor air quality categories, namely: (i) Windblown Dust, (ii) Transportation, (iii) Domestic Waste Burning, (iv) Space Heating and Cooking, (v) Biomass Burning, (vi) Industry, (vii) SASOL Industry, (viii) Landfill Site and (ix) Hospital. PM_{2.5} emissions will be quantified for the identified activities within each of the preceding poor air quality category and subsequently employed as an input into AERMOD to simulate the air quality within Sasolburg-Zamdela. This is conducted to estimate the level of contribution for each poor air quality category by employing emission factors and activity rates.

3.5.2 Emission factors

Emission factors are coefficients that quantify the number of pollutants released into the atmosphere from a specific source relative to the level of activity. The emission factors are typically expressed as the mass of a pollutant emitted per unit, for instance; for fine particulates

generated by vehicles is expressed as grams (g) of PM_{2.5} emitted per kilometre (km) travelled or as a proportion of the consumed fuel (Ho *et al.*, 2019:1060). For the purpose of this research, emission factors from existing literature and international policies are used for emission estimates. Considering that variation in literature sources may negatively influence the analyses, quality control will be conducted in ensuring that the employed emissions factors are relevant for the case study. The ensuing section provides an explanation for calculating the contribution of each poor air quality category by employing the applicable emission factor.

Windblown Dust

There are numerous assumptions when calculating windblown dust emissions, namely; it is assumed that the emissions follow a constant process where it is irregularly based on the meteorological conditions and activity variables (Liebenberg-Enslin, 2014:21). Moreover, emissions from windblown dust are dependent on the size of particulates, the specific activity that causes suspension, surface roughness and surface loading (Chang, 2006:23). As a consequence, emissions will be calculated in ensuing Equations 1 to 4 based on the Airborne Dust Dispersion model from Area Sources (ADDAS) model (Burger *et al.*, 1997). Model inputs will be set to include parameters that are based on research conducted by Liebenberg-Enslin (2014) and the Department of Environment, Forestry and Fisheries (2020).

$$E(kg.m^{-1}.s^{-1}) = 10^{(0.134C-6)} \times Q \times EF \quad 1$$

$$Q = C_o \frac{\rho a}{g} u^{*3} \times (1 + Y) \times (1 - Y) \quad 2$$

$$Y = \frac{U_t^*}{U^*} \quad 3$$

Where: E = emission rate

c = percentage of clay content

ρa = air density given at 1.22 kg.cm⁻³ of the typical atmosphere

g = gravitational acceleration given at 9.80665 m.s⁻²

u^* = friction velocity

U_t^* = threshold friction velocity

C_o = constant of proportional valued at 2.61

Friction velocity in the boundary layer is usually expressed in terms of the friction velocity and the height (z) as:

$$u(z) = \frac{u^*}{K} \ln\left(\frac{z}{z_o}\right) \quad 4$$

Where: K = von Karman constant (~0.4)

Transportation

Numerous factors influence the quantity of emissions emitted by vehicles that makes it exceedingly challenging to calculate vehicle emissions accurately. However, previous research (García-Olivares *et al.*, 2018:266; Yang & He, 2016:378; Wang *et al.*, 2022:2992) concur that vehicle emissions are considered as among the main contributors to PM emissions within urban areas. Vehicle emissions will be calculated based on research conducted by Thomas (2008), Colville *et al.* (2001) and the European Environment Agency (2019).

$$E(t.yr^{-1}) = EF (g.veh^{-1}.km^{-1}) \times VF \times L (km) \times 365 \quad 5$$

Where: EF = emission factor estimated in grams per kilometre travelled

VF = vehicle flow representing volume and mode of transportation

L = road length of vehicle travelled in kilometres

Modes of transportation that will be considered in the calculation of vehicles emissions are passenger cars, mini-bus taxis, light-duty vehicles and heavy-duty vehicles, employing emission factors that are verified by previous research. Ensuing Table 3-3 presents the emission factors that will be used in calculating the vehicle emission for each transportation mode.

Table 3-3: Vehicle emission factors in (g.veh⁻¹.km⁻¹) for PM_{2.5}

Transportation Mode	PM _{2.5}
Passenger Cars	0.0095 ± 0.007
Mini-bus Taxis	0.038 ± 0.004
Light-duty vehicles	0.015 ± 0.0015
Heavy-duty Vehicles	0.130 ± 0.019

Source: Ferm & Sjöberg (2015); Smit *et al.*, (2017); Zhao *et al.*, (2018) and European Environment Agency (2019).

Considering that accurate traffic count data is limited within the case study, the research used physical traffic count data conducted by Tshisi (2023) and Chidhindi (2022) for calculating vehicle emissions in Zamdela. Subsequently, since no traffic count data is available from SANRAL or any previous research for Sasolburg, the research assumed that each residential property comprises two passenger cars. As Sasolburg is regarded as a high-income residential precinct, the latter is validated by employing the South African Trip Data Manual, indicating that a single-family residential unit generates four trips per day (two in AM peak period and two in PM peak period) (Committee of Transport Officials, 2013:40). Subsequently, a similar approach through

referencing the South African Trip Data Manual will be used to calculate trips for the business centres, light industrial and heavy industrial areas. Furthermore, Geographic Information System (GIS) road datasets will be employed to determine the length of the roads, together with the type of road (class and surface) that are imperative when allocating emission factors. Since the case study is situated within an urban area, the average speed limit selected for the calculations is considered 60 km.h⁻¹ as stipulated by the South African National Road Traffic Act (1989) and its regulations for public roads within an urban area.

Domestic waste burning

Poor service delivery predominantly in dense, low-income areas result in high levels of open burning of domestic waste. In calculating the emissions from domestic waste burning, ensuing Equation 6 that was validated in the research conducted by Wiedinmyer *et al.* (2014) will be used.

$$E(t.yr^{-1}) = EF(g.kg^{-1}) \times WB(kg.yr^{-1}) \quad 6$$

Where: **EF** = emission factor calculated in grams per kilogram of the fuel burned

WB = total amount of solid waste burnt per kg per burning period.

The emission factor used to calculate PM_{2.5} from domestic waste burning is 9.8 g.kg⁻¹ (Wiedinmyer *et al.* 2014:9525).

The total amount of solid waste burned is the most critical activity data necessitated to calculate the emission of domestic waste burning. Following Equation 7 will be employed in calculating the total amount of solid waste openly burned per kg per annum (Wiedinmyer *et al.* 2014:9524).

$$WB(kg.yr^{-1}) = P \times Pfrac \times MSWg(kg.person.day^{-1}) \times Bfrac \times 365 \quad 7$$

Where: **P** = total number of people in the urban area (2011 Census Data)

Pfrac = fraction of total population that burn waste (General Household Survey, 2018). In Zamdela, it is estimated that approximately 10% of municipal solid waste is not collected. In Sasolburg, it is assumed that all waste is collected by municipal waste services and is considered in ensuing "Landfill" sector.

MSWg = annual waste generated per capita. The research presumes that an amount of 0.41 kg/person/day waste is generated in Zamdela (DEA, 2009).

Bfrac = fraction of municipal waste that is burnt in relation to the total amount of waste exposed to the fire. The research opted for a fraction of 0.6 as recommended by Wiedinmyer *et al.* (2014).

Space heating and cooking

The majority of South African citizens; particularly those residing in dense, low-income areas, are reliant on dirty fuels for their basic needs (Manyatsha *et al.*, 2022:64). Most of these citizens use coal, paraffin and wood for space heating and cooking, since it is considered as the most affordable and accessible option when compared to cleaner energy alternatives (Kapwata *et al.*, 2018:1). In calculating the impact of this sector, ensuing Equation 8 will be employed where the emission rates are estimated by multiplying fuel consumption with the emission factor as recommended in the research conducted by Mkhonto (2014) and Nkosi (2018) that investigated similar circumstances in dense, low-income areas.

$$E(t.a^{-1}) = EF(g.kg^{-1}) \times BC(kg.HH.yr^{-1}) \quad 8$$

Where: E = emission estimate in tons per year

EF = emission factor estimated in grams per kilogram of the fuel burned

BC = fuel consumption rate measured as kilogram of fuel per household per burning period

The emission factors that will be used for the purpose of this research are adopted from research conducted by Nkosi (2018), Makonese *et al.* (2015) and Chidhindi (2022). Please refer to Table 3-4 below, summarising the emission factors for each fuel source.

Table 3-4: PM_{2.5} emission factors for space heating and cooking per fuel source.

Fuel source	Emission factor for PM _{2.5}
Wood	13.5 ± 7.2
Coal	10.15 ± 6.7
Paraffin	0.63 ± 0.02
Gas	0.068 ± 0.01

Source: Nkosi (2018), Makonese *et al.* (2015), Chidhindi (2022) and Lavhelani (2021).

The rate of fuel consumption that will be employed is obtained from previous studies, namely; Nkosi (2018), Makonese *et al.* (2015), Chidhindi (2022) and Lavhelani (2021), together with the 2011 Census data. In view of the latter, it will be estimated that the average coal consumption per household is 4.9 kg to 9.1 kg per day during winter and between 3.3 kg and 6.9 kg per day during summer. For wood consumption, it will be estimated that on average households use approximately 20 kg per day during summer and 35 kg per day during winter. Consumption estimates for paraffin will be converted from litres to kilograms in order to calculate the emissions. Consequently, a density of 800 kg.m⁻³ will be employed for the calculation. In order to calculate gas emissions, the quantities will be converted from litres to tonnes, employing a density of 0.54 kg.l⁻¹ as defined by Afrox. Finally, the 2011 Census data will be used to demarcate the case study

in identifying the number of households and their respective use of each fuel source for various applications, namely; cooking, space heating and lighting.

Industry

Sasolburg-Zamdela comprises four distinct industrial areas, namely; one light industry area and SASOL Industry south of Eric Louw Way, together with the new light industrial area and SASOL Industry north of Eric Louw Way. The land uses identified during the desktop survey for the southern light industrial area indicated that the majority activities are associated with vehicle and dust emissions, since the land uses are mostly for commercial, building supplies and panel beaters. For the new northern light industrial area, the activities are also associated with vehicle and dust emissions, since the land uses are mostly large freight companies, distribution centres, cement and brick manufacturing and scrapyards. Moreover, since SASOL Industry generates a large number of traffic and comprise vast open spaces, vehicle and dust emissions will be calculated for both areas north and south of Eric Louw Way. Therefore, equations 1 to 5 above will be employed to calculate the emission rates for windblown dust and transportation for these areas. It should be noted that the emission rate for the SASOL Industry stacks will be calculated separately and is discussed in the ensuing section.

SASOL Industry

For the purpose of the SASOL Industry, the location of the existing stacks is identified and will be incorporated within AERMOD. In calculating the emission rate of the stack, data from previous research conducted by the North West University over VTAPA will be employed. It should be noted that the latter only calculated PM_{10} from industrial stacks and, as a consequence, had to be converted to $PM_{2.5}$ for the purpose of this research. In doing so, a fraction of the available emission measurements will be used to convert PM_{10} to $PM_{2.5}$. The latter is supported by Krause and Smith (2006:2), indicating that a fraction of 0.9 may be employed to convert existing PM_{10} measurements to $PM_{2.5}$. Therefore, the research will convert the available PM_{10} data from the VTAPA project in obtaining the necessary $PM_{2.5}$ concentrations that will be employed in AERMOD for dispersion modelling over the case study.

Landfill site and hospital

Similar to the industrial areas discussed in the preceding “Industry” sector, the landfill site and hospital are deemed area sources that are mostly responsible for fugitive dust and vehicle exhaust emissions. The reason for this is validated by the notion that only $PM_{2.5}$ will be considered for dispersion modelling of the case study. In relation to the landfill site, South Africa generally accommodates municipal solid waste within prepared layers that are subsequently covered with soil, resulting in vast unvegetated areas that generate fugitive dust emissions. Moreover, vehicle

exhaust emissions are generated at these sites through frequent visits of garbage trucks, together with heavy utility vehicles at the site. With reference to the size and nature of the Fezi Ngubentombi Provincial Hospital adjacent to Eric Louw Way, it was also considered to be a major traffic generator that comprises large unvegetated areas. Therefore, equations 1 to 5 above will be used to calculate emission rates for windblown dust and transportation over the landfill site and hospital. Also, two stacks (as discussed in preceding “SASOL Industry” sector) are considered for the Fezi Ngubentombi Provincial Hospital.

3.5.3 Setup of the AERMOD model for the case study

As discussed in the ensuing section, Sasolburg-Zamdela is selected as an appropriate case study by employing AERMOD in determining whether contemporary spatial planning approaches may well be employed as a solution to mitigate poor air quality in South African dense, low-income areas. AERMOD comprises two compulsory input data preprocessors, namely; (i) AERMET that is responsible for processing the meteorological data for the model domain and (ii) AERMAP that processes landscape data for the model domain.

AERMET

AERMET presents a general meteorological preprocessor that transforms raw meteorological data into a format appropriate for the use in AERMOD. It is initially employed to process surface meteorological data, surface characteristics and upper air soundings, creating two input data files, namely; surface data and profile data (US EPA, 2024a:1-1). The processing of these data files occurs in two distinct stages that are not related to the type of data being processed and may be run together or separately in one AERMET run. The aim of this is to characterise the vertical structure of the planetary boundary layer and the surface layer of the model domain. For the purpose of the research, meteorological data obtained from Lakes Software for 2016 will be employed and the measured surface profile parameters selected for processing are temperature, wind speed and direction and relative humidity. Subsequently, the data files will be aligned into 24-hour periods through processing the profile of the surface data, upper air data and site-specific data. Finally, the aforementioned data files will be integrated in providing a data input file for mixing height and planetary boundary layer. The process discussed above are illustrated in Figure 3-7 below.

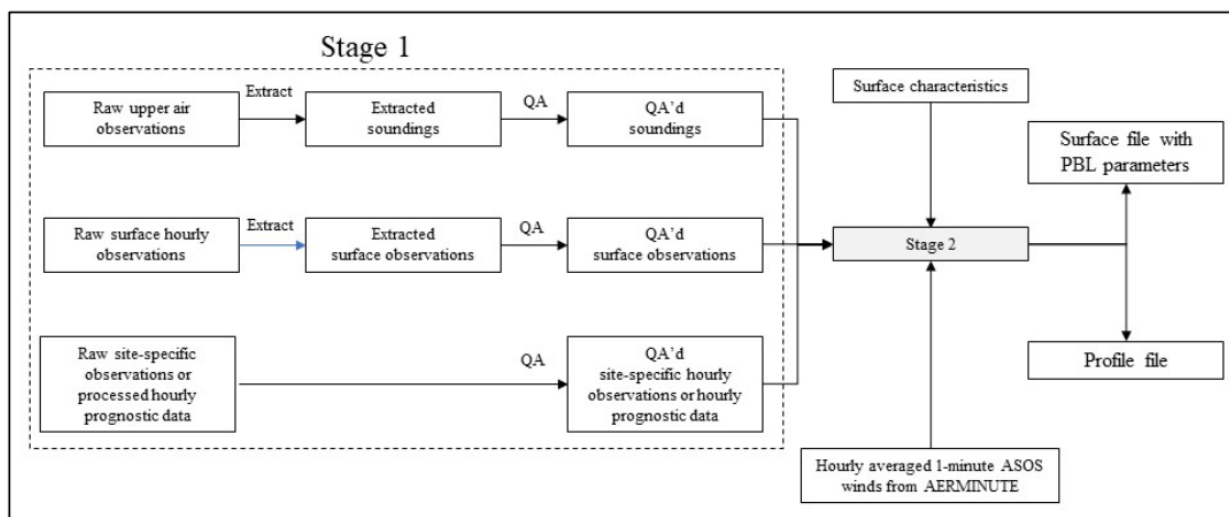


Figure 3-7: AERMET processing stages

Source: US EPA, 2024a:1-1.

AERMAP

The AERMAP processor will be employed in processing terrain data, together with input layers comprising poor air quality sources and receptors. AERMAP is capable of processing multiple standardised data formats that enables it to generate terrain base elevations for the incorporated sources and receptors, in addition to hill height scale values for each receptor within the model domain. Given that varying terrains significantly affect emission concentration at discrete receptors, AERMAP performs an imperative function in defining the base elevation at each source and receptor within the model domain. Consequently, AERMAP identifies the terrain height and location that exert the greatest impact on dispersion for each receptor (US EPA, 2018:1-1). In preparing AERMAP for the case study, topographic data will be collected from Shuttle Radar Topography Mission, while the land cover data will be obtained from WebGIS at a resolution of ~30m. The terrain of the case study domain will be established by employing the World Geodetic System 1984 (WGS84) projection datum on the Universal Transverse Mercator (UTM) coordinate system 35° South. Sasolburg-Zamdela are classified as an urban area, comprising a flat and elevated terrain.

AERMOD input data

The domain of the case study will be selected to include all urban areas identified within Sasolburg-Zamdela in investigating the impact of PM_{2.5} emissions. In doing so, it is deemed suitable to demarcate the case study at 16.38 km by 16.77 km, representing an urban area that comprises a flat and elevated terrain. The data period that will be considered for the case study is from 1 January 2016 until 31 December 2016 in representing 24 hour averaging periods for a

year. In attaining an exhaustive simulation of the localised effect of the identified poor air quality sources, a receptor grid will be set at 800m x 800m over the case study domain, together with discrete cartesian receptors within the neighbourhoods. The selection of the grid cell size is guided by the need to represent terrain and meteorological variations at a high resolution, while considering computational time required for modelling. Ensuing Figure 3-8 illustrates the case study domain, together with the receptor grid and location of the discrete cartesian receptors that will be modelled.

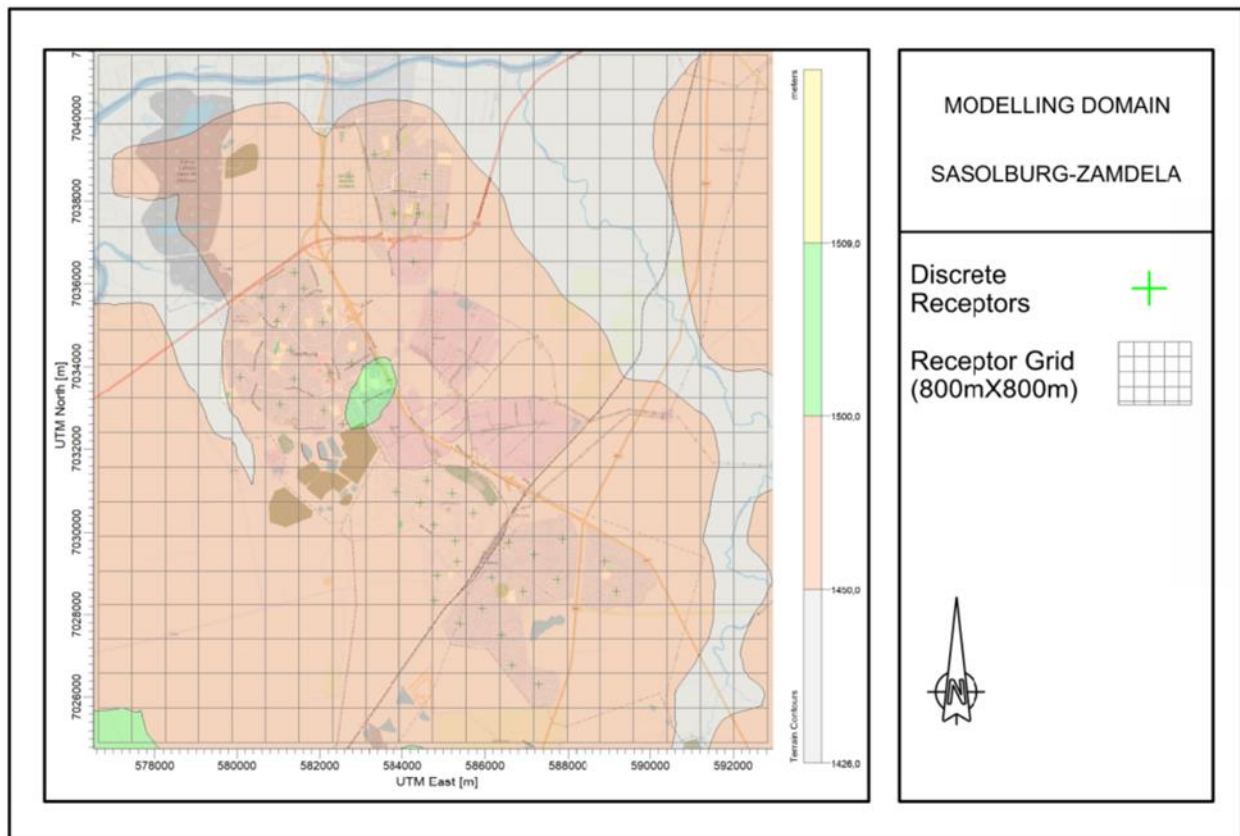


Figure 3-8: Modelling domain for Sasolburg-Zamdele

The AERMOD model currently supports six poor air quality source types that may be employed for dispersion modelling, namely; point, volume, area source, non-buoyant line, buoyant line and a newly added source type to investigate the building downwash effect when winds are oblique towards the face of a building (US EPA, 2024b:3-55). The desktop survey of the case study, identified three primary poor air quality source types that will be included in AERMOD for investigating the emission concentrations, namely, AREA_POLY, AREA_LINE and POINT. It is important to note that the input parameters for each source type vary and the compilation thereof for each respective source type are ensuing discussed.

The AREA_POLY source type will be used in specifying an area as a source that comprises a random shape of generally between three to 20 sides, however, the number of sides may be

increased through the modification of the NVMAX parameter in MODULE MAIN1. Utilising this source type grants significant flexibility to the user for specifying the shape for a certain area (US EPA, 2024b:3-67). Ensuing Table 3-5 that summarises an example of the input parameters for an AREA_POLY source type.

Table 3-5: Example of input parameters for an AREA_POLY source type

Model input	PM _{2.5}
Type	AREA_POLY
Identification	PAREA1
Description	Brownfield
Base elevation	1490
Release height	0.3
Emission rate (g/(s-m ²))	4.2627590E-07
Number of coordinates	16
X1 coordinate	581857.42
Y1 coordinate	7032488.00

The research considers it feasible to identify the following as area sources; (i) Windblown Dust, (ii) Domestic Waste Burning, (iii) Space Heating and Cooking, (iv) Biomass Burning, (v) Industry, (vii) Landfill Site and (viii) Hospital. Considering that the urban morphology and its associated land uses present a unique and complex challenge for modelling the case study domain and subsequently employing the “urban development principles”, the research deemed it feasible to incorporate various poor air quality sources under one sector, representing the total emission concentration for the respective area. Moreover, all small internal roads within neighbourhoods will be calculated and included into the particular area source, since these roads comprise lower traffic volumes, emission concentrations per unit length and present short and irregular patterns. The preceding results in complex emission characteristics that make area sources a suitable option to accurately approximate emissions in comparison to line sources. It is imperative to note that for AREA sources, the emission rate parameters that will be incorporated within the input file represent the emission rate per unit area. Therefore, for the purpose of the research, the emission rate parameter that will be calculated for AERMOD is represented as g/(s-m²).

In calculating emission concentrations for the Transportation sector, AERMOD enables the user to employ an AREA_LINE that is modelled as a line source where emissions are spread along a path, representing an elongated area source. The emission rate is included in g/(s-m²) and deemed to be distributed across the entire road width, in contrast to concentrating the emissions at a single point along the length of the road (US EPA, 2024b:3-71). The AREA_LINE source is considered as the most feasible option for modelling vehicle emissions, since arbitrary coordinate

points may be included into the source parameters to accurately represent the respective road. Moreover, various major roadways will be modelled in the case study and the AREA_LINE facilitates to designate the road width for each respective roadway. Ensuing Table 3-6 provides a summary of the input parameters for the AREA_LINE.

Table 3-6: Example of input parameters for an AREA_LINE source type

Model input	PM _{2.5}
Type	AREA_LINE
Identification	ARLN1
Description	Corridor
Base elevation	1490
Initial sigma Z (release height)	0.3
Length X (road width)	40m
Emission rate (g/(s-m ²))	1.4016509E-07
Line area ratio	10 (default)
Number of coordinates	24
X1 coordinate	587757.58
Y1 coordinate	7025812.33

Finally, the POINT source type is utilised to model poor air quality sources where emissions originate from a distinct location that comprises a vertical release height, for example; industrial stacks, flare stacks, cooling towers, etc. The latter is considered, since the combination of temperature and exist velocity enable AERMOD to estimate how far the plume will rise prior to dispersing. Additionally, the estimation of POINT sources incorporates the buoyance effect of emission that calculates the plume rise and dispersion (US EPA, 2024b:3-71). While it is acknowledged that the “urban development principles” (that will be discussed in Chapter 7) cannot mitigate PM_{2.5} emitted from the SASOL Industry, the research considers it appropriate to include the sector, since it is regarded as among the main contributors of poor air quality within the case study. Even though the PM_{2.5} cannot be directly reduced when employing the “urban development principles”, the impact thereof on the citizens may well be mitigated. The latter is deliberated in the following section for each respective development model. It is necessary to highlight that in contrast to the AREA_POLY and AREA_LINE source types, the emission rate parameter for the POINT sources input file is represented as g/s. The input parameters for the POINT sources are summarised in Table 3-7 below.

Table 3-7: Example of input parameters for a POINT source type

Model input	PM _{2.5}
Type	POINT
Identification	STCK1
Description	SASOL_CHEM
Base elevation	1490
Release height	20
Diameter of inner stack	0.95m
Exist velocity	6.5m/s
Exist temperature	1125K
Emission rate (g/s)	8.9200000E-06
Number of coordinates	1
X1 coordinate	587864.54
Y1 coordinate	7035060.26

Employing AERMOD on Sasolburg-Zamdela to investigate the effect of the spatial planning solutions

In completing the empirical phase, the analysis of a case study is considered as the most suitable approach (Yin, 2003:1), since the research attempts to address numerous “how” questions. Zainal (2007:1) states that a case study approach may be regarded as a rigorous analysis method when a detailed investigation is necessitated, enabling researchers to explore and understand a complex phenomenon. Yin (2012:4) further describes the case study approach as a means to extensively investigate current events within an actual setting. For this reason, the research opted for a single case study approach. The implementation of a single case study approach is applied when experiments on one entity are investigated during a specific time period, under diverse circumstances with at least one independent variable (Onghena, 2005:1850). Gaya and Smith (2016:533) reiterate that the investigation of a single case study provide tremendously compelling data to test emerging theories, provided that the opted entity comprise unique attributes and features necessitated in attaining the objectives of the research. As a result, the aforementioned is regarded an applicable research approach, since a single case may well provide more detail and robust results for testing an emergent theory (Løkke & Dissing-Sørensen, 2014:69).

The research deems it appropriate to select a type-C urban area within South Africa as a case study. The Council of Scientific and Industrial Science (CSIR) (2012:11) categorises a type-C urban area as a large town or regional service centre, comprising population ranging from 100 000 to 350 000. The selected urban area will be assessed by means of the AERMOD dispersion model in investigating the viability of spatial planning as a possible solution conducive to the mitigation of poor air quality in dense, low-income areas. Cohen *et al.* (2007:253) signify that case

studies include various hallmarks, validating the selection of this particular case study for the research, specifically; it depicts an extensive and meaningful explanation of events applicable to the research; it combines explanation with analyses of events and it emphasises explicit events that are applicable to the research. The selection of the case study is guided by the following criteria:

- In consideration of the research aim, it is regarded appropriate to select a South African urban area that experiences high levels of poor air quality, owing to its fragmented and separated urban form, endures continuous urban sprawl and comprises dense, low-income areas with insufficient infrastructure and service delivery,
- Selection of an urban area that is separated by a physical buffer, in particular; industrial activities, where the dense, low-income areas are situated away from economic activities that result in long daily commutes and dependency on privately owned vehicles.
- It is further deemed preferable to select a case study that is characterised as a type-C urban area, since the inputs into the emergent assessment tool will be more manageable in comparison to large data inputs of metropolitan areas and major cities within South Africa.

In view of the latter, the research selected a type-C urban area situated in the Free State Province, namely; Sasolburg-Zamdela. Figure 3-9 below illustrates the locality of the selected case studies in their demarcated Provinces within South Africa.

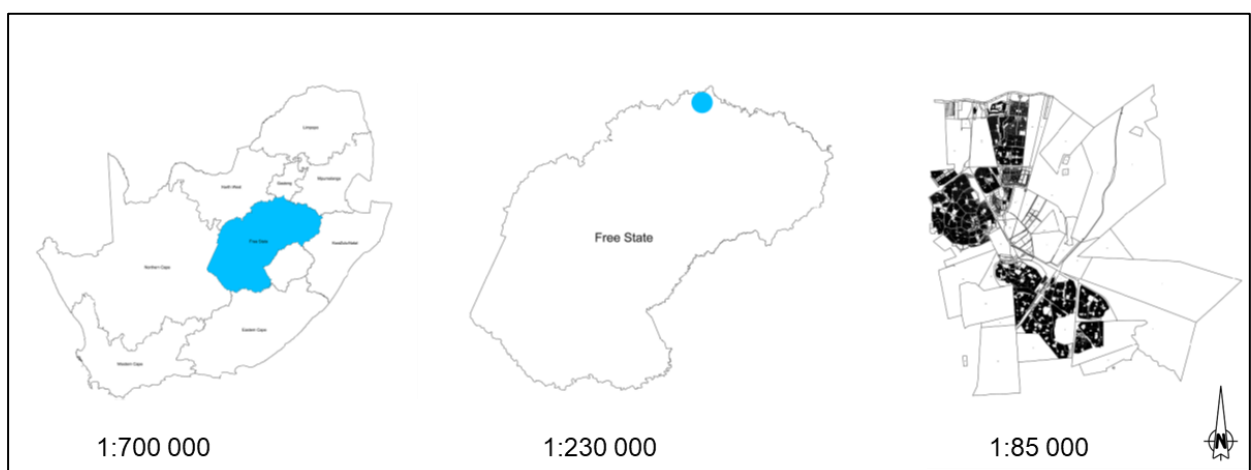


Figure 3-9: Locality map illustrating Sasolburg-Zamdela in relation to South Africa and Free State

3.6 Conclusion

The chapter presented the methodological approach opted in order to attain the research aim and objectives presented in Chapter 1. The rationale for the research approach was extensive discussed for each phase of the research and the specific techniques that will be employed. The subsequent chapters will present the results of the research, commencing with the literature review.

Chapter 4 – Investigating contributing drivers of poor air quality

4.1 Introduction

This chapter aims to address research Objective 1:

1. To identify, analyse and evaluate specific contributing drivers of poor air quality in South African dense, low-income areas.

From the commencement of the industrial revolution, poor quality and pollution episodes became a regular phenomenon in cities worldwide (Emberson *et al.*, 2001:107). These episodes are principally associated with fossil fuels combustion, emitting SO₂, carbon monoxide, nitrogen dioxide and PM emissions into the atmosphere (Choudhary & Garg, 2013:1). Studies indicate that these emissions have negative human health impacts, resulting in, inter alia, chronic respiratory diseases, lung cancer, tuberculosis and eye infections (Barnes *et al.*, 2009:4; Gómez-Baggethun & Barton, 2013:237; Cohen *et al.*, 2017:1908). Currently, poor air quality is a major health concern in various areas around the world; particularly in developing countries that are extensively reliant on fossil fuels for energy demands, while lacking proper air quality legislation and implementation (Fenger, 2009:19). Additionally, in developing countries a considerable amount of citizens reside in dense, low-income areas, making this population the most vulnerable group for poor air quality, owing to the lack of infrastructure, services and social-economic status (Zimmerman *et al.*, 2017:2).

South Africa encounters similar challenges due to rapid population growth and urbanisation, resulting in higher energy consumption. The combustion of fossil fuels for electricity at power plants to sustain the industrial, transportation and residential sectors are significantly contributing to poor air quality (Pretorius *et al.*, 2015:28). Furthermore, segregated developments exerted during the apartheid era resulted in the establishment of dual urban areas in close proximity to industrial areas and were situated within daily commuting distances from urban centres. This ensued in the racial separation of housing, infrastructure and service provision, preventing the delivery of drinking water, sanitation services, waste removal, adequate housing and electricity (Salo, 2014:6). Considering the preceding, Thambiran and Padayachi (2017:37) are convinced that ineffective spatial planning and deficient air quality legislation resulted in the poor air quality that many South African urban areas experience currently.

Moreover, air quality in South Africa was governed by the Atmospheric Pollution Prevention Act (APPA) (1965) that did not establish objectives or standards aimed at maintaining a healthy and clean environment for all South African citizens as prescribed by Section 24 of the Constitution (Thambiran & Diab, 2010:4). In addition, Moreoane (2021:12) states that the APPA adopted a

source-based approach by providing air quality standards and guidelines for specific poor air quality sources, while recommending limited regulatory measures for noise, dust and vehicle emissions. Accordingly, the APPA (1965) was revoked with the promulgation of the AQA (2004), signalling a paradigm shift in AQM from a fragmented to a holistic approach (Naiker *et al.*, 2012:63). In encouraging this vision, Engelbrecht and Van der Walt (2007:7) suggest that the AQA (2004) was the first ever South African air quality legislation that aimed to protect the environment through implementing mitigation strategies rather than simply regulating poor air quality. This is attained through Section 15(1) of the AQA (2004:18), requiring metros, districts and local municipalities to accept AQMPs as part of their compulsory IDP to facilitate appropriate planning and institutional procedures (Engelbrecht & Van der Walt, 2012:408). It is considered that this approach is the most effective means for mitigating poor air quality as observed by effective implementation of AQMP in urban areas globally (Gulia *et al.*, 2015:287).

Patel *et al.* (2020:2) affirm the importance of emission inventories as fundamental tools to accurately quantify pollutant emissions, understand their sources and develop strategies to effectively mitigate poor air quality. In extending this notion, Li *et al.* (2019:4326) reiterate emission inventories play an essential role in verifying the precision of emission data, comprehending the spatial dispersion of pollutant emissions, pinpointing primary sources of emissions, analysing annual variations in pollutant concentrations and facilitating research into urban pollution. However, the research conducted by Tshehla and Wright (2019:2) reveal that since the commencement of the AQA (2004), no formal research has been completed to identify and quantify all poor air quality sources, urging future investigations on source apportionment to efficiently implement mitigating strategies. Keita *et al.* (2021:3692) confirm Tshehla and Wright's view, arguing that the majority emission inventories currently available are developed at a global scale and are not specific for regions in Africa, resulting in discrepancies of emission factors and distribution of poor air quality sources. In view of the latter, the structural arch of this chapter will investigate global and local documents that address drivers of poor air quality within urban areas, namely; energy generation, transportation, mining and industries, household air pollution, agriculture and waste management in an attempt to identify possible poor air quality sources.

4.2 The most significant and associated sources of poor air quality

Poor air quality is unique for each country as the level and frequency of different sources differ from countries that implement strategies to restrict emissions in relation to countries that continue the use dirty fuels as the main source of energy for development (Fowler *et al.*, 2020:21). The ensuing section discusses the general sectors within global and South African urban areas contributing to poor air quality in an attempt to identify all possible poor air quality sources.

4.2.1 Energy generation

Recent studies indicate that coal-fired power plants are considered as one of the most significant sources of poor air quality worldwide, owing to its accessibility and affordability (Banica & Istrate, 2016:831; Amster & Levy, 2019:1; Koplitz *et al.*, 2017:1467; Adil'bayeva *et al.*, 2016:1). In supporting the latter, Xiang *et al.* (2023:8-9) identify that energy generation through the combustion of fossil fuels substantially contribute poor air quality. It is argued that the impact of energy generation not only have a significant effect on localised air quality, but also on wider regions owing to spatial spillover (Zhou *et al.*, 2023:14). Consequently, the spatial distribution of power plants plays a significant role on localised air quality, since the air pollution emitted by the facilities contribute to high levels of PM and gaseous emissions in surrounding areas (Cichowicz & Steleowski, 2018:49-50). In addition, the authors determine that the general wind direction could have a major influence on the concentration of air pollutants in the areas surrounding power stations. The latter highlights that the general wind direction is an important factor when considering the location of future power plants.

Tong *et al.* (2018:12909) indicate that coal-fired power plants have a greater impact on the environment when compared to other sources of poor air quality sources. The reason for this is that power plants are not only significant contributors of global greenhouse gases, but also effect ecosystems and biodiversity through deforestation and the destruction of riverbeds (Hudedmani *et al.*, 2016:693-694). Additionally, Gao *et al.* (2018:250) reaffirm the exposure to emissions emitted from coal power plants have critical health corners, inter alia; heart disease, lung cancer, high mortality rate, stroke and obstructive pulmonary disease. As a result, efforts on mitigating emissions emitted by power plants have been investigated, suggesting that focussed emission reduction strategies and the decommissioning of inefficient and small-scale power plants may well result in a decline in air pollutants (Maennel & Kim, 2018:1). Additionally, Wilkie *et al.* (2022:309) maintain that the promulgation of emission control policies; especially the employment of a wider energy mix, are an effective means in attaining climate, air quality and health benefits.

South Africa, in a similar fashion, is heavily reliant of fossil fuels for energy generation, contributing more than 83% of the total CO₂ emission in South Africa (Pretorius *et al.*, 2015:4). Morakinyo *et al.* (2020:2) confirm that South Africa depends significantly on dirty fusels for electricity generation, with the national energy mix of approximately 94% attributed to coal. This is resultant from supplying affordable and ample electricity to industries as part of the South African industrial development strategies. Even though the South African Government implemented directives in reducing emissions emitted from coal-fired power plants, the abundance of coal, cheap labour and vast additional subsidies will presumably hinder the mitigation of energy generation related emissions (Pretorius *et al.*, 2015:4). In addition, Langerman *et al.* (2023:1) lament that none of the coal-fired power plants owned by Eskom are compliant with the emission standards enforced

by the South African Government during 2020. As a consequence, it is estimated that these power plants exceed the Minimum Emission Standards of SO₂ by 3 to 6 times. The concern is that the elevated levels of SO₂ oxidises in the atmosphere, creating secondary sulphate aerosols that raise PM_{2.5} levels within the area (Morosele & Langerman, 2020:2). The preceding is especially concerning within the declared Priority Areas where power plants regularly exceed Minimum Emission Standards to support mining and industrial activities (Cairncross *et al.*, 2018:330). The aforementioned emphasises the major air quality challenges South Africa faces, owing to the extensive dependency of dirty fuels used for energy generation.

4.2.2 Transportation

Transportation; especially vehicles comprising diesel and gasoline engines, is continually affecting air quality on a global and local scale (Winkler *et al.*, 2018:1). Currently, 94% of the global vehicle fleet are dependent on fossil fuels (García-Olivares *et al.*, 2018:266), emitting a significant amount of harmful emissions in the form of CO₂, carbon monoxide, hydrocarbon, nitrogen oxides, polycyclic aromatic hydrocarbons and PM (Davidson & Naidoo, 2018:2). Owing to population growth and high levels of urbanisation over the past few decades, transportation emissions have increased significantly. Lucas (2011:5) concurs, indicating that growing urbanisation increases the number of privately owned vehicles, diesel dominated freight fleet and airlines. Moreover, the planning and design of urban transportation systems influences the agglomeration of land use patterns, associated emissions and urban health (Romero-Ania & Oliva, 2021:2). Consequently, the road transportation sector is considered amongst the main sources of poor air quality within urban areas (Yang & He, 2016:378). In a study investigating emission levels for various transportation modes, Cepeda *et al.* (2017:29) observed that private vehicles and busses are considered the main transportation contributors to poor air quality in urban areas.

Although certain transportation modes contribute significantly to poor air quality in urban areas, research suggest that driving patterns play a pivotal role in the emissions emitted by the transportation sector. Ericsson (2000:338) affirms this notion, depicting that the effect of driving patterns on poor air quality is complex and a challenge that is influenced by multiple factors, namely; urban form, design and layout of street networks, time of day and industrial activities. Zhou *et al.* (2018:2) further stress that urban form particularly affects the emissions emitted by the transportation sector, owing to urban traffic patterns and the travel behaviour of citizens. The reason therefor is that a sprawling or fragmented urban form increases travel distances and poses various challenges to provide sufficient public transportation services (Tiwari *et al.*, 2021:1385). Wang *et al.*'s (2023:2992) research that investigated the relationship between urban traffic and air quality, further demonstrated that the increase in urban traffic result in higher pollutant

concentrations, especially in dense urban areas. Zulfikri (2023:25) shares Wang *et al.*'s (2023:2992) findings by asserting the use of privately owned vehicles increase the exposure to poor air quality in urban areas. In addressing the latter, the author recommends that transportation associated emissions can be mitigated through the use of efficient public transportation to decrease overall ridership.

Additional efforts aimed at mitigating transportation related emissions within urban areas have focussed on spatial planning and land use policies, urban form and decision-making (Wang *et al.*, 2022:5547). Strategies intended to promote walking/cycling, efficient public transportation and sustainable urban transportations systems are proposed as means to decrease emissions from the transportation sector (Kuşkan & Çodur, 2022:52). In concurrence, Ambarwati and Indriastuti (2019:49) establish that implementation of an effective rail system is imperative to not only address urban mobility challenges, but also resolve associated poor air quality within rapidly expanding urban areas. Their investigation shows that the total vehicles and associated emissions within an urban area can be decreased with the introduction of a highly functional rail system.

While the transportation sector in South Africa has similar impacts on poor air quality in urban areas, the factors are contrasting to those of developed countries owing to the nature and characteristics of contemporary South African cities (Haq & Schwela, 2012:1). During the previous regime, spatial planning policies enforced spatial segregation by locating dense, low-income areas outside the urban periphery and away from economic centres and employment opportunities (Shilpi *et al.*, 2018:5). This spatial disparity between segregated urban areas and employment centres caused long commuting distances for the majority of South African citizens, resulting in the dependency on privately owned vehicles (Kerr, 2017:323). Moreover, the majority segregated urban areas generally do not comprise adequate public transportation infrastructure, further aggravating the reliance on privately owned vehicles or mini-bus taxis (Chakwizira *et al.*, 2011:61; Lourens, 2012:21). The lack of effective public transportation encourages more citizens to use unsustainable modes of transportation that increase the emissions emitted by the transportation sector (Gwilliam *et al.*, 2004:4).

Despite various efforts introduced since the advent of democracy, it appears that infrastructure inequalities still persist in formerly segregated urban areas, inter alia; poorly maintained roads and railways, prevalence of unpaved roads, lack of non-motorised transportation facilities and limited modes of public transportation (Rukema, 2022:4). Beltran *et al.* (2012:2) extend the notion, arguing that the lack of sufficient infrastructure within dense, low-income areas result in non-exhaust particulate emissions in the form of road dust resuspension. Also, the failure to afford more sustainable transportation modes traps the majority of South African citizens in a cycle of reliance on high-emission modes of transportation (Lucas, 2011:6). Even though strategies are

implemented within the metros to reduce transportation emission, the mini-bus taxi industry currently dominates the public transportation modal split; especially in dense, low-income areas (Allen, 2013:5). This is a major concern considering that these mini-bus taxis comprise old engine technologies and are limited to the number of passengers compared to other public transportation modes, resulting in a larger vehicle fleet (Noah, 2002:9).

4.2.3 Mining and industries

This sector provides a sufficient and incessant supply of raw materials utilised in the manufacturing, building and construction sectors necessitated for a country's economic development (Fugiel *et al.*, 2017:159). Giljuma *et al.* (2022:1) lament that rapid growth of affluence and rising demand for minerals to produce energy transition technologies, infrastructure and consumer products resulted in the exponential growth of global mining operations over the past 20 years, extracting approximately double the resources when compared with 2000. Accordingly, mining activities are considered among the main contributors to global poor air quality, both directly and indirectly (Kumar & Rajput, 2022:734). Mining generally necessitates the excavation and movement of vast quantities of rock and earth, resulting in the suspension of dust. Mining activities through blasting, drilling, sizing and the transportation of minerals on gravel roads release coarse and fine particles, contributing to poor air quality (Mishra & Das, 2017:2). In addition, Bugarski and Hummer (2020:121) insist that the prevalent use of diesel-powered machinery, owing to the durability and cost-effectiveness, are considered among the main contributors of poor air quality in mining regions. The mining of metals, processing of minerals, smelting and combustion of fossil fuels emit numerous pollutants into the atmosphere (Zhou *et al.*, 2019:1). These pollutants include, inter alia; SO₂, CO₂, NO_x, VOCs, lead, mercury and arsenic that have long lasting effect on air quality (Ghosh *et al.*, 2014:263).

The establishment of mining regions often involve the clearing of vast areas in accommodating mining activities and associated infrastructure (Giljum *et al.*, 2022:1). As a consequence, mining not only results in the deforestation within lease boundaries, but also beyond. While forests are cleared for mineral excavation, processing and associated infrastructure within lease boundaries, the impacts outside of the boundaries are possibly more complex and extensive, since deforestation could extend over vast distances in accommodating urban development and expansion of the supply chain (Sonter *et al.*, 2017:2). Therefore, aerosol and PM emissions are expected to significantly increase, since fires are typically used for final clearing in land preparations (De Oliveira *et al.*, 2020:2). Since the mining sector will presumably increase to sustain future development, alternative means are continuously explored to remedy vast amounts of dust generated through nearly all stages of mining activities (Murzin & Gorlenko, 2020:1). Dust is characterised as coarse and fine PM that are generated through open operations, namely;

blasting, drilling, grinding, crushing and handling (Kahraman & Erkayaoglu, 2020:549). Rezasoltani *et al.* (2024?:2) by extension elucidate that wind erosion of exposed surfaces, specifically; tailing ponds, waste rock piles and open pit mines significantly contribute to fugitive dust emissions.

The challenges with industrial emissions are unique for each country owing to their level of development, however, the increase in technology-based industries create new challenges in both developed and developing countries (Xianghua, 2009:149). Although various efforts were introduced to curb industrial emissions, the manufacturing of steel and iron, bricks and cement, coal combustion, oil refineries and metallurgical activities are identified as among the main industrial sources of poor air quality in developed countries (Guan *et al.*, 2017:57). In addition, Kjellstrom *et al.* (2006:818) assert that dust formation from mining, quarrying, cement factories and smelters emit significant amounts of PM, NO_x, SO₂ and CO.

South Africa is considered as the most industrialised country in southern Africa with extensive mining and metallurgical activities, contributing 66% of the subcontinents industrial sulphur (Kgabi, 2012:152). As a result of the profuse coal reserves and the focus on development, South Africa comprises an energy and carbon intensive industrial sector that is dependent on fossil fuels for electricity generation, contributing approximately 90% of SO₂ and NO₂ nationally (Morakinyo *et al.*, 2022:1). Apart from the high levels of energy consumption, the separated spatial planning approach ensured that dense, low-income areas are located in close proximity to mining regions and industrial facilities for inexpensive labour (Harrison & Todes, 2014:15). As a result, these urban areas experience high levels of poor air quality; especially from windblown dust (Mpanza *et al.*, 2020:2). In the cases where mining activities have ceased, the negative effects of windblown dust from unrehabilitated areas are still prevalent in the residential areas. Dust from mine tailings is a significant contributor to poor air quality in the South African mining belt; especially during spring where dust storms effect the residential areas residing nearby (Oguntoke *et al.*, 2013:2).

4.2.4 Household air pollution

Generally, developed countries experience significant challenges relating to the exposure of household air pollution, however, the nature thereof is different than those of developing countries (Grainger *et al.*, 2014:781). Citizens in developed countries spend approximately 90% of their time indoors, increasing the exposure of tobacco smoke, hearths, mould, radon, allergens and dust (Liu *et al.*, 2008:122). Reaffirming the preceding, Ferguson *et al.* (2020:2) highlight that NO₂ and PM_{2.5} are emitted through cooking, heating and smoking. In addition, indoor VOC emissions are contributed through cleaning activities that employ solvents and aerosols. Although household air pollution has greatly decreased in developed countries over the past 50 years, income and the

level of development within a community are a major factor influencing the frequency and type of emissions (Landrigan *et al.*, 2016:11). In supporting this notion, Rogalsky *et al.* (2014:806) estimate that citizens residing in poor rural areas rely on dirty fuels for space heating and cooking, exposing them to high amounts PM, SO₂, NO₂ and CO emissions. In extension, Taylor *et al.* (2014:646) reveal that housing characteristics, inter alia; airtightness, ventilation systems, internal and external layout and occupant behaviours impact exposure levels among various socio-economic groups. Susanto *et al.* (2021:98) share Rogalsky *et al.*'s (2014:806) argument, identifying that ventilation within households is a critical factor influencing the concentration of indoor air pollution and it is proposed that enhanced ventilation systems within buildings is the most effective means to remedy indoor air pollution and limit emission concentrations.

South Africa, similarly to other developing countries, is significantly affected by household air pollution (Barnes *et al.*, 2009:5). Even though South Africa experiences a general shift towards cleaner energy sources, most citizens still heavily rely on dirty fuels for their basic needs (Manyatsha *et al.*, 2022:64). The majority residents residing in dense, low-income areas use coal, paraffin and wood for space heating and cooking, since it is considered a more affordable and accessible option when compared to cleaner energy alternatives (Kapwata *et al.*, 2018:1). Research indicates that citizens residing around coal mines typically use coal for space heating and cooking, while electricity is used for illumination. In instances where the supply of coal and wood are scarce, citizens generally opt for paraffin or animal dung for space heating and cooking (Morakinyo & Mokgobu, 2022:2). Continuous urbanisation and associated growth of dense, low-income areas resulted in a major backlog of basic service and electricity provision, making dirty fuels the only main choice as a household energy source (Naidoo *et al.*, 2014:34).

Numerous efforts from the South African Department of Minerals and Energy were implemented in providing electricity to all households, however, owing to the accessibility and affordability the majority of households still prefer the use of dirty fuels (Balmer, 2007:27). Moreover, the majority households use insufficient cook stoves in poorly ventilated houses, resulting in high levels and periods of exposure to household emissions (Naidoo *et al.*, 2014:36). While indoor air pollution is mostly attributed to combustion dirty fuels for space heating and cooking, Borge *et al.* (2023:74) suggest that household concentrations; especially in dense, low-income areas, are intensified by external factors. Nkosi *et al.* (2017:1) in support of Borge *et al.*'s notion, identify that the proximity of industrial and mining activities in relation to residential areas may well increase concentration levels of indoor air pollutants. The authors further argue that poor maintenance, structural damage and the quality of housing all influence the level of infiltration of outdoor air pollutants. Accordingly, the Department of Health (2019:9) stresses the significance to remedy the exposure of indoor air pollutants; especially within low-income areas, since the dwelling units are poorly constructed and overcrowded, comprising insufficient living space and inadequate ventilation.

4.2.5 Agriculture

Agriculture has a significant impact on poor air quality owing to its diverse activities and intensity (Aneja *et al.*, 2009:4235). Highly intensive livestock farming, resuspension of dust during ploughing and harvesting, the use of pesticides and fertiliser, over grazing, biomass burning, transportation and deforestation are among the main activities that significantly contribute to poor air quality (Gibberd, 2010:44). Intensive livestock farming is responsible for the release of odorous gases, fine and coarse PM, endotoxins and harmful gases like ammonia, nitrous oxide, CO₂, SO₂ and methane (Harizanova-Bartos & Stoyanova, 2018:1072; Garland *et al.*, 2017:34). While organic materials like manure, bedding, straw, animal feed, feathers, skin flakes and hair are primary sources of PM emitted from livestock, Winkel (2016:104) stresses the significant role of livestock farming in contributing to anthropogenic fine PM. This PM primarily consists of secondary inorganic aerosols such as ammonium sulfate and ammonium nitrate that are formed through the reaction with gaseous ammonia (Bauer *et al.*, 2016:5394; Brunekreef *et al.*, 2015:832).

Agricultural dust generated through tilling, cultivating and harvesting exhibit a substantial threat to air quality; particularly due to the presence of fine particles, namely; PM_{2.5}, PM₁₀ and total suspended particulate. The machinery used in these activities cause severe disturbances of surface soil, rendering it more prone to wind erosion that amplifies the release of agricultural dust (Jia *et al.*, 2023:1). In addition, López-Aparicio *et al.* (2013:3) assert that crop operations, for instance; handling by harvest machinery, loading of crops and the transportation thereof contribute to PM. An additional factor contributing to agricultural emissions is the prevalent use of fossil fuels in agricultural machinery. In supporting this notion, the European Agricultural Machinery Industry Association (2022:7) highlights that the use of tractors, harvesters, and irrigation pumps contribute significantly to poor air quality by emitting of pollutants like NO₂, SO₂, CO and PM. Farmers often use controlled burning for clearing crops residues and revitalisation land and is presumed to be the most significant contributor to emissions from the agricultural sector. Although burning is considered a vital ecological process, the frequency at which it is conducted and periods within the year may significantly influence the atmospheric chemistry and air quality (Roberts *et al.*, 2009:849). The utilisation of agricultural pesticides and fertilisers can significantly impact air quality through the application of chemicals that emit VOCs and NO_x, which are deemed precursors to ground-level ozone formation and contribute to smog formation (Coscolla & Yusa, 2016:427; Lenka *et al.*, 2016:1). Moreover, certain pesticides may contain compounds, in particular; organophosphates or chlorinated hydrocarbons that may volatilize into the atmosphere and pose significant health and environment risks (Tudi *et al.*, 2021:7). Moreover, the overuse or improper application of fertilisers could result in the release of ammonia into the atmosphere, contributing to fine PM formation and nitrogen deposition (Wyer *et al.*, 2022:5).

Despite its decline in recent years, the South African agricultural sector still plays a significant role in the economy by providing employment, income and livelihoods to millions of people; particularly in rural areas where opportunities for formal employment may be limited (Zwane & Montmasson-Clair, 2016:2). As deliberated above, the agricultural sector contributes substantially to poor air quality within South Africa. Similar to international trends, the South African agricultural comprises various sub-sectors, however, the Department of Agriculture, Land Reform and Rural Development (2023:2) signifies that crop production; especially in central South Africa, is the chief agricultural product. As a consequence, the use of fossil fuels dependant machinery is prevalent in not only crop production, but also transportation of the products (Omotoso & Omotayo, 2024:8). In a similar notion, Lekunze and Lekunze (2017:4) deplore that agricultural machinery used in South Africa are mostly cheap and outdated, resulting in inefficient burning of fossil fuels that intensify emissions. Finally, the employment of burning for the management and preparation of agricultural land is mainly practised owing to its affordability and conveniency (Ndlovu *et al.*, 2019:107). Van Wilgen *et al.* (2008:22) further accentuate that emissions from agricultural burning are intensified within winter periods (July to October) when most farmers prepare for summer crops, since rainfall during this period is limited and high wind speeds occur that increase the rate and transport of emissions.

4.2.6 Waste management

Municipal solid waste comprises various types of waste, for instance; household food waste and yard waste, containers and packaging, together with waste generated by industrial, commercial and institutional activities (Wiedinmyer *et al.*, 2014:9523). Research (Chen *et al.*, 2020:1) suggests that globally an estimated 7 to 9 billion tonnes of waste are generated per annum with municipal solid waste accounting for 2 billion tonnes, however, waste production rates and compositions vary significantly across different countries and regions (Hoornweg & Bhada-Tata, 2012:14). Waste management strategies comprise several methods, for instance; collection, landfilling, incineration, recycling and composting (Vijayalakshmi, 2020:68-69). Municipal solid waste is deemed a major source of poor air quality, considering that approximately 41% of global waste is disposed through burning practices (Jayarathne *et al.* 2018:2260). Incineration of municipal solid waste involves technologies aimed at efficient and controlled combustion in order to capture energy and mitigate emissions (Cho *et al.*, 2020:1). In contrast to the latter, open burning of waste without emission control strategies may either occur in residential areas where waste is generated or disposal or landfill sites (Ferronato & Torretta, 2019:4). Within developed countries, urban areas mainly comprise efficient waste management services where waste is collected and appropriately disposed of, while rural areas where limited waste collection services are available, household waste is commonly burnt (Wiedinmyer *et al.*, 2014:9523). Similarly, in developing countries comprising inadequate waste collection services, domestic burning of waste

is prevalent. In spite of the fact that waste is transported to landfill sites in these regions, it often ends up being burned in open, uncontrolled fires (Etea *et al.*, 2021:2036).

The burning of waste, whether in residential areas or at landfill sites, releases various atmospheric pollutants, emitting CO₂, methane, nitrous oxide and PM (Menikpura & Sang-Arun, 2013:1). Additionally, the management and disposal of waste are generally considered as sources of greenhouse gasses similarly to other forms of combustion. Owing to the global effect of these emissions, developed countries continue to avoid landfills and open burning, increasing the use of waste incinerators (Eriksson & Finnveden, 2016:1). These incinerators are generally used for the combustion of liquid and solid waste, comprising tall stacks and uniquely designed combustion chambers. The chambers ensure that waste is burned at high temperatures, while providing longer burning periods and efficient waste ignition that result in more complete combustion and fewer emissions (Guendehou *et al.*, 2006:5).

South Africa, similarly to other developing countries, mainly employ landfilling for disposal of waste, with approximately 90% of all waste generated in South Africa being disposed at landfill sites (Godfrey & Oelofse, 2017:4). Also, while most urban areas dispose waste in regulated landfill sites, major use of unregulated sites and burning in open dumps are applied in other areas (Fakoya, 2014:120). However, many communities are challenged with insufficient infrastructure of waste collection coverage and disposal, resulting in residential open waste burning; especially in dense, low-income areas (Cogut, 2016:7). The latter is affirmed by Rodseth *et al.* (2020:1), expressing that vast inequalities are evident in the level of waste management services provided by local municipalities, where large urban areas comprise sufficient resources and infrastructure to provide waste collection and proper disposal, while rural areas lack the capacity, equipment and treatment facilities to offer any form of waste management services. As a consequence, merely 61% of South Africa citizens have kerbside waste removal services, however, this statistic is extremely biased as the majority of dense, low-income, tribal and rural areas comprise no waste removal infrastructure or services (DEA, 2014:1).

Von der Heyde (2014:58) argues that factors, for instance; limited and inadequate road access, high population density, insufficient layout and spatial planning and incessant growth of informal urban areas limit the provision of effective waste collection services. Owing to the preceding, citizens residing in dense, low-income areas opt for illegal dumping in streets, vacant and underutilised land and parks in disposing of their waste (Jakeni *et al.*, 2024:2). Palamuleni and Tshabalala (2023:210) lament that the illegal dumping of solid waste within dense, low-income areas has a significant impact on poor air quality, since waste is generally burned to manage the volume. The health impacts of open burning on residents within dense, low-income areas are significant, owing to the unique composition of household waste that result in high levels of PM, CO₂, carbon monoxide, dioxins and toxic gases (Rabaji, 2019:80). In responding to the growing

pressures of waste emissions, the South African Government proposed new waste management strategies and technologies, in particular; the implementation of high energy waste to energy solutions, however, progress remains slow and South Africa continues to grapple with the reduction of waste emissions (Godfrey & Oelofse, 2017:8).

4.3 Evaluating the current understanding of poor air quality in South Africa Air Quality Management System

The purpose of the preceding thematic analysis is to determine the prevalent poor air quality sources within urban areas in order to assess the relevance of South African AQMPs towards mitigating poor air quality. In response, the assessment matrix as discussed in preceding Section 3.2.2, is employed to evaluate how the identified contributing drivers of poor air quality are incorporated in the compilation of the AQMPs by investigating their consideration throughout the AQM steps. The assessment of each respective AQM step is discussed in the ensuing section. Following Table 4-1 provides an overview of the findings for the South African AQMPs identified in Section 3.2.3.

Table 4-1: Assessment of South African air quality management plans

		Categories				
		AQM Steps				
Purposefully Selected AQM Steps Purposefully Selected Poor Air Quality Sources		Inventory	Standards	Dispersion	Monitoring	Mitigation
Significant Categories						
Vehicle tailpipe emissions		100%	29%	29%	52%	81%
Vehicle Entrained Dust		62%	24%	5%	14%	33%
Manufacturing		76%	19%	19%	33%	48%
Power Stations		48%	10%	14%	29%	33%
Oil Refineries		38%	14%	5%	10%	10%
Smelter		52%	5%	5%	10%	14%
Landfill Sites		67%	5%	0%	5%	62%
Solid Waste Burning		62%	5%	0%	5%	48%
Fugitive Dust		48%	19%	5%	24%	43%
Space Heating and Cooking		95%	0%	24%	52%	67%
Food Processing		48%	14%	0%	0%	5%
Controlled Agricultural Burning		62%	0%	5%	14%	48%
Tillage		52%	0%	0%	0%	19%
Crop Sprays		48%	0%	5%	5%	29%
Coal Mine Fires		5%	0%	0%	0%	0%
Mine Tailings		33%	33%	10%	29%	24%
Mining		48%	19%	19%	38%	10%

4.3.1 Poor air quality sources in the inventory step

Preceding Table 4-1 illustrates the efficiency of AQMPs in considering the poor air quality sources within the “inventory” step. While not all the poor air quality sources can be prevalent in a specific municipality, it appears that the prepared AQMPs grapple to identify the majority of the sources in the “inventory” step, since only 6 of the identified poor air quality sources were considered by more than 60% of the AQMPs. The latter is evident, since only “vehicle tailpipe emissions”, “manufacturing” and “space heating and cooking” were considered by more than 70% of the AQMPs. As a consequence, majority AQMPs fails to consider the majority of the identified poor air quality sources in the “inventory” step during their preparation.

4.3.2 Poor air quality sources in the standards step

Table 4-1 above illustrates the failure of prepared AQMPs to establish standards for the identified poor air quality sources in their respective “inventory” step. The major concern is that within the

21 AQMPs, five poor air quality sources were not considered when establishing standards for the poor air quality sources identified in their respective “inventory” steps. This is evident; especially in so far as “space heating and cooking” is concerned, since it was considered by 95% of the AQMPs in the “inventory” step and by 0% of the AQMPs in the “standards” step. Moreover, the AQMPs fail to establish standards for the poor air quality sources identified in the inventory step, for example; “mine tailings” is the only poor air quality source that were considered by a similar percentage in the “inventory” and “standards” step.

4.3.3 Poor air quality sources in the dispersion step

The foregoing Table 4-1 demonstrates the failure to implement dispersion modelling effectively in the prepared AQMPs. Similar to the “standards” step, five poor air quality sources are not implemented in dispersion modelling during the preparation of the AQMPs. Furthermore, the AQMPs fail to perform dispersion modelling on all the poor air quality sources that are identified in their respective “inventory” step. The latter indicates that municipalities may comprise insufficient funding or technical capacity to perform dispersion modelling effectively. This is apparent since not one poor air quality source is considered by more than 29% of the AQMPs. It is further noted that various AQMPs merely perform dispersion modelling on common emissions without linking it to the associated poor air quality source. The aforementioned is not considered in the assessment, since the poor air quality sources should be identified to determine their priority for the subsequent AQM steps as stipulated by the Manual for Air Quality Management and Planning.

4.3.4 Poor air quality sources in the monitoring step

Table 4-1 above highlights a greater emphasis on monitoring the poor air quality sources when preparing the AQMPs. It is indicated that only three of the poor air quality sources were not implemented in the “monitoring” step in the preparation of the AQMPs. This is further supported by the assessment, indicating that in most instances the percentage of poor air quality sources considered by AQMPs in the “monitoring” step are higher when compared to the “standard” and dispersion” step, respectively. Even though a greater number of AQMPs implemented the “monitoring” step, the number of poor air quality sources considered for monitoring are still notably insufficient when compared to their respective “inventory” step. Furthermore, it appears that similar to the “dispersion” step, monitoring is neglected due to the possible lack of funds or technical capacity.

4.3.5 Poor air quality sources in the mitigation step

Preceding Table 4-1 presents the mitigation strategies implemented for the poor air quality sources identified in their respective “inventory” step. It is determined that during the preparation of all the AQMPs, not one poor air quality source was considered by an equal number of AQMPs in the “mitigation” than in “inventory” step. However, “vehicle tailpipe emissions”, “power stations”, “fugitive dust” and “landfill sites” are considered by roughly the same percentage of AQMPs when developing mitigation strategies. The aforementioned reiterates the lack of AQMPs to consider the “mitigation” step during preparation, since the majority of the poor air quality sources identified in the “inventory” step are only addressed by half of the AQMPs when implementing mitigation strategies. Nevertheless, considering that the AQMPs do not implement mitigation strategies for a similar amount that is identified in the “inventory” step, the “mitigation” is regarded to be more comprehensively addressed with relation to the “standards”, “dispersion” and “monitoring” steps. However, following the assessment of the consideration of the poor air quality sources, it is argued that the ability of the agencies to compile inclusive and effective AQMPs is questionable, considering the lack of implemented mitigation strategies that are required for reducing poor air quality.

4.4 Conclusion

In an effort to effectively mitigate poor air quality sources, emission inventories play a critical role in accurately measuring pollutant emissions, understanding their sources and formulating effective mitigation strategies (Patel *et al.*, 2020:2). However, it is argued that since promulgation of the AQA (2004), limited research has been conducted in identifying and quantifying all poor air quality sources in South Africa. Despite the latter, the investigated documents are exceedingly relevant in highlighting the potential poor air quality sources within urban areas that may well be considered in South African AQM. The assessment reveals a substandard representation of an effective AQM lifecycle in terms of the identification of the poor air quality sources and the necessary efforts in reducing their emissions. It is important to note that in most cases, the “inventory” step obtained a higher value than the other steps, indicating that during the preparation of the South African AQMPs the subsequent steps; especially “dispersion” and “monitoring”, are neglected due to the possibility of insufficient technical capacity or funds. The assessment indicates an inconsistency in the prepared AQMPs in regards to the type and size of the municipality. This is a serious predicament considering that the air quality of all the municipalities selected for this research are considered poor or potentially poor (DEA, 2018:50), necessitating a detail and comprehensive AQMP in terms of the Manual for Air Quality Management and Planning (DEAT, 2008:52). The occurrence of the major gap between the “inventory” and the subsequent AQM steps demonstrates the significant emphasis that is placed on the identification of poor air quality sources rather than implementing measures to effectively improve poor air

quality. This may be a result of previous practices, seeing that the APPA employed source-based method with no conclusive means for reducing emissions (Thambiran & Diab, 2010:4).

A summary of the poor air quality sources utilised in compiling the assessment matrix is provided in the following Table 4-2.

Table 4-2: Purposefully selected contributing drivers of poor air quality

<u>Poor air quality sectors</u>	<u>Reference</u>	<u>Theory</u>	<u>Contributing Drivers of poor air quality</u>
Energy Generation	Istrate & Banica, 2016:831; Amster & Levy, 2019:1.	Coal-fired power plants are considered as one of the most significant sources of poor air quality worldwide.	Power plants
	Weimin <i>et al.</i> , 2023:8-9.	Energy generation through the combustion of fossil fuels substantially contribute poor air quality.	Combustion of fossil fuels
	Zhou <i>et al.</i> , 2023:14.	Impact of energy generation have a significant effect on localised poor air quality and wider regions owing to spatial spillover.	Location of power plants
	Cichowicz & Stelęowski, 2018:49-50.	The general wind direction could have a major influence on the concentration of air pollutants in the areas surrounding power stations.	Proximity to power plants Meteorological conditions
	Hudedmani <i>et al.</i> , 2016:693-694.	Power plants significant contributes to global greenhouse gases and effect ecosystems and biodiversity through deforestation and the destruction of riverbeds.	Deforestation
	Pretorius <i>et al.</i> , 2015:4.	South Africa is heavily reliant of fossil fuels for energy generation, contributing more than 83% of the national carbon emissions.	Combustion of fossil fuels
Transportation	Winkler <i>et al.</i> , 2018:1.	Transportation; especially vehicles comprising diesel and gasoline engines, is continually affecting air quality on a global and local scale.	Dirty fuel
	García-Olivares <i>et al.</i> , 2018:266.	Currently, 94% of the global vehicle fleet are dependent on fossil fuels.	Dirty fuel
	Lu, 2011:5.	Growing urbanisation increases the number of privately owned vehicles, diesel dominated freight fleet and airlines.	Number of Vehicles Privately owned vehicles Dirty Fuel
	Cepeda <i>et al.</i> , 2017:29.	Study investigating emission levels for various transportation modes observed that private vehicles and busses are considered the main transportation contributors to poor air quality in urban areas.	Privately owned vehicles Busses

Poor air quality sectors	<u>Reference</u>	<u>Theory</u>	<u>Contributing Drivers of poor air quality</u>
	Ericsson, 2000:338.	Driving patterns play a pivotal role in the emissions emitted by the transportation sector.	Driving patterns
		Multiple factors influence driving patterns, namely; urban form, design and layout of street networks, time of day and industrial activities.	Design and layout
	Zhou <i>et al.</i> , 2018:2.	Urban form particularly affects the emissions emitted by the transportation sector, owing to urban traffic patterns and the travel behaviour of citizens.	Design and layout
	Tiwari <i>et al.</i> , 2021:1385.	Sprawling or fragmented urban form increases travel distances and poses various challenges to provide sufficient public transportation services.	Travel distance
			Design and layout
	Wang <i>et al.</i> , 2023:2992.	Increase in urban traffic result in higher pollutant concentrations, especially in dense urban areas.	Design and layout
	Shilpi <i>et al.</i> , 2018:5.	Locating townships outside the urban periphery and away from economic centres and employment opportunities	Travel distance
			Design and layout
	Kerr, 2017:323.	Disparity between segregated urban areas and employment centres caused long commuting distances, resulting in the dependency on privately owned vehicles	Design and layout
			Travel distance
			Privately owned vehicles
	Chakwizira <i>et al.</i> , 2011:61.	Segregated urban areas do not comprise adequate public transportation infrastructure, further aggravating the reliance on privately owned vehicles or mini-bus taxis.	Privately owned vehicles
			Mini-bus taxis
	Rukema, 2022:4.	Infrastructure inequalities still persist in segregated urban areas, inter alia; poorly maintained roads and railways, prevalence of unpaved roads, lack of non-motorised transportation facilities and limited modes of public transportation.	Non-exhaust emissions
	Beltran <i>et al.</i> , 2012:2.	Lack of sufficient infrastructure within dense, low-income areas result in non-exhaust particulate emissions in the form of road dust resuspension	Non-exhaust emissions
	Allen, 2013:5.	Mini-bus taxi industry currently dominates the public transportation modal split; especially in dense, low-income areas	Mini-bus taxi
	Noah, 2002:9.	Mini-bus taxis comprise old engine technologies and are limited to the number of passengers compared to other public transportation modes, resulting in a larger vehicle fleet	Engine technology
			Number of vehicles

Poor air quality sectors	Reference	Theory	Contributing Drivers of poor air quality
Mining and industries	Fugiel <i>et al.</i> , 2017:159.	Provides raw materials utilised in the manufacturing, building and construction sectors necessitated for a country's economic development.	Excavation
	Giljuma <i>et al.</i> , 2022:1.	Rapid growth and rising demand for minerals to produce energy transition technologies, infrastructure and consumer products resulted in the exponential growth of global mining operations over the past 20 years.	Excavation
	Mishra & Das, 2017:2.	Mining necessitates the excavation and movement of vast quantities of rock and earth, resulting in the suspension of dust.	Excavation
			Material handling
		Mining activities through blasting, drilling, sizing and the transportation of minerals on gravel roads release coarse and fine particles, contributing to poor air quality.	Blasting
			Drilling
			Sizing
			Material handling
			Transportation
	Bugarski & Hummer, 2020:121.	Use of diesel power machinery, owing to the durability and cost-effectiveness, are considered among the main contributors of poor air quality in mining regions.	Dirty fuel
	Zhou <i>et al.</i> , 2019:1.	The mining of metals, processing of minerals, smelting and combustion of fossil fuels emit numerous pollutants into the atmosphere.	Excavation
			Refinery
			Smelting
			Dirty fuel
	Giljuma <i>et al.</i> , 2022:1.	Establishment of mining regions involve the clearing of vast areas in accommodating mining activities and associated infrastructure.	Deforestation
	De Oliveira <i>et al.</i> , 2020:2.	Aerosol and PM emissions are expected to significantly increase, since fires are typically used for final clearing in land preparations.	Land clearing
			Fires practices
	Murzin & Gorlenko, 2020:1.	Alternative means are continuously explored to remedy vast amounts of dust generated through nearly all stages of mining activities.	Dust generation
	Kahraman & Erkayaoglu, 2020:549.	Dust is characterised as coarse and fine PM that are generated through open operations, namely; blasting, drilling, grinding, crushing and handling.	Blasting
			Drilling
			Sizing
			Material handling
	Rezasoltani <i>et al.</i> , 2022:2.	Wind erosion of exposed surfaces, specifically; tailing ponds, waste rock piles and open pit mines significantly contribute to fugitive dust emissions.	Mine tailings / windblown dust
			Steel manufacturing

Poor air quality sectors	Reference	Theory	Contributing Drivers of poor air quality
	Guan <i>et al.</i> , 2017:57.	The manufacturing of steel and iron, bricks and cement, coal combustion, oil refineries and metallurgical activities are identified as among the main industrial sources of poor air quality in developed countries.	Brick manufacturing
			Cement manufacturing
			Refinery
			Metallurgy
	Kjellstrom <i>et al.</i> , 2006:818.	Dust formation from mining, quarrying, cement factories and smelters, coupled with gas release from chemical production may originate from industrial processes.	Excavation
			Quarrying
			Smelting
			Cement manufacturing
			Refinery
	Harrison & Todes, 2014:15.	Separated spatial planning ensured that dense, low-income areas are located in close proximity to mining regions and industrial facilities for inexpensive labour.	Proximity
	Groundwork, 2014:18.	Where mining activities have ceased, the negative effects of windblown dust from unrehabilitated areas are still prevalent in the residential areas.	Mine tailings / windblown dust
Household air pollution	Liu <i>et al.</i> , 2008:122.	Citizens in developed countries spend approximately 90% of their time indoors, increasing the exposure of tobacco smoke, hearths, mould, radon, allergens and dust.	Tobacco smoke
			Heating
			Mould
			Radon
			Allergens
			Dust
	Ferguson <i>et al.</i> , 2020:2.	NO ₂ and PM _{2.5} are emitted through cooking, heating and smoking.	Heating
			Cooking
	Landrigan <i>et al.</i> , 2016:11.	Income and the level of development within a community are a major factor influencing the frequency and type of emissions.	Quality housing
			Household income
	Rogalsky <i>et al.</i> , 2014:806.	Citizens residing in poor rural areas rely on dirty fuels for space heating and cooking.	Dirty fuel
			Heating
			Cooking
	Manyatsha <i>et al.</i> , 2022:64.	Most South African citizens still heavily rely on dirty fuels for their basic needs.	Dirty fuels
	Kapwata <i>et al.</i> , 2018:1.	Residents in dense, low-income areas use coal, paraffin and wood for space heating and cooking, since it is more affordable and accessible when compared to cleaner energy alternatives.	Household income
			Heating
			Cooking
	Morakinyo & Mokgobu, 2022:2.	Citizens residing around coal mines typically use coal for space heating and cooking, while electricity is used for illumination.	Proximity to mine/industry
			Dirty fuel
			Cooking appliance

Poor air quality sectors	<u>Reference</u>	<u>Theory</u>	<u>Contributing Drivers of poor air quality</u>
	Naidoo <i>et al.</i> , 2014:36.	Majority households use insufficient cook stoves in poorly ventilated houses, resulting in high levels and periods of exposure to household emissions	Household income
	Language, 2020:229.	Trace elements of road dust were observed inside the households due to main roads within these areas are commonly paved, while the minor arterials located between dwelling units are unpaved.	Quality housing
			Unpaved roads
	Nkosi <i>et al.</i> , 2017:1.	Proximity of industrial and mining activities in relation to residential areas may well increase concentration levels of indoor air pollutants.	Proximity to mine/industry
	Department of Health, 2019:9.	Dwelling units within low-income areas are poorly constructed and overcrowded, comprising insufficient living space and inadequate ventilation	Quality housing
Agriculture	Gibberd, 2010:44.	Highly intensive livestock farming, resuspension of dust during ploughing and harvesting, the use of pesticides and fertiliser, over grazing, biomass burning, transportation and deforestation are among the main activities that significantly contribute to poor air quality.	Livestock farming
			Resuspension of dust
			Ploughing and harvesting
			Pesticides and fertiliser
			Biomass burning
			Transportation
			Deforestation
	Jia <i>et al.</i> , 2023:1	Agricultural dust generated through tilling, cultivating and harvesting exhibit a substantial threat to air quality, particularly due to the presence of fine particles.	Resuspension of dust
			Ploughing and harvesting
		The machinery used in these activities cause severe disturbances of surface soil, rendering it more prone to wind erosion that amplifies the release of agricultural dust.	Transportation
			Windblown dust
	López-Aparicio <i>et al.</i> , 2013:3.	Crop operations, for instance; handling by harvest machinery, loading of crops and the transportation thereof contribute to PM.	Crop operations
		The prevalent use of fossil fuels in agricultural machinery.	Dirty fuels Agriculture machinery
	European Agricultural Machinery Industry Association, 2022:7.	Use of tractors, harvesters, and irrigation pumps contribute significantly to poor air quality by emitting of pollutants.	Agriculture machinery
		Farmers often use controlled burning for clearing crops residues and revitalisation land.	Biomass burning

Poor air quality sectors	<u>Reference</u>	<u>Theory</u>	<u>Contributing Drivers of poor air quality</u>
	Coscolla & Yusa, 2016:427.	The utilisation of agricultural pesticides and fertilisers can significantly impact air quality through the application of chemicals.	Pesticides and fertiliser
	Omotoso & Omotayo, 2024:8.	Use of fossil fuels dependant machinery is prevalent in not only crop production, but also transportation of the products.	Dirty fuel
			Agriculture machinery
	Lekunze & Lekunze, 2017:4.	Agricultural machinery used in South Africa are mostly cheap and outdated, resulting in inefficient burning of fossil fuels that intensify emissions.	Agriculture machinery
	Ndlovu <i>et al.</i> , 2019:1	Burning for the management and preparation of agricultural land is mainly practised owing to its affordability and convenience.	Biomass burning
Waste management	Wiedinmyer <i>et al.</i> , 2014:9523.	Municipal solid waste comprises various types of waste, for instance; household waste namely food and yard waste, containers and packaging, together with waste generated by industrial, commercial and institutional activities.	Household waste
			Garden waste
			Commercial waste
	Vijayalakshmi, 2020:68-69.	Waste management strategies comprise several methods, for instance; collection, landfilling, incineration, recycling and composting.	Collection/Transportation
			Landfill
			Controlled burning
			Composting
	Jayarathne <i>et al.</i> 2018:2260.	Municipal solid waste is deemed a major source of poor air quality, considering that approximately 41% of global waste is disposed through burning practices.	Controlled burning
	Ferronato & Torretta, 2019:4.	Open burning of waste without emission control strategies may either occur in residential areas where waste is generated or disposal or landfill sites.	Unregulated burning
			Landfill
	Wiedinmyer <i>et al.</i> , 2014:9523.	In developed countries, urban areas mainly comprise efficient waste management services where waste is collected and appropriately disposed of, while rural areas where limited waste collection services are available, domestic waste is commonly burnt.	Collection/Transportation
			Unregulated burning
	Etea <i>et al.</i> , 2021:2036.	In developing countries comprising inadequate waste collection services, domestic burning of waste is prevalent.	Unregulated burning
	Guendehou <i>et al.</i> , 2006:5.	Incinerators are used for the combustion of liquid and solid waste, comprising tall stacks and uniquely designed combustion chambers	Controlled burning
	Godfrey & Oelofse, 2017:4.	90% with all waste generated in South Africa being disposed at landfill sites	Landfill
			Landfill

Poor air quality sectors	<u>Reference</u>	<u>Theory</u>	<u>Contributing Drivers of poor air quality</u>
	Fakoya, 2014:120.	While most urban areas dispose waste in regulated landfill sites, major use of unregulated sites and burning in open dumps are applied in other areas	Unregulated burning
	Cogut, 2016:7.	Many communities have insufficient waste collection coverage and disposal, resulting in residential open waste burning; especially in dense, low-income areas	Unregulated burning
	Jakeni <i>et al.</i> , 2024:2	citizens residing in low-income areas opt for illegal dumping in streets, vacant and underutilised land and parks in disposing of their waste.	Illegal dumping
	Tshabalala, 2023:210.	Illegal dumping of solid waste within low-income areas has a significant impact on poor air quality since waste is generally burned to manage to volume.	Unregulated burning

Chapter 5 (Mis)alignment between spatial planning and air quality management policy directives in South Africa?

5.1 Introduction

This chapter aims to address research Objective 2:

2. To examine the level of interface between the South African air quality and spatial planning directives.

Currently, urban areas contribute significantly to global poor air quality resultant from transportation, residential, commercial, waste incineration and metallurgical activities (Valavanidis *et al.*, 2016:5). Incessant population growth and vast urbanisation rates complicate matters further by locating citizens on the urban periphery that induce the loss of open spaces, greater travel distances and an increase in energy consumption (Cho & Choi, 2014:5969). Haase *et al.* (2018:20) assert that urbanisation in developed countries are currently 80 percent in contrast to developing countries that remains mostly rural with an urbanisation population of 45 percent. However, owing to greater opportunities and national directives, regions in developing countries are urbanising quicker than those currently comprising high urbanised populations (Dahiya, 2012:46). Alarming, the United Nations (2019:1) report that notwithstanding the existing global urbanisation trends, urban areas will drastically increase in the near future, indicating that the “global urban population is projected to grow by 2.5 billion urban dwellers between 2018 and 2050”.

Responding to the growing concern of urbanisation and its associated poor air quality, countries are cooperating through the implementation of various measures to ensure a healthy environment for future generations (Maamoun, 2017:2). Considering the global mixing of poor air quality emissions and its transboundary nature, international collaboration is necessitated in mitigating poor air quality (Stavins *et al.*, 2014:1007). As a response, multilateral international environmental agreements (IEAs) were created that constitute lawful binding regulations between multiple states in addressing common challenges (Horwitz, 2017:10). Since the UN Conference on the Human Environment held at Stockholm in 1972, 90 IEAs have been promulgated, inter alia, the Helsinki (1985) and Oslo Protocol (1994) to reduce sulphur, the Montreal Protocol (1987) to reduce groups of halogenated hydrocarbons that deplete ozone, in addition to the Kyoto Protocol (1997) and Paris agreement (2015) to reduce greenhouse gasses that result in global warming (Finus, 2003:1; Ringquist & Kostadinova, 2005:87). When ratifying an IEA, individual nations are obligated to revise their current air quality directives in attaining the binding emission targets set by these agreements (Bodansky, 2010:212).

South African greenhouse gas emissions are among the highest in the world, owing to energy generation, metallurgical industries and transportation (Wang *et al.*, 2024:10). In response to the latter, South Africa ratified a number of IEAs; in particular, the United Nations Framework Convention on Climate Change (UNFCCC) in 1997, the Kyoto Protocol in 2002 and the Paris Agreement in 2016 (Goitom, 2018:112). Due to growing pressure from its international obligations, South Africa promulgated the AQA during 2004 as an alternative approach to the “outdated” APPA (Barnwell, 2009:8). The main aim of the Act (2004) is the shift in source-based approach to ambient AQM as a new control strategy (Engelbrecht & Van der Walt, 2012:408). This new strategy entails the introduction of, among other, an emission inventory, standards, ambient monitoring, dispersion monitoring and mitigation strategies as tools for effectively mitigating poor air quality (Naiker *et al.*, 2012:64). In implementing the preceding tools, Section 15 (AQA, 2004:18) presents the adoption of AQMPs into national, provincial and local government development plans. In support of this notion, Engelbrecht and Van der Walt (2007:7) are of opinion that the inclusion of AQMPs into various development plans may encourage equal social and economic development, while protecting the natural environment. Although all levels of government are authorised by the AQA, Barnwell (2009:25) signifies that the majority of responsibilities were delegated to local governments, necessitating the implementation, compliance and monitoring of air quality. Barnes *et al.* (2014:661) endorse this notion, signalling that countries presenting an improvement in air quality introduced an AQM system that focusses on monitoring and managing poor air quality sources at the lowest government level. In attaining the latter, Engelbrecht and Van der Walt (2012:408) emphasise that the AQA (2004) requires a local municipality to incorporate the AQMP into its compulsory IDP.

In the new democratic dispensation, local government should function as a robust system to ensure a democratic and reliable government for local communities by guaranteeing the delivery of services, encouraging social and economic development and promoting a safe and healthy environment (Retief & Cilliers, 2015:563-586). Following the repeal of the Local Government Transition Act (LGTA) and its Amendment Act, Act 61 of 1995, the MSA (2000) was introduced to empower local government in attaining its legal mandate, constitutional goals and increasing its responsibilities and authority; especially in rural areas. As mentioned above, the AQA (2004:18) presents an additional measure for supporting local municipalities in managing their air quality through the inclusion of AQMPs into their IDP as contemplated in Chapter 5 of the MSA. The cornerstone of the Act is the IDP, necessitating the shift in spatial planning from segregated urban areas to more racially inclusive and integrated communities. The Act requires all municipalities to adopt an IDP as the vehicle for the effective development of a municipality by aligning, integrating and coordinating the SDF, AQMP, Disaster Risk Management Plan (DRMP), Environmental Management Plan (EMP), Integrated Waste Management Plan (IWMP), Integrated Energy Plan (IEP), Water Services Development Plan (WSDP), Economic

Development Plan (EDP), Housing Sector Plan (HSP) and Integrated Transport Plan (ITP). It replaced the segregated driven planning policies of the past with integrated development by aligning all municipal sector plans that are effectively coordinated with the national development priorities and objectives (Simphiwe, 2014:8). Even though scholars (Ndlovu, 2006:76; Asha & Makalela, 2020:2) have argued that the IDP failed in attaining its goals, Harrison (2001:190) suggests there appears to be consensus that integrated development planning result in more effective and sustainable outcomes than project-based methods; especially in municipalities with resource constraints and limited capacity. The author further highlights that IDPs may benefit municipalities that lack sufficient capacity and funds in allocating their scarce resources with regards to the development objectives.

IDPs are considered the vehicle for aligning strategic objectives, budgeting and project implementation in ensuring the effective management of the municipal area (Khumalo, 2015:2). In response to the proceeding, the research investigates the current alignment between spatial planning and AQM within the South African context by investigating existing policy directives. The rational for this is that the failure to integrate AQM into spatial and other development planning processes has intensified the mitigation of air quality (DEAT, 2007:9). In support, Zou *et al.* (2016:2) propose that spatial planning should accompany the municipal AQM process, since rapid urbanisation characterised by low-density urban sprawl illustrates a direct correlation with poor air quality. Spatial planning solutions are increasingly considered an essential measure in mitigating poor air quality on a local scale (Institute of Air Quality Management, 2017:6).

5.2 Air quality directives

Considering the global nature of poor air quality and its emissions, countries opted for a multilateral approach by implementing international agreements between various national states (Cherry *et al.*, 2014:xx). However, given the increasing nature of urbanisation, energy consumption and transportation, Bulkeley and Betsill (2003:2) suggest that while substantial emphasis is placed on a global scale, local authorities play an essential role in mitigating poor air quality. In view of the foresaid, the ensuing section will present an overview of international and local air quality directives to determine possible instances where spatial planning may have an impact on air quality.

5.2.1 International air quality directives

The Convention on Long Range Transboundary Air Pollution (CLRTAP) which convened during 1979 is considered as the initial attempt in addressing poor air quality emissions through a collective approach (Agren, 2009:253). The Convention (1979) introduced a framework of strategies to reduce and prevent poor air quality on a regional scale that mainly included North

America and Europe (Isaksen, 2020:1). It originated as a flexible framework for cooperation, however, in expanding the scope of emissions, the CLRTAP presented a set of protocols that comprised obligated emissions reduction targets for parties, namely; the Helsinki protocol (SO₂), the Sofia protocol (NO_x) and the Geneva protocol (VOCs) (Gesley, 2018:124; Isaksen, 2020:1). The Convention (1979) affirms that countries should endeavour to limit, reduce and prevent these emissions through employing suitable technologies that are economically feasible, providing countries the flexibility to implement their own strategies (Agren, 2009:255). Owing to the flexibility and the narrow scope of the CLRTAP and its protocols, scholars (Byrne, 2015:38; Yamineva & Romppanen, 2017:193) question its effectiveness to address poor air quality. In responding to the latter, Dekker *et al.* (2010:1) suggest that even though the CLRTAP had little to no impact on poor air quality, it played a decisive role in the development of future IEAs.

In providing a greater transparency and inclusivity, the UNFCCC came into effect during 1992, comprising a set of principles, emission targets and reduction methods (Stavins *et al.*, 2014:1011). Following a process of negotiations, the Conventions (1992) opened the Kyoto protocol for signature in 1997 and finally implemented during 2005, establishing binding national commitments for the mitigation of greenhouse gas (GHG) emissions (O'Brien & Gowan, 2012:10). Additionally, the Kyoto protocol presented clean development mechanisms by aiding parties; especially developing countries, in reducing the cost to attain their agreed emission targets (Heller, 1999:203). The Protocol (1997) was considered as the initial phase where developed countries were charged to incrementally reduce their emissions in a limited frame, facilitating a realistic approach in realising emission targets (Horwitz, 2017:35). By contrast, developing countries were excluded from attaining their emission targets, since developed countries were mainly responsible for emitting the majority global GHG emissions before 1997 (Sandler, 2017:352). The effectiveness of the Kyoto protocol remains a controversial topic given the current nature of global air quality (Maamoun, 2017:7), however, the Protocol (1997) is the first international air quality directive to propose “methods for improving spatial and land use planning” within national air quality directives (United Nations, 1998:9).

In attaining the main objectives set by the Kyoto protocol, the UNFCCC ventured in new negotiations to incorporate the remaining developed countries that neglected to ratify the Kyoto protocol in 1997 (Van der Gaast & Alessi, 2015:2). The Copenhagen Conference during 2009 failed to fulfil its extraordinary anticipation, since parties could not attain consensus regarding the Copenhagen Accords (O'Brien & Gowan, 2012:10). As a result, parties were not legally bound to fulfil any commitments and merely “took note of the negotiations” (Rogelj *et al.*, 2010:2). Nevertheless, the Accords (2009) laid the foundation for future negotiations by incorporating developing countries to present “nationally appropriate mitigation actions”, recognising the responsibility of countries to introduce their own mitigating policies and strategies (Depledge,

2017:39). Subsequently, the Cancun Agreement of 2010 shifted from a top-down to a bottom-up approach by securing of national emission targets, establishing the Green Climate Fund and improving transparency through review methods (The Climate Institute, 2010:1). The Agreement (2010) introduced new means of capacity building and funding for developing countries, together with guidelines in preventing emissions relating to deforestation and land use alterations (Van der Gaast & Alessi, 2015:3).

Following a series of futile conference of parties, the UNFCCC finally introduced a “truly multilateral agreement” during 2015 (Alessi, 2015:4). The Paris Agreement of 2015 introduced a contemporary bottom-up approach in attaining reduced GHG emissions through nationally determined contributions (NDCs), enabling countries to establish their individual emission mitigation and adaptation strategies (Yamineva & Romppanen, 2017:195). These NDCs are central to the Paris Agreement (2015) as they compel parties to “prepare, maintain and communicate successive NDCs every five years and are mandatory under international law” (Roberts, 2016:2). The Agreement (2015:4) further urges parties to attain their targets set by NDCs to implement local mitigation measures through appropriate policy and strategies. In response to the latter, the Agreement (2015) proposes a long-term, development orientated approach by encouraging parties to adopt long-term low emission development strategies (LT-LEDS) (Waisman *et al.*, 2016:1). Waisman *et al.* (2019:263) is of opinion that LT-LEDS are imperative for future air quality actions as they provide an essential perspective on investment decisions, while integrating air quality measures with future development strategies for the first time. Rocha and Falduto (2019:8) concur that the introduction of LT-LEDS may present opportunities for national governments to align their air quality and development policies, while attaining socio-economic development objectives.

5.2.2 South African air quality directives

The initial approach of the South African AQM system was guided and informed by the APPA (1965) (DEAT, 2005:2). The Act (1965) provided control measures through the registration of specific industrial processes, emission control of diesel vehicles, control of dust and the declaration of smoke-controlled areas (Scorgie, 2012:21). The APPA (1965) was considered ineffective and outdated as it followed a basic approach to prevent poor air quality by implementing source-based control measure without considering the growing impact of emissions on ambient air quality (Thambiran & Diab, 2010:4). For this reason, the DEA (2016:8) is convinced that the focus on significant point sources; especially industrial sources, resulted in the establishment of various poor air quality hotspots throughout the country.

Following the democratic election in 1994, the Parliament pursued equal and inclusive legislation, repealing, inter alia, the APPA (Naiker *et al.*, 2012:62). The Act (1965) violated the right towards

a clean and healthy environment of South African citizens, proclaiming it unlawful in regards to Section 24 of the Constitution (Thambiran & Diab, 2010:4). In response to the latter, the Parliament promulgated the AQA during 2004, introducing a holistic approach for AQM by addressing the limitations of earlier approaches through incorporating principles and objectives that focus on emission prevention and minimisation (Naiker, 2007:58). Engelbrecht and Van der Walt (2007:7) endorse this notion, indicating that the AQA (2004) focusses on environmental conservation through effective mitigation strategies in lieu of regulating poor air quality. In doing so, Section 15(1) of the AQA (2004:18) obligates the implementation of an AQMP for all national and provincial departments responsible for the preparation of environmental implementation plans or environment management plans. Section 15(2) further declares that all municipalities should adopt within their compulsory IDP, an AQMP in facilitating proper institutional and planning measures (Engelbrecht & Van der Walt, 2012:408). This contemporary strategic approach is a substantial shift from previous legislation, since the AQA (2004) recognises for the first time the significance of integrating spatial planning and AQM for more viable and cost-effective solutions (DEA, 2005:10).

In attaining the goals for effective AQM, Section 7 of the AQA (2004) facilitates the development of a National Framework for Air Quality Management that should be revised every five years. The Framework functions as a blueprint for AQM by providing measures and procedures that encourage a holistic and integrated approach through the implementation of national norms and standards (Naiker *et al.*, 2012:65). Accordingly, the Framework (2007:23) provides various steps in the environmental governance lifecycle that should be implemented for the continued improvement of air quality, for instance; (i) information management, (ii) problem identification and prioritisations, (iii) strategy development, (iv) environmental impact management, (v) authorisations, (vi) compliance monitoring and (vii) enforcement. Additionally, the Framework (2007) delineates certain functions to different government authorities where national government is responsible for categorising priority pollutants that present health risks, determine acceptable emission standards and monitoring protocols (Naiker, 2007:66; Scott, 2010:3). Moreover, the Amended Framework (DWEA, 2012:30) enables municipalities to manage their respective jurisdictions by introducing municipal by-laws to facilitate the establishment of AQMPs, emission standards in accordance with national standards and perform atmospheric emission licensing.

In supporting the goals presented by the National Framework for Air Quality Management, the DEAT, now the Department of Forestry, Fisheries and the Environment (DFFE), introduced the Manual for Air Quality Management and Planning during 2008. The purpose of the aforementioned is to guide national, provincial and local government in AQM planning by establishing “best practice guidelines on definition of objectives, strategies, plans and procedures for each sphere of government, in order to meet the requirements of the AQA (2004) on good

AQM planning and reporting”. In doing so, the purpose thereof is to provide guidance in the compilation of AQMPs in attaining the goals outlined in Section 15 and 16 of the AQA (DEAT, 2008:1). The main aim of the Manual (2008) is to develop a comprehensive and consistent process to guide the compilation of AQMPs for the effective planning and management of air quality in identified areas. In attaining the latter, the DEAT outlines specific content and requirements necessitated to improve AQM, namely; (i) goal setting, (ii) baseline air quality assessment, (iii) AQM system, (iv) intervention strategies, (v) action plan implementation and (vi) evaluation and follow up (Naiker *et al.*, 2012:66).

During 2019, the government promulgated the Strategy to address poor air quality in dense low-income settlements: a “burning” issue in an attempt to mitigate poor air quality within geographical areas where ambient air quality standards are continually exceeded and poses a significant threat to human health and the environment (DEA, 2019:1). It is identified that poor air quality within these urban areas stem from various sources; especially, space heating and cooking, unpaved road surfaces, biomass and waste burning, vehicle emissions, burning of tires and proximity to industrial and mining activities (Language, 2020:47). Provided that the majority of South African households are classified as low-income, the Strategy aims to provide the necessary steps to effectively mitigate the effects of poor air quality in dense, low-income areas (Department of Health, 2019:9). In doing so, it recommends a collaborated, multi-stakeholder and multi-departmental approach in ensuring that activities aimed at reducing poor air quality are integrated and coordinated (DEA, 2019:1). In attaining the preceding, the Strategy (2019) introduces various activities, among other, “Activity 2c: Influence development-planning initiatives to take into account air quality issues”. In this regard, the DEA acknowledges the significance of spatial planning in AQM by recommending a coordinated approach between development planning and air quality sections in local and other government spheres in ensuring the consideration of existing conditions of dense, low-income areas in current and future planning operations (DEA, 2019:23).

It is evident that while certain international and local air quality directives reference the integration of spatial planning within the AQM system, the majority directives mainly focus on stringent standards and innovative technologies in mitigating poor air quality. Sivaramanan (2015:9) concurs, highlighting that governments should encourage the use of clean alternative fuels, low emission technologies and optimal performance engines to maintain acceptable air quality levels. However, Moorcroft and Barrowcliffe (2015:6) argue that spatial planning plays a significant role in minimising future air quality challenges, since land use patterns dictate the location of significant point sources, while influencing travel behaviour and associated vehicle emissions. In response to the latter, the ensuing section will focus on the current South African national, provincial and local spatial planning and land use management policy directives in identifying possible references to air quality improvement in emphasising the current South African (i) legal

framework, (ii) correlation between legislation and (iii) alignment arrangements between spatial planning and AQM.

5.3 South African spatial planning and land use management directives

Owing to social and economic injustices, the government contends to rectify inequality, poverty and unemployment through “inclusive economic growth” that is mostly considered as conflation to air quality priorities (Petrie *et al.*, 2018:9). However, the AQA (2004) presents a contemporary approach towards AQM that fits faultlessly within the current spatial planning system, aiming to address the growing global and national poor air quality challenges (DEAT, 2005:11). In view of the latter, the ensuing section will investigate the current spatial planning policy directives in determining certain instances where AQM is referenced.

5.3.1 South African spatial planning policy

In an attempt to address growing poverty and unemployment levels, the National Planning Commission (2012:24) introduced the NDP to guide future development within South Africa. The Plan aims to present practical steps in attaining sustainable and equal development by requesting the cooperation of all sectors; especially housing, energy, waste disposal, transportation, infrastructure and services (Klausbrückner *et al.*, 2016:71). The NDP (2012) further emphasises the need to enable growing employment opportunities and economic development, while encouraging the shift towards a low-carbon economy (Drewes & Van Aswegen, 2013:201). This is considered as a major focus for future development in South Africa, since a clean and healthy environment is highlighted as a critical element for a quality living standard by the NDP (Kota, 2016:28). Additionally, a major concern that threatens the environment and its associated resources are the dysfunctional development patterns experienced by South African urban areas (National Planning Commission, 2012:16). In supporting the latter, Pieterse (2002:3-37) clarifies that land use patterns enforced by the previous regime ensued the establishment of dual urban areas where marginalised communities resided in precincts situated outside the urban periphery, resulting in a “tentacle pattern” where these areas were connected to the main Central Business District (CBD) with a transportation corridor. In resolving this, the NDP (2012:233) emphasises the need in chapter 8 by addressing the “challenge of apartheid geography and create conditions for more humane and environmentally sustainable living and working environments”. The National Planning Commission (2012:236) accentuates the effect of development on the environment; especially the damaging nature of industries coupled with low-density urban development that employ energy intensive land use patterns and result in poor air quality. In addressing the preceding, the NDP (2012:246) insists on employing contemporary planning approaches, necessitating efficient housing, infrastructure and services that are fully integrated with a reliable public transportation system.

In realising the goals presented by the NDP (2012), the Department of Planning, Monitoring and Evaluation (DPME) introduced the MTSF as a five-year implementation plan and monitoring network to align all national, provincial and local development programmes (DPME, 2014:5). The Framework (2014) highlights the responsible use of natural resources that is necessary to assist the transition towards a low carbon and inclusive economy. The MTSF(2014) further requests that all development challenges should be redressed through environmental consideration to minimise the impacts of poor air quality; especially within dense, low-income areas (DPME 2019:146). In doing so, the Framework (2014) places emphasis on reducing GHG emissions, preparing municipalities to combat climate change, encouraging a just transition to a low-carbon economy and enhance ecological infrastructure.

The NDP (2012) further recognises the significance of an effective and efficient transportation system as one of the nine factors influencing living standard (Department of Transport, 2015:6). As a response the Department of Transport introduced the NATMAP (2016) that reinforces the NDP's vision to provide a fast, accessible and reliable transportation system that encourages sustainable economic growth, while preserving the environment (Morapedi & Makhari, 2017:779). Chapter 9 underlines that even though all transportation modes have reduced their energy consumption since 1990, the increase in population growth and private car vehicles have negated the gains, warranting the shift towards alternative transportation modes that are less energy intensive (Department of Transport, 2015:7). Currently, the transportation sector is considered as the dominant energy consumer within urban areas that is liable for approximately 70% of the metros GHG emissions (Wolpe & Reddy, 2015:10). The Department of Transport (2018:5) suggests, without due intervention, the impact of the transportation sector may well have a detrimental effect on "land resources, water quality, air quality and biodiversity". It further claims that urban areas are one of the main contributors to South Africa's poor quality, emitting high levels of nitrous oxides and PM. In addressing the latter, Chapter 14 of the NATMAP (Department of Transport, 2016:2) recognises that sufficient public transportation and an increase of intermodal facilities located in close proximity to mixed-land uses may well reduce the demand for transport related energy consumption and its associated impact on the urban area.

The NLTsf was implemented during 2015 as a strategic instrument for guiding transportation development in all spheres of government (Schoeman, 2017:283). The Framework (2015:14) recognises the development outcomes set out by the NDP (2012) by introducing priorities that apply sufficient transportation planning to attain social, economic and health objectives, while minimising environmental impacts. This is done by implementing effective transportation policy that decrease GHG emissions through encouraging alternative energy use, effective spatial development patterns and the provision of efficient public transportation infrastructure. The Framework (2015) further emphasises the decrease in private car commutes and the shift of

freight transportation from road to rail may well serve as significant mitigation measures (Department of Transport, 2015:40; Cairncross *et al*, 2018:339). Even though transportation is considered as an important element that should be considered in AQM (DEA, 2014:142), the NLTsf (2015:52) neglects to present specific strategies on rectifying the transportation sector's impact on poor air quality within urban areas.

In guiding the future management and development of South Africa urban areas, the government introduced the IUDF in 2016 (Department of Cooperative Governance and Traditional Affairs, 2016:7). The Framework (2016) is presented as a response to the newly implemented Sustainable Development Goals and Chapter 8 of the NDP (2012), focussing on the transformation of urban areas in a safe, inclusive, resilient and sustainable manner (Department of Transport, 2015:7). The IUDF (2016) places emphasis on rectifying the enduring fragmented urban form that resulted in long daily commutes and its associated high GHG emissions (Abrahams *et al.*, 2018:11). In addressing the latter, the Framework (2016) aims to maximise the performance of urban areas by integrating planning, investment and budgeting in a manner that augments the urban form (DRDLR, 2022:27). While the IUDF (2016) does not specifically address environment and poor air quality as significant priorities it does, however, acknowledges the necessity of integrating and aligning various government departments (human settlements, transportation, environmental affairs) to develop "inclusive, resilient and liveable urban areas" (Department of Cooperative Governance and Traditional Affairs, 2016:8,48).

Chapter 8 of the NDP (2012), together with Section 12 of the SPLUMA (2013) call for the preparation of a NSDF in guiding the spatial development within South Africa. The NSDF (2022:22,80) endorses the NDP's aim by emphasising the alteration of existing and fragmented national spatial development patterns towards more liveable, inclusive, integrated and environmentally sustainable urban areas. In this regard, the NSDF (2022) promotes the integration and collaboration of relevant departmental policies and action plans in attaining the envisioned national spatial development patterns (Laubscher *et al.*, 2016:120). In doing so, the Framework (2022:42) suggests that future urban areas should be developed at higher densities, comprising greater land use mixing that are successfully integrated with public services and facilities through an effectively connected public transportation system. The NSDF (2022:77) further stresses the NDP's (2012) vision of shifting towards a greener, low-carbon economy by implementing more compact, mixed-land use development patterns that effectively integrate urban and rural areas and support sufficient municipal services and transportation infrastructure investment.

5.3.2 South African spatial planning legislation

Following the democratic elections during 1994, the national government faced monumental challenges in relation to spatial restructuring, improving the quality of life for previously disadvantaged communities, while advancing the new South Africa (Binns & Nel, 2002:137). In doing so, the national government introduced a contemporary government structure where local government would play a significant role in assisting the development goals introduced by national government. The aim of this approach is to remedy the inequalities instilled into the South African urban areas and local government by encouraging the development and transformation in a democratic manner (Steytler & De Visser, 2007:1–3). This should be done through enhanced delivery of basic services and infrastructure, while ensuring the general well-being of the citizens within their respective municipal areas (Madumo, 2015:154).

In attaining the latter, national government promulgated the MSA during 2000 that presented a new dispensation for South African local governments, introducing new independent government spheres, together with provincial and national governments (Steytler *et al.*, 2000:1). In doing so, the MSA (2000) delegates principal authority for service provision and development within the local community, while upholding the living standards of its citizens and encourage viable economic growth that supports a safe and healthy environment, referring specifically to the impacts of land use management, poor air quality and waste management (Bosman, 2003:20; Mngoma *et al.*, 2011:111). Succeeding in its obligatory responsibilities, local municipalities are required to adopt a compulsory IDP (five-year strategic plan) as the primary strategic planning instrument that “directs and informs all planning and development, and all decisions with regard to planning, management and development” (MSA, 2000:44).

By employing this approach, local governments are capable of creating a development plan for the short, medium and long term. As a means to facilitate inter-departmental cooperation, Section 26 of the MSA (2000:38) stipulates that a municipality should incorporate various sector plans into its IDP, inter alia, SDF, DRMP, EMP, IWMP, IEP, WSDP, EDP, HSP and ITP. With the promulgation of the AQA during 2004, Section 15 placed excessive emphasis on municipal air quality through its obligation to accommodate AQM into legal framework and policies. Therefore, the AQA (2004) necessitates local municipalities to include AQMPs into their compulsory IDP under Chapter 5 of the MSA (2000) for resource distribution (Tshehla & Wright, 2019:2). This view of integrating AQM within IDPs is in line with international trends that encourage the consideration of air quality interests into future spatial, economic and social development projects (Coetzee *et al.*, 2000:11). Even though the MSA (2000) did not originally address municipal air quality, the promulgation of the AQA (2004) necessitates the implementation of AQMPs as a new sector plan within the IDP, encouraging the integration of AQM into spatial planning and associated practices.

During 2013, parliament introduced the SPLUMA as a contemporary national framework legislation for land use management in redressing spatial injustices and segregated development patterns (Charman *et al.*, 2017:22). The Act (2013) signifies a decisive shift towards a normative planning approach that provides a comprehensive, uniform and recognisable system of land use management and spatial planning in South Africa (Mashiri *et al.*, 2017:154). It further encompasses the NDPs (2012) vision to ensure effective and inclusive socio-economic development, while highlighting environmental protection for future generations (Mashiri *et al.*, 2017:149). It recognises the significance of incorporating environmental concerns when providing sustainable and effective use of land as a means to create efficient, humane and liveable urban areas (Nel, 2016:80). In attaining the latter, the SPLUMA (2013) imposed five development principles that should be applied to land use management, spatial planning and land development in South Africa, namely; (i) spatial justice, (ii) sustainability, (iii) efficiency, (iv) resilience and (v) good governance (Barnes & Nel, 2017:220). Additionally, the SPLUMA (2013) endorses a contemporary spatial planning system through the integration of spatial policy, planning and land use management; especially at municipal level in realising South Africa's development outcomes (Nel, 2016:80).

Similar to the AQA (2004) and its accompanying AQMPs, Chapter 4 of the SPLUMA (2013) authorises the implementation of SDFs on national, provincial and municipal level as a contemporary spatial planning tool, promoting liveable and integrated urban areas by maximising land and resource efficiency (DRDLR, 2011:4; Musvoto *et al.*, 2016:188). Section 26 of the MSA (2000:38) requires the inclusion of SDFs as a supporting sector plan into their compulsory IDP in addressing priority development areas, identifying appropriate land use and proposing adequate residential densities (SACN, 2023:6). Importantly, the SPLUMA (2013) provides more guidance with regards to the content of SDFs that was evidently lacking under the MSA regime (Joscelyne, 2015:45). While the SPLUMA does not specifically reference urban air quality and its management, Section 21 of the Act (2013) explicitly specifies the importance of including "strategic assessment of environmental pressures" when compiling SDFs, indicating a congruence with the NEMA legislative family (DEA, 2016:114; SPLUMA, 2013:32). However, despite the optimism to incorporate AQM within spatial planning practices, Du Plessis (2014:80) is of opinion that greater alignment between environmental policies and spatial planning is required.

5.3.3 South African spatial planning guidelines

With the advent of democracy, the prevalent segregated land use patterns left major spatial ramifications for South African urban areas (Dlamini & Reddy, 2018:2). As a result, the national government embarked on developing sustainable and vibrant urban areas by introducing

numerous planning documents to facilitate compact urban forms, higher urban densities, mixed-land use development and the integration of public transportation planning (Du Plessis, 2015:218). Chief amongst these documents was the introduction of the Guidelines for Human Settlement Planning and Design during 2000 by the National Housing Department through the cooperation of various departments and stakeholders. This was done owing to the “mutual concern for the quality of the built environment and the country’s natural resources, as well as a common recognition of the role that human settlement planning and the provision of engineering services plays in its protection or destruction” (CSIR, 2000:1). Consequently, the Guidelines (2000) were developed to not merely support professionals in providing sufficiently serviced urban areas, but to establish sustainable and vibrant human settlements. This should be done by incorporating the provision of engineering services within layout planning and design (CSIR, 2000:2). In doing so, Schlotfeldt (1995:2) prominently expressed that urban planners and engineers ought to be supplied with guidelines aiming to support the decision-making process, in contrast to generic standards that impose absolute limits. The Guidelines (2000) are presented by the discussion of various sectors in their respective chapters, recommending that the concept of sustainability should form the cornerstone of any type of development (CSIR, 2000:4). While detail guidelines are not presented to mitigate poor air quality in the design and layout of urban areas, reference to poor air quality is made in Chapter 5: Ecological Guidelines for Settlement-Making. This section highlights that the location and distance of industries in relation to residential areas should be considered, the incorporation of public transportation in spatial planning to reduce vehicle emissions and the provision of green buffer zones around land uses that produce significant levels of poor air quality (CSIR, 2000:273).

As deliberated in Section 5.3.2, the national government responded with a paradigm shift by introducing the IDP through the MSA (2000), delegating responsibilities to local government to facilitate the process of integrated development planning in establishing sustainable and vibrant urban areas (Harrison 2006:188). This meant that local government should prepare a strategic plan to guide and coordinate all activities and service delivery within its municipal authority. However, critique was raised with its introduction, since the IDP was in direct conflict with other spatial planning instruments, the aim was ambiguous and the content thereof was undetermined (Harrison, 2006:186). The aforementioned is supported by the SACN (2020:2), highlighting that IDPs remain compliance driven with limited participation from various sectors and stakeholders.

In an effort to rectify the latter, the Department of Provincial and Local Government (DPLG) introduced the IDP Guide Pack during 2000 in equipping municipalities and officials with the means to prepare IDPs (Schoeman, 2004:98). Moreover, the guidelines intend to aid all stakeholders involved in the integrated development planning process by clarifying the purpose of the proposed IDP, allocating specific roles and responsibilities to all sectors involved, coupled

with the proposed planning procedures (SACN, 2020:2). This is done to establish a platform for the integrated sharing of spatial data and information necessitated to attain the vision of the IDP. In attaining the latter, the spatial alignment of various sector plans should represent the location, land uses and rights of all proposed projects (DRDLR, 2012:25). In essence, the IDP should be regarded as an intersectoral, priority focussed process that may incorporate every sector, “depending on local priorities as the primary guiding factor”. It should be noted that each sector agency within a municipality comprises their own planning and/or legislative requirements and should subsequently align in the IDP process (DPLG, 2000:12). By following this process may well enable municipalities to attain strategic and realistic objectives relating to existing challenges in an integrated manner through implementing mitigation strategies faster and more effectively (Ntlabezo, 2013:22). In doing so, the IDP Guide Pack (DPLG, 2000:3) endeavours to be a more exhaustive guideline by proposing the differentiation of information into six Guide Packs aimed at targeting group specific needs. This is attained by recommending key components that should be incorporated during the preparation of an IDP (DPLG, 2001:4). Table 5-1 below summarises these key components with its subsections.

Table 5-1: IDP components

IDP components	
The Analysis	Assessing the current level of development within the Municipal Jurisdiction that highlight specific communities lacking access to basic services.
Development Strategies	- Includes the vision of the municipality and local transformation requirements. - Propose development priorities and objectives of the Council. - Introduce development strategies of the Council.
Project	Identify projects necessitated to attain the vision and objectives of Council.
Integration	- Ensure effective integration with the Municipal Sector Plans and other integrated programmes. - Guide the integration of performance targets and performance indicators in relation to the Municipal Sector Plans.
Approval	- Link Municipal Budget (internal and external funding) to planning in ensuring the implementation of projects. - Ensure development is directed by the IDP

When considering the latter, it is evident that the national government in association with various departments made extraordinary efforts in providing local government with the necessary means to facilitate sustainable urban areas. However, critique amongst South African scholars is rising regarding the success of IDPs (Mabin, 2002:49; Harrison, 2006:204, De Visser, 2009:15). The aforesaid is supported by Coetzee (2010:15), characterising IDPs as “an octopus with too many tentacles – a system that not only created confusion and frustration in local governments, but also an impoverished system that is not well-understood, supported and respected by the leaders and participants”. While these viewpoints may have merits to a certain extent, the SACN (2022:263) is of opinion that the IDP model in itself has not failed, but rather its inability to provide real

meaning to the model's intention with regards to localising development challenges and involving local communities in government affairs.

As discussed in Section 5.3.2, the notion of SDFs was strongly established through the MSA (2000) and its associated regulations, however, the requirements of an SDF were augmented during 2013 with the promulgation of the SPLUMA (Wüst, 2022:57). Section 20(2) of the SPLUMA (2013), similar to the MSA (2000), maintained the notion that local municipalities should provide SDFs as a mechanism to establish objectives for future urban development in guiding spatial planning together with the provision of infrastructure and services (Laubscher *et al.*, 2016:48). Chapter 4 of the SPLUMA (2013) further reflects on the focus and basic requirements necessitated to prepare and compile a SDF (SPLUMA, 2013:20). With reference to Section 26(e) of the MSA (2000), a SDF is an integral component of the IDP and should provide basic guidelines for the land use management and planning of a municipality (CS Consulting, 2013:12). However, the stipulations introduced by the MSA (2000) dealing with SDFs should be read closely with Part E of the SPLUMA (2013), since the MSA (2000) only provides the core components of a SDF, while Section 21 of the SPLUMA (2013) presents detailed requirements of what a SDF should include (Laubscher *et al.*, 2016:129).

The SDF and other sector plans are essential components of a complete IDP, however, it is important to note that the SDF not only functions as a sector plan, but also a guiding mechanism for municipal management (SACN, 2015:5). While this commonality resulted in confusion regarding the responsibility and content of IDPs and SDFs, the fundamental distinction lies in the spatial expression of a SDF (Joscelyne, 2015:34). Furthermore, a SDF should provide the spatial strategy for the municipality by incorporating the spatial plan, spatial perspective and five (5) year spatial priorities into the IDP as a sector plan (Pulumo, 2015:10). The South African Local Government Association (SALGA) (2012:1) laments that SDFs are not effective in redressing the spatial inefficiencies and inequalities. Through investigating the quality and status of SDFs, SALGA discovered that consultants grapple to apply national and provincial policies, principles and spatial planning concepts during the preparation of SDFs. Further supporting the investigation of SALGA, Dewar and Kiepel (2012:35) argue that there is significant confusion regarding the content of recently formulated SDFs. Coetzee (2010:15) similarly criticises that SDF appear divorced and isolated from IDPs, other sector plans and the general city development strategies. In remedying the latter, the DRDLR developed SDF guidelines in an attempt “to establish and clearly communicate the expectations of the SDF's role, resources, content, and use as per the requirements of the SPLUMA” (DRDLR, 2014:1). Also, essential distinction is provided in terms of the different types of municipalities and what their respective SDFs should entail (SALGA, 2012:2), however, for the purpose of this research, emphasis will be placed on

the content of municipal SDFs. Please refer to Table 5-2 below that provides an overview of the content of a municipal SDF.

Table 5-2: SDF components

SDF Components	
Executive Summary	• Overview of main finding and summary of recommendations for the municipal SDF.
Background and Purpose	• Provide background information with regards to aims and objectives, terms of reference, study area etc.
Policy Context and Vision	• Present a contextual framework for the alignment of National, Provincial and Municipal policies in attaining the strategic objectives for the study areas. • Interpret the guiding principles of SPLUMA with reference to local significance. • Develop a draft spatial vision in accordance with the SPLUMA guiding principles.
Spatial Challenges and Opportunities	• Conduct a review of the various sector plans to inform the process of the Biophysical, Socio-economic and Built environment analysis. • Synthesise the above analysis into key issues and identify their spatial implications for the municipality to provide mitigation strategies.
Spatial Proposals	• Provide a final spatial vision through a short term (5 year) and a long term (10-20 year) with reference to above finding. • Develop a spatial concept illustrating the final vision for the municipality. • Present spatial strategies to attain the final spatial vision of the SDF. • Combine spatial strategies by overlaying the spatial proposals into a consolidated SDF and map.
Implementation Framework	• Develop policies that will support the achievement of the recommended spatial strategies. • Prepare guidelines that are relevant to attain the spatial strategies. • Develop a capital investment framework that articulates the manner in which the spatial strategies will be attained. • Produce effective details on how the SDF proposals should inform the IDP and its associated sector plans.

As highlighted above, the SPLUMA (2013) reiterates the strong notion of integration through the SDF, emphasising the need for SDFs to align and integrate the various sector plans and policies (Wüst, 2022:61). Moreover, Naiker *et al.* (2012:63) reaffirm the devolution of authority to local municipalities in AQM, since they are regarded as the most appropriate government level to address localised air quality challenges, while providing holistic and proactive management with associated strategic direction. In view of the latter, it is concerning that the only instance where air quality is referenced within the SDF Guidelines is during the preparation of the provincial and regional SDFs (DRDLR, 2014:22). On a municipal level, the SDF Guidelines make provision for the alignment and inclusion through the development of “spatial concept based on inputs from sector plans and encourage the revision of sector plans based on the SDF spatial proposals. In attaining the latter, it is suggested that the spatial proposals and implementation framework should be incorporated into the revision of the IDP and appropriate sector plans (DRDLR, 2014:67).

5.4 Conclusion

The MSA was introduced during 2000 as an alternative approach to empower local government in facilitating integrated development on a municipal level. In doing so, Chapter 5 of the Act (2000) requires that local municipalities should implement a compulsory IDP as the means for aligning, integrating and coordinating development through various sectoral strategies, including those relating to spatial planning and AQM, through effective budget allocations. The preceding is supported by Simphiwe (2014:8), reiterating that this approach replaced the segregated planning policies by adopting an integrated development approach by means of the alignment of municipal sector plans that are adequately coordinated with the objectives and priorities of national government.

Notwithstanding the IDP's function as the vehicle for integrated development, it appears that various challenges remain to sufficiently align the sector plans. This is reiterated by the work of Harrison (2006:186), critiquing the clarity of the IDP, since the goals are in conflict with other spatial planning instruments, the aim is unclear and the compilation thereof is uncertain. Also, SACN (2020:2) identified that the adoption of IDPs remain a compliance exercise for local authorities that is compiled without the necessary participation from various sectors and stakeholders. The Public Affairs Research Institute (2018:30) further determined that the lack of integration may be attributed to their independent development, resulting in inefficient budget allocation and disconnected implementation. The latter highlights a critical concern within the integrated development narrative, since the existing application depicts a fragile correlation between spatial planning and AQM, even though the IDP is designed to function as a unifying framework. The difficulty may be that spatial planning is mainly guided by development policies, namely; the NDP, the IUDF and the NSDF that prioritise inclusive economic development that generally conflicts with air quality objectives (Petrie *et al.*, 2018:9). By contrast, AQM is primarily governed by the AQA and the National Framework for Air Quality Management that provides minimum standards and extensive guidelines in managing air pollutants (Naiker *et al.*, 2012:65).

The misalignment between spatial planning and air quality policy directives are illustrated in ensuing Figure 5-1 when analysing the specific emphasis placed on various themes. The research argues that the preceding may be attributed to the silo approach when compiling major sectoral legislation and their respective policies and development plans. This is evident as far as the AQM policy directives are concerned, since no specific reference is made to spatial planning within the NEMA (1998), AQA (2004) or National Framework for Air Quality Management (2012). While the SPLUMA (2013) refers to the NEMA (1998) and "any other legislation that regulates a specific aspect of the environment", the Act (2013) fails to specifically reference the AQA (2004) and National Framework for Air Quality Management (2012) that are regarded as the primary mechanism for AQM in South Africa. While fundamental strategic planning frameworks, namely;

the NDP (2012), the NLTsf (2015) and the NSDF (2022) reference themes to reduce emission (low carbon economy, green cities and sustainable transportation), no distinct emphasises is placed on poor air quality within the aforementioned policies.

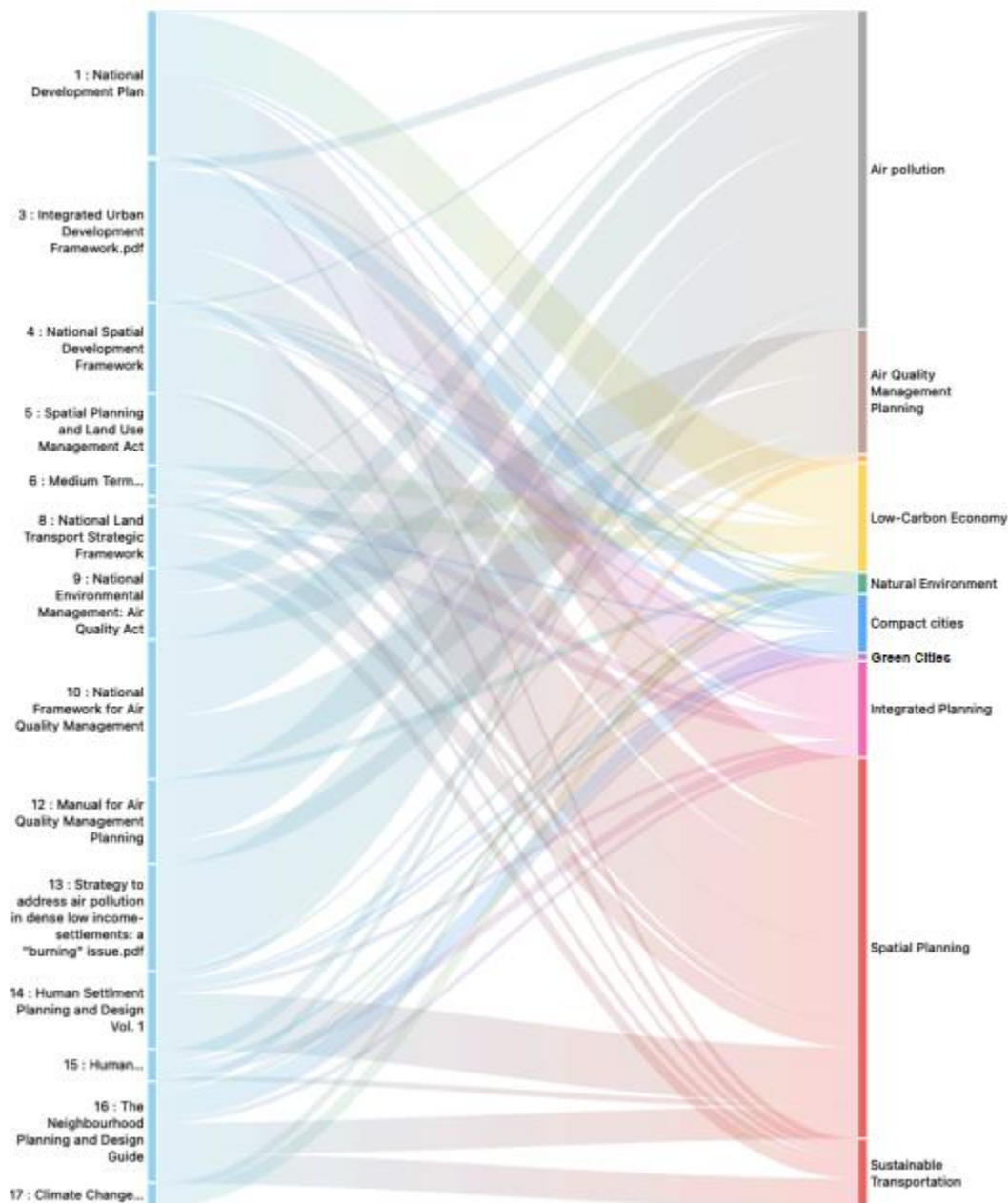


Figure 5-1: Alignment between South African spatial planning and air quality management policy directives.

While it appears that misalignment between spatial planning and AQM policy directives are prevalent, the promulgation of the recently prepared Strategy to poor air quality in dense, low-income areas during 2019 highlights a paradigm shift. The Strategy (DEA, 2019:27) explicitly reflects the importance of spatial planning within the South African AQM system, suggesting that “air quality issues” should influence spatial planning initiatives. The Strategy (2019) further reiterates the importance of liaison between spatial planning and air quality municipal

departments in ensuring coordination and effective implementation of initiatives (DEA, 2019:27). The lack of alignment between spatial planning and AQM in South Africa may be attributed to the development of policy directives in different periods, leading to disjointed approaches that lack explicit cross-references. While SPLUMA focuses on spatial development frameworks, it only makes broad references to environmental legislation without specifically addressing AQM. Similarly, the AQA (2004) does not integrate spatial planning instruments within the respective legislative and policy framework. This isolated approach for establishing policy directives may well reflect the diverse priorities of their respective timeframes, rather than being updated in tandem in ensuring cohesion between spatial planning and AQM governance. As a consequence, the South African AQM system, particularly under the AQA, is primarily focused on command and management measures for industrial emissions. Even though this approach is essential, it presents a narrow approach that lacks sufficient integration between other sectors that have a significant impact on air quality. The latter demonstrates a significant gap in including broader sectoral considerations into AQM, especially; energy, transportation and spatial planning that are fundamental to successfully address air quality; especially within urban areas.

The lack of definitive integration, together with limited indirect references across the various themes signify the absence of alignment between spatial planning and AQM within South Africa. This identifies an opportunity for greater cohesive coordination, where the IDP as the recommended mechanism for integrated development should establish its role in ensuring the integration between spatial planning and air quality objectives. The research argues that existing disparities should be addressed by employing an holistic approach by integrating air quality objections into the various sector plans; especially the SDF. Effective alignment between spatial planning and AQM policies may well enhance the efficiency of both frameworks. In conclusion, an adequate integrated development approach may not only result in more sustainable development patterns of South African urban areas, but also ensure improved air quality outcomes that benefit all communities.

Chapter 6 Investigation of contemporary spatial planning approaches that may be conducive to poor air quality

6.1 Introduction

This chapter aims to address research Objective 3:

3. What possible contemporary spatial planning approaches may well improve poor air quality?

With growing global urbanisation rates and associated sprawl, land is progressively becoming an imperative resource in supporting human life and social development. (Chen *et al.*, 2019:1). Alarmingly, urban areas currently cover less than 3 percent of the world's surface, while producing 78 percent of anthropogenic carbon emissions (Bereitschaft & Debbage, 2013:612). Urban form effects urban air quality as land use patterns, define the location of poor air quality sources and patterns of exposure (Salmond *et al.*, 2018:1). Sharma *et al.* (2018:4) concur, asserting that the urban morphology and its associated land uses influence urban air quality; especially as the emission levels of human activities, transportation, burning of fossil fuels and biomass for energy, agricultural and industrial activities adversely affect the level of urban emissions. Romieu and Hernandez-Avila (2003:77) affirm this view, indicating that poor air quality and its accompanying emissions have a more substantial impact on citizens living in developing countries, owing to different exposure levels, socio-economic status, population structure, infrastructure and services.

South Africa is similarly confronted with the detrimental challenges of poor air quality resultant from incessant urbanisation, however, the squalidness of the country's history ensued a range of unique difficulties (Matooane *et al.*, 2004:1). Supporting this view, Pieterse (2002:3-37) reiterates that previous spatial planning policies resulted in the development of dual central business district and mono-functional residential neighbourhoods that were separated by a physical or land use barrier. Consequently, poor spatial planning situated heavy industrial development in close proximity to dense, low-income areas, comprising mainly the deprived urban population (Harrison & Todes, 2014:15). While numerous efforts are implemented to improve the infrastructure and service delivery, these urban areas continue to experience distinctive environmental challenges that may influence their quality of life (Matooane *et al.*, 2004:1).

The responsibility of urban planning is to guide future development within urban areas by affectively locating urban transportation, infrastructure and land uses (El Aziz, 2016:5). Efficient urban planning may address poor air quality by strategically locating polluting land uses and exposed citizens, while promoting an optimal urban form that minimises emissions (Verdini *et al.*,

2025:14). Compact urban forms introduce higher inner-city densities that encourage greater public transportation ridership and walkability, resulting in lower vehicle kilometres travelled and transportation-related emissions (Marshall, 2008:3134). Recent studies argue that compact urban forms do not necessarily result in improved air quality, since higher density development situated in close proximity to major transportation routes increase the exposure of citizens to poor air quality (Clark *et al.*, 2011:7031; Marshall *et al.*, 2009:1755; Schweitzer & Zhou, 2010:364). Borrego *et al.* (2006:462) argue that even though transportation and large point source related emissions have been curbed through the employment of cleaner technologies and fuels, urban areas continue to demonstrate continual “environmental stress, loss of open space, traffic congestion, noise and air quality degradation”.

As deliberated above, urgent means are required to adapt urban areas in improving poor air quality by providing sufficient transportation services, connecting residential, employment, commercial, leisure and educational activities, while determining suitable allocations for potentially polluting land uses (Cariolet *et al.*, 2015:1; Moorcroft & Barrowcliffe, 2015:6). Condon *et al.* (2013:5) in support argue that the form and function of urban areas may either increase or reduce the energy demand, affecting the location and frequencies of poor air quality emissions. While various studies (Zhou *et al.*, 2018:1; Zou *et al.*, 2016:1; Xu *et al.*, 2016:1) verified the connection between air quality and urban form, the relationship between poor air quality and specific urban characteristics is still disputed (Mansfield *et al.*, 2015:902).

Ultimately, the Department of Planning, Monitoring and Evaluation (2005:9) recognises that the absence of land use, transportation, energy, housing and other planning processes in AQM have raised the cost of addressing poor air quality, while impeding the management of significant poor air quality sources. In response, Condon *et al.* (2009:5) encourage spatial planners to consider AQM within planning processes, since the effective management of urban characteristics may play a significant role in reducing poor air quality within urban areas. The preceding prompted the research to investigate contemporary spatial planning approaches in determining possible solutions that may be implemented to mitigate poor air quality within South African dense, low-income areas.

6.2 Addressing urban air quality through contemporary spatial planning approaches

Resultant from the ineffective and dysfunctional South African urban patterns and the contribution to poor air quality, it is argued that urban planning should play an integral role in AQM (DEA, 2016:125; City Health Department & Air Pollution Control Section, 2005:3). The latter is supported by Sharma *et al.* (2018:4), indicating that urban planners comprise the ability to efficiently “plan the spatial distribution of point sources of pollution, such as industries, landfills, treatments plants, transportation routes, open spaces, which impact the quality of air in an urban region”. However,

considering the unique patterns and forms of South African cities, spatial planners and environmental specialists are pondering the most effective urban forms to improve the poor urban air quality. Notwithstanding the aforementioned, Spiekermann and Wegener (2018:68) caution that when a single planning approach is implemented in isolation to resolve complex urban challenges, it will most likely fail, recognising that multiple approaches should be considered as a means to improve air quality. The ensuing section investigates the compact city, TOD, smart growth, new urbanism and green urbanism spatial planning approaches with special reference in its ability to improve urban air quality. This will be conducted in identifying the most significant “urban development principles” that may well be conducive towards the mitigation of air quality in South African urban areas.

6.2.1 Compact city

The compact city approach is often considered to have been initially used by Dantzig and Saatay during 1973 in an effort to improve the efficiency of urban resources (Ahlfeldt & Pietrostefani, 2017:6). As a consequence of high urbanisation levels and economic growth, Burges (2000:12), as early as 2000, recognises that the compact city approach gained attention to combat high demand for food, fresh water, energy and land. With growing pressure on agricultural land and natural habitats induced by fragmented development patterns, low density urban sprawl and dependency on private car use, the aim shifted to mitigate the incessant increase in energy consumption and emissions (De Schiller & Evans, 2000:117). The compact city attains this by intensifying central development, proximate higher residential and commercial density that are linked with efficient public transportation systems and curb sprawl through development restrictions in designated areas (Gugger & Kerschbaumer, 2013:56). Bibri *et al.* (2020:13) acknowledges that when development is restricted within designated areas, high potential agricultural land located on the urban periphery is protected and minimises the risk for urbanisation. While the list of advantages for the compact city approach is particularly long, the chief rationale for this approach is its ability to reduce energy consumption and emissions through the employment of efficient development patterns (Holden & Norland, 2005:2148).

While the compact city approach is widely debated in literature (Bibri *et al.*, 2020:2), it is clear that three main characteristics are prevalent, namely; economic density, morphological density and mixed-land uses (Ahlfeldt & Pietrostefani, 2017:7). Economic density relates to the total citizens residing and working within a specific spatial unit that is generally measured through employment or population density (Neuman, 2005:15). Conversely, morphological density refers to the built environmental and are associated with physical aspects of the compact city, for instance; the agglomeration of urban footprint, total impervious surfaces, demarcation of urban boundaries, street connectivity and building volumes (Burton, 2002:226). Finally, mixed-land use recognises

the integration of residential, leisure, employment and retail opportunities across and within buildings to reduce travel distances and private car dependency (Wardner, 2014:3). The proponents of the compact city approach consider it as a remedy to urban sprawl by restricting urban growth within specified areas, densifying designated urban zones and promoting mixed-land use development to enhance public transportation and energy efficient urban design (Arbury, 2005:15). It is argued that the compact city approach not only reduces transportation related emissions through the encouragement of pedestrian and public transportation networks, but also diminishes the energy consumption of infrastructure development through the reuse of existing built-up areas (Matsumoto, 2011:5). Ensuing Figure 6-1 presents rudimentary design of the compact city approach on the district (left), town (centre) and city (right) level. Even though the scale and design of the compact city approach differs on each level, the core characteristics of the approach remains similar, for instance; each circle maintains a clear urban boundary, economic and social activities and high-density residential development are focussed within the centre, while residential densities decrease gradually away from the urban centre.

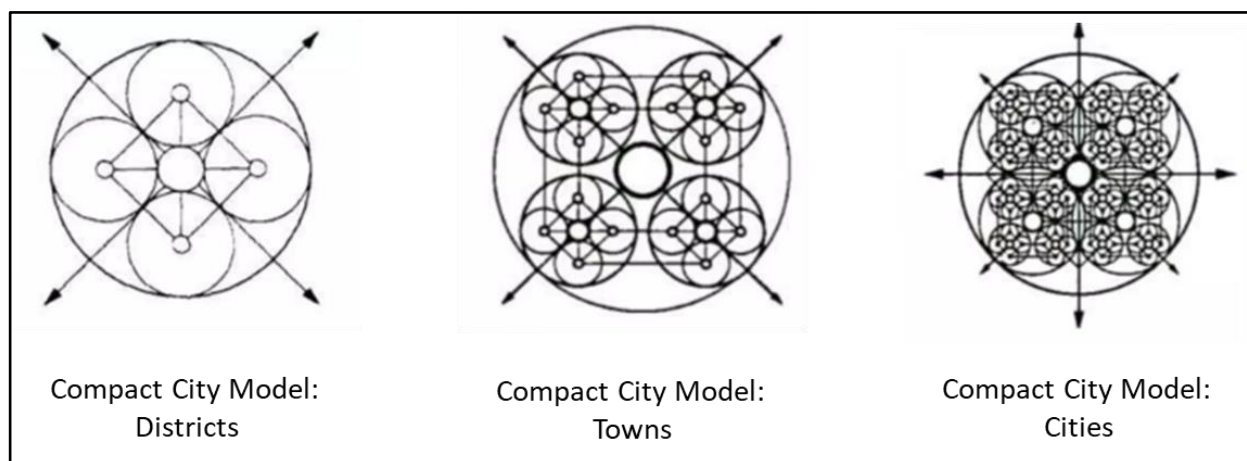


Figure 6-1: Compact city model

Source: Jadhav et al., 2013.

Although the compact city approach comprises numerous environmental and energy advantages, researchers (Burton, 2000:1974; Schweitzer & Zhou, 2010:365) criticise its ability to mitigate air quality within urban areas. Further arguing against this approach, Burton (2000:1974) claims that compact city development may presents health risk from localised poor air quality, induced by traffic congestion and the proximity of industrial and residential uses. Empirical studies conducted by Schweitzer and Zhou (2010:368), and Bereitschaft and Debbage (2013:613) are not conclusive regarding compact development patterns and the mitigation of air quality. The researchers conclude that more compact urban forms may well increase the exposure to poor air quality, since more citizens are located adjacent mass transportation axis and dense urban centres that generate high emission concentrations. Moreover, Jenks and Jones (2010:6) express

their concern regarding the loss of green open spaces through the implementation of compact development patterns. The authors believe the increase of impervious surfaces and built-up areas influence the ventilation and cooling of urban areas, increasing the energy consumption and dispersion rate of emissions.

Although the compact city approach is excessively debated in current literature, the research argues that certain characteristics thereof may well be employed to mitigate poor air quality within the unique spatial patterns of South Africa. Urban areas are complex systems and implementing the compact city as a single solution will most likely fail. Batty (2010:120) in his work, *Complexity in City Systems*, notes that the intervention of complex systems should be met with extreme caution. However, the author further suggests that the “most effective intervention is based on small scale change which enables a system to meet its own goals”. It is, therefore, argued that the characteristics of the compact city approach might be introduced on a neighbourhood or smaller scale than the entire city. When considering the segregated nature of South African urban areas, this small-scale approach may be simpler to implement. Matsumoto (2011:17) is in agreement, identifying that compact development patterns on a neighbourhood scale encourage high density and mixed-land use development, promote pedestrian friendly transportation modes and effective public transportation systems, enhance environmental conservation and mitigate poor air quality.

6.2.2 Transit-oriented development

In his book *The Next American Metropolis*, Calthorpe (1993:56) initially defines TOD as a mixed-land use community situated within a 600m or 10-minute walking distance from the nearest transportation node and central commercial area. He further suggests that TODs should mix “residential, retail, office, open space and public uses in a walkable environment”, encouraging employees and residents to use public or pedestrian friendly transportation modes. Despite comprising similarities to the compact city approach with regards to mixed use development, TOD emphasises the enhancement of accessibility and mobility through effective transportation. Dieleman and Wegener (2004:318) concur, conveying that TOD generally comprises a light rail transit system as the core public transportation in the region, coupled with a dense and frequent bus system, operating as a feeder for the light rail transit nodes. The authors highlight the significance of concentrating employment opportunities, services, social amenities and residential uses at transit nodes to increase transit ridership, while decreasing privately owned vehicles. Moreover, it is argued that, unlike other urban development approaches, TODs should aim to serve a dual purpose as both a node within the larger metropolitan or regional area and an ideal location on its own merits (Belzer & Autler, 2002:4). This means that stations should not only provide adequate transportation services to function as regional trip destinations, but also serve

as trip origins by locating coherent neighbourhoods in close proximity to transit stations (Bertolini, 1999:201). Cervero (2009:27), with regards to the latter, proclaims that when transit nodes serve as both trip destination and origin, it may well increase the accessibility within the metropolitan region through producing two-way travel flow. Salat and Ollivier (2017:7) identify this as a vital component for a successful TOD, since a well-designed transit node comprising commercial activities, residential uses and social amenities increase the regional accessibility by creating a land use pattern that facilitates alternative transportation modes. As precedingly discussed, Figure 6-2 below depicts the original design of a TOD that locates commercial and employment activities around the transportation node, while high density residential neighbourhoods are situated within 600m from the transportation node and integrated through effective public open spaces.

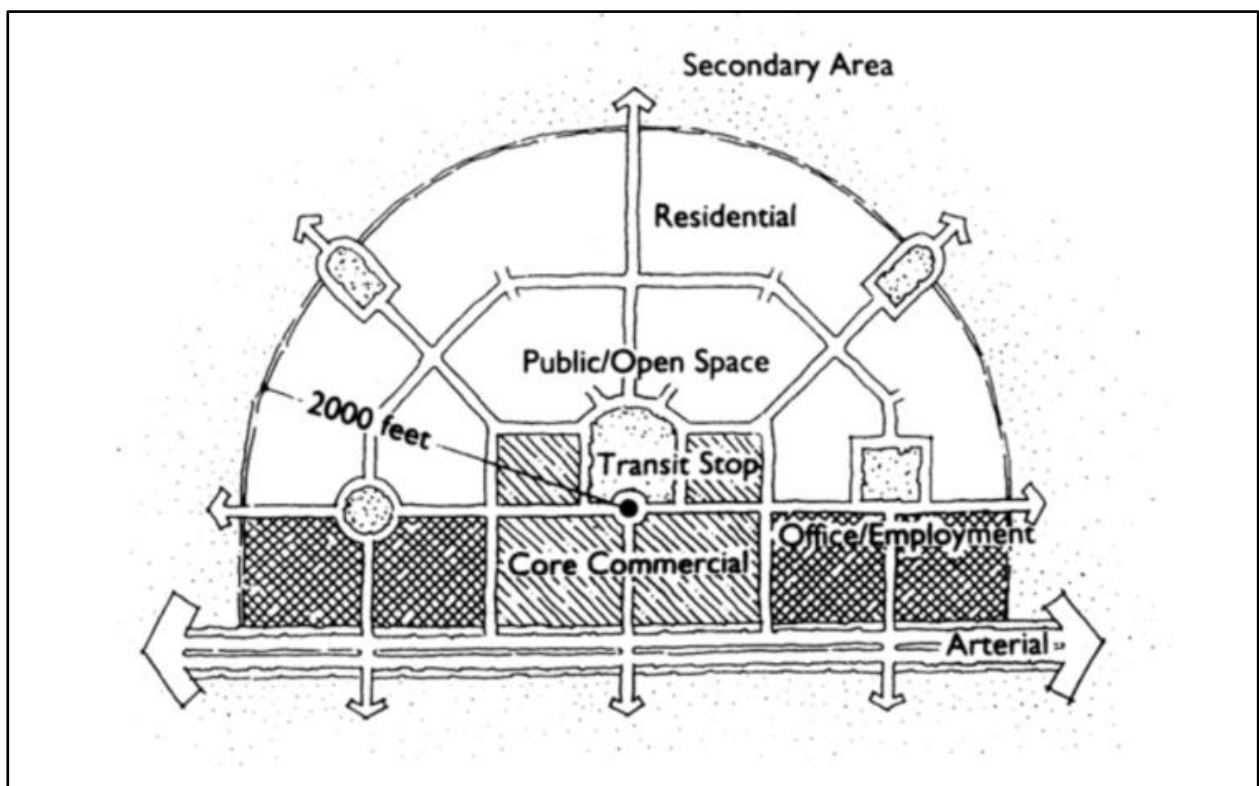


Figure 6-2: TOD design

Source: Calthorpe, 1993:56.

While extensive research has been conducted regarding the appropriate typology and scale of TODs, it is argued that TODs should be diversified in an integrated network to ensure accessibility throughout the metropolitan region and increase public transportation ridership (Bertolini *et al.* 2009:4). Calthorpe (2011:86) further differentiates that TODs comprise three main locations in metropolitans, namely; urban centres, urban fringe locations and neighbourhood locations. Urban centre TODs are generally located in close proximity to rail transit lines within the urban core, comprising a high density, mixed-land use patterns that focus on employment clustering (Hess &

Lombardi, 2004:26). TODs in urban fringe locations are situated at industrial zones outside the urban core. These areas commonly employ urban regeneration projects through infill development or brownfield regeneration at underutilised transit lines (Calthorpe, 2011:87). This is conducted to reduce the urban footprint by re-using historic buildings, improve accessibility across and along the metropolitan region and provide pedestrian friendly transportation opportunities that encourage a healthy urban area (Salat & Ollivier, 2017:30). Finally, TODs in neighbourhood locations are strategically placed along local bus routes to feed into the existing rail transit lines. These neighbourhood TODs also encourage the employment of mixed-land use development but at medium to low densities, placing emphasis on housing, social amenities, walking and cycling as the preferred transportation mode to serve the surrounding community (Sohoni, 2016:3222).

Considering that the implementation of TODs is mainly driven by its potential to reduce private car use through alternative transportation modes, the National Academies of Sciences Engineering and Medicine (2004:120) signifies that TODs constitute a more efficient development pattern that reduces cost, resources and energy. They further reiterate its capacity to conserve open spaces, encourage walking, promote healthier lifestyles and provide a clean urban area for residents. In attaining the latter, Curtis (2008:287) suggests that metropolitan regions should comprise a range of TODs that are effectively integrated with various transportation modes. This integration is considered amongst the most effective approach to implement TODs in developing countries, since they are not limited to expensive rail transit (Wilkinson, 2006:230). With regards to the unique nature of the current modal split and form of South African urban areas, it may be argued that the most cost effective and sufficient public transportation network is bus rapid transit (BRT) systems (Vaz & Venter, 2012:619). The system is considered as a flexible and rapid transportation service that integrates urban nodes, vehicles and running ways (National Academies of Sciences Engineering and Medicine, 2003:10), through larger busses on dedicated bus lanes that offer residents frequent, fast and congestion free trips (Ugo, 2014:2). Notwithstanding the growing literature regarding road transportation and its detrimental impact on urban air quality, Bel and Holst (2015:20) argue that BRT systems may be introduced as an alternative public transportation mode to increase accessibility within urban areas, while reducing emissions. Lindau (2010:17-27), in agreement, signifies that an appropriately implemented BRT system integrated with sufficient pedestrian friendly transportation networks may well decrease urban energy consumption and emissions from automobiles. As South Africa confronts urban challenges of declining open space, infrastructure cost, traffic increase and congestion, TOD and its associated network of transportation modes may be introduced as an alternative spatial planning solution in mitigating poor air quality.

6.2.3 Smart growth

The smart growth proponents claim the approach is considered as the most prominent spatial planning approach to attain effective land use management and sustainable urban development (Leigh & Hoelzel, 2012:90). In scrutinising the smart growth approach as an alternative for urban sustainability, Dierwechter (2017:8) argues that the popularity of this approach is found in its crux to encourage efficient urban development on a metropolitan scale as appose to other spatial planning approaches. The author highlights, in a broad sense, that smart growth aims to focus future development in adequately serviced cities and neighbourhoods by employing planning instruments like restriction, mixed land uses, public transportation and regional coordination in curbing low density urban sprawl. Lewis and Knaap (2012:49), in elaboration, affirm that smart growth is dedicated to restrict incessant urban sprawl by introducing neighbourhood restoration programs, urban revitalisation projects, and identifying future growth and high-density development zones within metropolitan regions.

With growing urbanisation and high levels of automobile dependent sprawl, smart growth is proposed as a suitable solution, since it establishes land use patterns that encourage multiple transportation modes, conserve open spaces and concentrate development in ensuring the effective use of infrastructure and resources (Bochner *et al.*, 2002:1). Also, the approach is dedicated to protect sensitive agricultural land and revitalise urban centres and neighbourhoods by promoting compact development patterns, comprising mixed-land uses that are effectively integrated with different housing typologies and commercial activities to accommodate a range of income levels (Geller, 2003:1411). It is argued that new development should be primarily restricted within existing urban areas through infill development and brownfield regeneration and not directed to undeveloped areas outside the urban periphery, strengthening the concept of re-using existing urban infrastructure (Handy, 2005:146). As a result, smart growth may create high density mixed-land uses and transit friendly development patterns that promotes sufficient land use management and improve public transportation ridership (State of Maryland, 1997:31). Ensuing Figure 6-3 illustrates the proposed development in the downtown neighbourhood in Troy, Michigan. The development presents how smart growth may be implemented to address urban sprawl, by employing urban infill and regeneration projects to introduce high density mixed-land use development, together with public open spaces to limited private vehicle ridership and encourage pedestrian orientated transportation.



Figure 6-3: Smart growth design for downtown Troy, Michigan

Source: Michigan Public, 2017.

While smart growth intends to direct development within designated urban areas to curb incessant urban sprawl, its objective is not to restrict or stem future growth (Danielsen *et al.*, 1999:516). Even though this approach focusses on developing the urban economy through the integration of strong economic centres, Burchell *et al.* (2000:823) further emphasise its ability to serve local communities and their surrounding environment. Moreover, Pont *et al.* (2021:379) suggest that higher density development may reduce the impact of cities on the environment by ensuring that residents are accommodated on smaller erven, resulting in less urban land consumed for development which ultimately conserve valuable agricultural areas, open spaces and ecologically sensitive areas. Ultimately, the successful implementation of smart growth is necessitated by public and private investments through encouraging regional development into city centres and inner-city suburbs. The latter is attained through urban regeneration and revitalisation programmes to restore existing derelict urban centres and inner-city suburbs that promote the future growth of urban regions (Burchell *et al.* 2000:823).

While numerous efforts have been implemented to readdress the spatial imbalances, Pieterse (2004:82-83) noted that current spatial planning practices tend to reinforce spatial segregation. It is indicated that high-income neighbourhoods are generally located in close proximity to urban centres and employment opportunities, while low-income areas are situated outside urban fringes that result in long daily commutes and inadequate development standards. Wheeler (2002:111)

questions these practices, arguing that when development is homogenous, it produces “unattractive, monotonous urban landscapes, a lack of housing for all income groups, class and racial segregation, and job-housing imbalances that lead to increased driving, congestion, and air pollution”. In response, the research conducted by Wang *et al.* (2013:69) investigate the feasibility of the smart growth approach as a solution to reduce vehicle tailpipe emissions by considering land use mix, local transportation density and connectivity. Their research indicates that when development comprises a sufficient mix of land uses that are effectively integrated with multiple transportation modes and technologies, it may well decrease automobile related emissions. In supporting the latter, Frank *et al.* (2006:2) imply that diverse spatial planning objectives, inter alia, emission reduction and energy consumption, may be attained when smart growth development patterns are implemented. The scholars found that the incorporation of higher densities, mixed-land uses and connectivity within urban areas encourage both transit ridership for regional accessibility and pedestrian friendly transportation modes for local destination, reducing the total vehicle miles travelled and associated emissions. Additionally, the energy consumption of urban areas may be reduced, since single-family dwellings generally utilise excessive energy for cooling and heating (Alexander & Tomalty, 2002:398).

6.2.4 New urbanism

Even though new urbanism seems in certain cases synonymous to smart growth, it comprises significant differences. For instance, smart growth was established by a community of policy planners and environmentalists, while new urbanism was framed by physical planners and architects, placing emphasis on the physical form as the precondition for augmenting economic, social and ecological elements in urban areas (Knaap & Talen, 2005:109). New urbanism promotes design-based development that was founded on the principles of traditional urban development to curb incessant sprawl and urban decline through building and rebuilding cities, towns and neighbourhoods (Alias *et al.*, 2011:79). The proponents of new urbanism use it as a collective term, incorporating the traditional neighbourhood development of Duany and Plater-Zyberk and the TOD articulated by Calthorpe, Kelbaugh, and Liebermann (Bohl, 2000:762).

Cozens and Hillier (2008:52) depict new urbanism as a systematic development approach, aiming at developing dense mixed-use neighbourhoods and precincts that emphasis pedestrian friendly transportation systems, while comprising diverse housing topologies. Alias *et al.* (2011:79), in agreement, elaborate that this approach supports the inclusion of wider sidewalks, grid network layout, various housing topologies, commercial, businesses and social amenities situated in close proximity to encourage walking and cycling. Moreover, new urbanism promotes the conservation of critical agricultural land that are effectively integrated with surrounding neighbourhoods and towns in providing adequate green open spaces for public use (Hickichi, 2003:10).

A significant element of new urbanism is its endeavour to function at various scales within a metropolitan region, for example; the city, neighbourhood, district and the corridor, and finally the built environment, property and blocks (Knaap & Talen, 2005:109). At the regional level, Veras and Amorim (2005:272) signify that new development in proximity to the urban edge should be integrated, through transportation corridors, with the existing neighbourhoods, while development located outside the urban periphery should be organised as small towns or villages to support housing and retail. The authors further highlight that these towns and villages should encompass diverse public and private land uses in supporting the regional economy to restrict the accumulation of poverty in one area. The ensuing levels are the neighbourhood, the district and the corridor which are considered the essential elements to build and rebuild a metropolitan region (Congress for the New Urbanism, 2000:10).

The neighbourhood and district are regarded as a compact, high-density areas comprising a balance between public amenities, diverse housing, parks, retail, and schools to encourage social interactions. These areas should be effectively integrated with a corridor that functions as a continuous element that connects and articulates the metropolitan structure (Hall & Porterfield, 2001:122). In view of the latter, Duany and Plater-Zyberk (1994:12) argue that in managing the built environment, various existing urban challenges may be addressed, for instance; economic decline, social isolation, congestion and pollution. New urbanism recommends the inclusion of diverse housing typologies and price levels in neighbourhoods in attracting residents of various income levels, ages and races, encouraging social interaction that is necessitated for healthy communities. The Congress for New Urbanism (2000:10) proposes that at the street and building scale, neighbourhoods should be designed with consideration of their unique identity, applying the original architectural style that support local geography, culture, history and climate. In reiterating the aforesaid, Alias *et al.* (2011:78) caution that new urbanism is not an alternative approach aiming at duplicating old neighbourhoods, but a design movement that focusses on the establishment of new neighbourhoods based on conventional design principles, while supplying contemporary amenities that are requested by residents. Figure 6-4 below illustrates the urban-rural Transect introduced by Duany & Plater-Zyberk during 2003. The notion of the Transect is to delineate Transect Zones within an urban area that organise various types of human environments along continuum from urban to rural in assisting appropriate density, land use and zoning within each zone to encourage mixed-land use and walkable communities.



Figure 6-4: Urban transect proposed by new urbanism

Source: Duany & Plater-Zyberk, 2003:vii.

It appears that South African urban development since 1994 reinforces spatial segregation and fragmented development by establishing mono-functional low-density neighbourhoods outside the urban periphery. This results in an inefficient urban form that increases urban sprawl, congestion, infrastructure cost, social exclusion and poor air quality (Turok, 2001:2349-2377). In response to the incessant segregated and fragmented development, Bohl (2000:762) argues that new urbanism may be employed to implement design-based strategies of conventional urban forms to halt further urban sprawl and revitalise urban and neighbourhood vitality. Ellis (2002:264) further reiterates that new urbanism is not only paramount in increasing the walkability within neighbourhoods, but also to decrease automobile dependency in the metropolitan region, since effective design may influence travel behaviour. In agreement, Hikichi (2003:2) claims that areas comprising social services, facilities and job opportunities within walking distance may decrease the number of long trips and encourage the use of pedestrian transportation, resulting in the reduction of transportation related emission.

Critiques maintain that freeways in corridors integrating the neighbourhoods and district are viable solutions to reduce traffic and improve accessibility. However, new urbanism encourages the use of transit and other forms of public transportation, since the development of more freeways induce longer trips that result in congestion and pollution (Congress for the New Urbanism, 1996:99). Furthermore, sound development that comprises diverse housing typologies, commercial activities, social amenities and public open spaces within a close walking distance may aid in the reduction of poor air quality in South African urban areas. In supporting the latter, Garde (2020:454) expresses the affective implementation of new urbanism design strategies may well result in “less vehicle miles travelled, increased transportation modes, increased transit ridership,

increased household disposable income from the use of public transit; increased local economic development and reduced air pollution and energy consumption”.

6.2.5 Green urbanism

Owing to distorted South African spatial patterns, urban forms are characterised by resource-intensive growth, resulting in disproportionate and inefficient growth in various sectors; particularly in energy, transportation, water and waste. Urban areas facilitate unsustainable energy, contributing to a rapid increase in waste sites, rising soil pollution and decreasing freshwater resources (SACN, 2016:10). Muyemeki *et al.* (2021:1) highlight that among the most significant contributors to PM in South African urban areas are unsustainable transportation modes, industries, waste burning, residential fuel burning and windblown dust. Campbell (2018:308) crucially emphasises that urban planners currently face immense pressure over equity versus economic growth and environmental protection over economic growth, stating that “conflict in development is where the real action for urban planners will be: seeking to resolve both environmental and economic equity issues at once”. In supporting the latter, Lehmann (2011:245) reiterates that with the incessant pressure of climate change, it is imperative to re-conceptualise existing urban areas and their associated systems of infrastructure to be more compact, mixed-use and polycentric.

In supporting the aforementioned, Nassar (2013:339) argues that green urbanism may be introduced, as an urban model, to attain zero-waste and zero-emission within the exiting urban form. This should be done to encourage energy-efficient urban forms, by introducing compact development patterns, urban regeneration and transformation of dilapidated CBD, while encouraging urban forms that are socially and economically sustainable. The focus is to implement walkable, mixed-use developments through transit-orientated neighbourhoods, that aims to curb urban sprawl and encourage a sense of community (Lobejko *et al.*, 2015:23). In principle, green urbanism recognises the importance of ecosystem services and urban greening, inducing the conservation of critical green infrastructure within urban areas in order to decrease pollution, mitigate severe urban climates and produce a cost-effective urban drainage system. By doing this, it not only creates an urban system that creates healthy communities, but also conserve and improve ecological diversity within the urban area (Jabareen, 2006:43).

The principles of green urbanism principles as introduced by Lehman (2011:245), are proposed as a multidisciplinary approach that incorporates “landscape architects, engineers, urban planners, ecologists, transport planners, physicists, psychologists, sociologists, economists and other specialists”. This is done to ensure the reduction in energy, water, and materials, while considering viable spatial development patterns that encourages the conservation of natural resources. Additionally, the implementation of green infrastructure and green design principles

within urban areas limit energy usage, food scarcity and exploitation of materials at every level of the city or district life-cycle. Zaręba (2016:2) argues that green urbanism consolidates three essential aspects, namely; materials and energy, ecosystem services (water and biodiversity) and green infrastructure, and urban and transportation planning. As a consequence, urban areas should minimise their material and energy consumption by employing a more compact development through the encouragement of densification strategies, promote infill development on underutilised “Brownfield” sites and implement urban renewal projects on deteriorating buildings and structures (Lehmann, 2008:418).

Ensuing Figure 6-5 depicts the design principles of green urbanism by promoting high-density, mixed-use development that contains urban sprawl and land consumption to optimally utilise existing urban resources. In doing so, the urban form reduces the need for transportation, while encouraging pedestrian orientated transportation. In addition to the latter, significant emphasis is placed on green and blue infrastructure within the urban area that integrates urban green spaces (parks, green roofs and urban gardens) with urban blue spaces (rivers, lakes and stormwater management systems) to promote urban biodiversity, improves air and water quality and mitigates the urban heat island.



Figure 6-5: Green urbanism design

Source: Samskara Studio, 2024.

Medearis and Daseking (2012:69) recognise that urban planning may be considered to attain sustainable development through the identification of design and techniques in reducing the ecological footprint of urban areas. Tang (2010:179) further affirms that urban form plays a vital

part in managing the use of energy and materials within contemporary urban areas. Handy (2015:1) maintains that the provision of additional and wider roads may increase automobile and truck traffic within urban areas, resulting in urban sprawl and suburban development that increase energy demand and consume green spaces. It is therefore, essential to provide urban areas that focus on urban greening and mixed-use development, while providing multi modal transportation opportunities. The preceding will ensure a variety of medium density housing typologies that are supported by diverse transportation option that attains a balance for residential and employment opportunities. The latter is supported by the success Curitiba's BRT, where land use and transportation planning were implemented in conjunction with housing, waste and environmental policies that resulted in the reduction of energy consumption and the associated environmental impact of automobiles (Lindau, 2010:17-27).

Contemporary South African urban areas are mostly characterised by incessant population growth, urban sprawl, diminishing open spaces and natural resources, water and food security and an energy sector dominated by coal challenge the quality of life for South African citizens (SACN, 2016:21). Green urbanism, equally to compact city development (refer to Section 6.2.1), TOD (refer to Section 6.2.2), smart growth (refer to Section 6.2.3) and new urbanism (refer to Section 6.2.4), aims to implement mixed-land use development that is efficiently incorporated with green transit-orientated neighbourhoods to increase reliable public transportation in intercepting incessant urban sprawl. However, Lehmann (2011:263-264) cautions that the mere implementation of strategies is not sufficient to establish a vibrant urban area. The author further reiterates that sustainable urban development is complex and requires a holistic, multi-dimensional approach with unique adaptation strategies. In support, Galychyn and Üstündağ (2017:398) extend Lehmann's (2011) principles by arguing that the design of sustainable urban areas may be attained by introducing a multi-dimensional approach that focusses on "human-orientated transportation system (integrated soft and public transportation modes), rail-integrated communities and healthy neighbourhoods".

Inturri and Ignaccolo (2013:11) additionally reaffirm that the most effective means for urban areas to minimise their overall emissions and energy consumption are the integrated approach of land use, transportation planning and green infrastructure. This approach stresses the significance of higher density neighbourhoods around green transportation nodes, with specific reference towards mixed use developments that comprise affordable housing opportunities. It is imperative that these transportation nodes comprise efficient public transportation that are integrated with surrounding land uses in ensuring increased public transportation ridership to curb continual urban sprawl, resulting in the protection of critical agricultural resources and decrease urban pollution. Consequently, growing evidence suggest that the principles of green urbanism may well be employed to limit energy consumption, mitigate air and water pollution, lessen the need for

automobiles, conserve open space and sensitive ecosystems to ultimately create more liveable and human-oriented urban areas (Jabareen, 2006:48).

6.3 Collective impact approach as means to address poor air quality within South African urban areas.

The “Collective Impact Approach” is considered a novel assumption that no single government department, policy, organisation or project have the adequate capabilities to address the progressively complex social challenges humanity currently experience (Collective Impact Forum, 2023). As a consequence, this approach facilitates cross sectoral and interdisciplinary collaboration of various organisations and entities by abandoning their individual agendas in attaining public welfare through shared measurement and coordinated efforts (Ennis & Tofa, 2020:3). In their initial work, Kania and Kramer (2011:39) argue that individual organisation initiatives offer mostly isolated affects that fails to provide systemic change and conclude that “complex problems can be solved only by cross-sector coalitions”. This approach strongly aligns with the notion of Retief *et al.* (2016:56), suggesting that the pursuit for a single perfect solution ought to be avoided. In supporting these arguments, Paracchini *et al.* (2011:79) caution against oversimplifying the challenges of the multifaceted world and instead recommend the development of a framework comprising multiple indicators to guide solutions-seeking efforts.

The IUDF (2016:15) highlights that South African urban areas are incessantly hindered by proposed development policy directives aimed at rectifying social and spatial segregation and economic exclusion, resulting in high poverty levels and poor quality of life. Following the first democratic election during 1994, the South African Government introduced contemporary international spatial planning models in an attempt to redress prevalent spatial challenges and dysfunctional urban forms. However, it is argued that these models have not effectively succeeded in creating viable and sustainable urban areas as initially expected (UN-Habitat, 2014:7). The inefficiency may be attributed to the fact that most of the models originated in 20th century America in an attempt to replicate the realities of American urban areas in other urban areas around the world (González & Medina, 2004:74).

As early as 1915, Park (1915:578) recognised the complexity and unique nature of urban areas that are continuously shaped by the habits and traditions of the residents who inhabit them. As a result, contemporary urban areas demand comprehensive consideration of their intricate nature and diverse spatial planning aspects to resolve urban challenges effectively (Gallegos, 2017:162). Acknowledging this reality implies that a singular spatial planning approach is not sufficient for attaining future development goals in urban areas. By contrast, it may be argued that a broadened perspective is required through the integration of multiple spatial planning approaches, as emphasised by Spiekermann and Wegener (2018:68). Nonetheless, Säynäjoki *et al.* (2014:6623)

are concerned that “competing discourses exist within urban development and urban planners appear to struggle with the challenge in promoting area specific environmental quality through municipal land use planning”. Not necessarily opposing these arguments, the cautions by Freilich and Popowitz, (2010:4) should similarly be noted that mere “spot sustainability”, instead of cohesive strategies, will likely not offer a desired outcome. As a consequence, the proposition of contemporary spatial planning approaches as a collective and unique solution for mitigating poor air quality in South African urban areas is reasonable. The preceding is endorsed by Haughton (1997:194), stressing that each attribute possess significant qualities and advantages independently.

6.4 Conclusion

The incessant population growth and associated urbanisation present significant challenges for urban areas, particularly concerning air quality (Superczynski & Christopher, 2011:2533). Exceedingly high population densities, economic activities resulting in the increase in privately owned vehicle, high levels of energy consumption and the loss of green open spaces contribute to poor air quality (Zhou *et al.*, 2018:1). Recent studies clarify that urban form, characterised by layout and land use patterns, transportation systems, infrastructure, energy, water and waste services have a direct impact on the amount and frequency of emission (Liu *et al.*, 2018:1555; Yuan *et al.*, 2018:413; Hankey & Marshall, 2017:494; Clark *et al.*, 2011:7028).

South African urban areas are regarded as among the most inefficient urban areas globally owing to its dislocated and disconnected development patterns. This inefficiency stems from spatial planning policies that enforced racially segregated development and spatial exclusion, creating a decentralised urban form (SACN, 2016:10; Turok & Borel-Saladin, 2014:2). Du Plessis and Landman (2002:4) affirm that these policies resulted in incoherent urban areas characterised by fragmentation, segregation, inequality and inefficiency. It appears that despite numerous efforts from the government since 1994 in addressing spatial injustices through urban planning policies aimed at densification and spatial transformation, South African urban areas remain fragmented and unequal (Van Niekerk, 2019:69). As a consequence, prevalent low-density urban sprawl, segregated urban areas and high urbanisation rates continue to create unsustainable urban areas (Shikwambana & Tsoeleng, 2020:210), contributing to the increase in transportation demand, energy consumption and poor air quality; especially from privately owned vehicles (Yuan *et al.*, 2018:413). Additionally, these fragmented and sprawling land use patterns exert pressure on waste management systems, resulting in open burning of municipal solid waste (Organisation for Economic Co-operation and Development, 2018:11).

While emissions from large point sources and vehicles have been mostly reduced by means of cleaner fuels and technological advances, urban areas continuously experience environmental

pressure; especially in respect of air quality (Kim *et al.*, 2018:1). In an effort to remedy the latter, the Department of Planning, Monitoring and Evaluation (2005:9) proposes the concept of “sustainable cities” by incorporating AQM within development plans on national, provincial and local government Levels. However, the newly promulgated IUDF (2016), regarded as the principal government policy to guide the future development of South African urban areas, does not provide any explicit guidelines on the integration of air quality within proposed urban land use patterns.

Considering the complex spatial forms of South African urban areas, the research argues that an alternative approach is required to adapt existing urban areas in mitigating poor air quality. The latter is supported by Park (1915:578), asserting that the geometrical form of urban areas is a “purely artificial construction, which might conceivably be taken apart and put together again”. In support, the nature and complexity of existing South African urban areas may well encourage the national government to adopt a collective impact approach as a suitable spatial planning solution for the mitigation of poor air quality. Spiekermann and Wegener (2018:68) asserted that an individual planning approach or model is inadequate to remedy diverse and complex urban challenges, highlighting the need to adopt an integrated approach that include the compact city, TOD, smart growth, new urbanism and green urbanism in a collective manner.

These contemporary spatial planning approaches were purposefully selected considering that they share similar objectives for the reduction poor air quality within urban areas in attaining sustainable development. By concluding the literature review, the “urban development principles” of the discussed spatial planning approaches will be developed into a theoretical matrix and subsequently in an assessment matrix to conduct the case study analysis. Examination of the contemporary spatial planning approaches was conducted in exploring the possible “urban development principles”, summarised below, that will may well be conducive towards the mitigation of poor air quality within South African urban areas. The empirical phase will be conducted in the following chapter by applying a process of open coding (Cohen *et al.*, 2018:671) in further progressing the copious principles identified in the thematic analysis, into the mentioned theoretical and subsequent assessment matrix. Ensuing Table 6-1 demonstrates the purposefully selected “urban development principles” identified in the literature.

Table 6-1: Purposefully selected “urban development principles”

<u>Spatial planning approaches</u>	<u>Reference</u>	<u>Theory</u>	<u>Urban development principles</u>
Compact city	Gugger & Kerschbaumer, 2013:56.	Intensify central development, proximate higher residential and commercial density that are linked with efficient public transportation systems and curb sprawl through development restrictions in designated areas.	Urban intensification
			Integrate land uses
			Public transportation
			Restriction zones
	Bibri <i>et al.</i> , 2020:13.	When development is restricted within designated areas, high potential agricultural land located on the urban periphery is protected and minimises the risk for urbanisation.	Restriction zones
	Ahlfeldt & Pietrostefani, 2017:7.	Three main characteristics are prevalent, namely; economic density, morphological density and mixed-land uses.	Urban densification
			Mixed-land use
	Arbury, 2005:15.	Compact city addresses urban sprawl by restricting urban growth within specified areas, densifying designated urban zones and promoting mixed-land use development to enhance public transportation and energy efficient urban design.	Restriction zones
			Urban densification
			Mixed-land use
			Public transportation
	Matsumoto, 2011:5.	Compact city reduces transportation related emissions and reduces energy consumption through the reuse of existing built-up area.	Public transportation
			Brownfield regeneration
	. Batty, 2016:30.	Compact city approach might be introduced on a neighbourhood or smaller scale than the entire city.	Densification zones
	Matsumoto, 2011:17.	Compact development on a neighbourhood scale encourages high density and mixed-land use development, promote pedestrian friendly transportation modes and effective public transportation systems.	Densification zones
			Mixed-land use
			Active transportation
			Public transportation
Transit-oriented development	Calthorpe, 1993:56.	Mixed-land use community situated within a 600m or 10-minute walking distance from the nearest transportation node and central commercial area.	Mixed-land use
			Link transportation and commercial nodes
		Mix “residential, retail, office, open space and public uses in a walkable environment”, encouraging employees and residents to use public or pedestrian friendly transportation modes.	Public transportation
			Active transportation
		TOD enhances access and mobility through effective public transportation, comprising integrated transport	Link transportation and commercial nodes

	Dieleman & Wegener, 2004:318.	modes that are connected with supporting land uses at transit nodes.	Transportation modes
	Bertolini, 1999:201.	Transportation nodes should function as regional trip destinations and serve as trip origins by locating neighbourhoods in close proximity to transit stations.	Mixed-land use
			Densify around nodes
	Salat & Ollivier, 2017:7.	Transit nodes comprising mixed-land uses increase the regional accessibility by creating a land use pattern that facilitates alternative transportation modes.	Mixed-land use
			Transportation modes
	Calthorpe, 2011:86.	TODs comprise three main locations in metropolitans, namely; urban centres, urban fringe locations and neighbourhood locations.	Nodal hierarchy
	Hess & Lombardi, 2004:26.	Urban centre TODs are linked with rail transit in the urban core, comprising a high density, mixed land use pattern that focus on employment clustering.	Link transportation and commercial nodes
			Urban densification
			Mixed-land use
	Calthorpe, 2011:87.	Urban fringe TODs are situated in industrial zones that should employ urban regeneration projects through infill development or brownfield regeneration at underutilised transit lines.	Infill development
			Brownfield regeneration
	Sohoni, 2016:3222.	Neighbourhood TODs are placed along local bus routes to feed into the existing rail transit lines, encouraging mixed land use development at medium to low densities that encourage walking and cycling as the preferred transportation mode.	Integrate transport network
			Mixed-land use
			Appropriate density
			Active transportation
	Curtis, 2008:287.	Cities should comprise a range of TODs that are effectively integrated with various transportation modes.	Nodal hierarchy
			Integrate transport network
	Vaz & Venter, 2012:619.	Most cost effective and sufficient public transportation network is buss rapid transit (BRT) system.	Buss rapid transit
	Bel & Holst, 2015:20.	BRT provides an alternative public transportation mode to increase accessibility within urban areas, while reducing emissions.	Transportation modes
Smart growth	Lindau, 2010:17-27.	Effectively integrated BRT and pedestrian friendly transportation networks may decrease energy consumption and use of automobiles.	Buss rapid transit
			Active transportation
	Dierwechter, 2017:8.	Smart growth aims to focus future development in cities and neighbourhoods by restriction, mixed uses, public transportation.	Restriction zones
			Mixed-land use
			Public transportation
			Brownfield regeneration

	Lewis & Knaap, 2012:49.	Restrict urban sprawl by introducing neighbourhood restoration programs, urban revitalisation projects, and identifying future growth and high-density development zones.	Restriction zones
			Densification zones
	Bochner <i>et al.</i> , 2002:1.	Smart growth establishes land use patterns that encourage multiple transportation modes, conserve open spaces and concentrate development.	Transportation modes
			Encourage green spaces
			Urban densification
	Geller, 2003:1411.	Protect sensitive agricultural land and revitalise urban centres and neighbourhoods by promoting compact development patterns, comprising mixed land uses.	Encourage green spaces
			Brownfield regeneration
			Mixed-land use
			Urban densification
	Handy, 2005:146.	Restrict development to existing urban areas through infill development and brownfield regeneration.	Infill development
			Brownfield regeneration
	State of Maryland, 1997:31.	Smart growth may create high density mixed land uses and transit friendly development patterns.	Urban densification
			Mixed-land use
			Public transportation
	Pont <i>et al.</i> (2021:379).	Higher density development may reduce the impact of cities on the environment by ensuring.	Urban densification
	Burchell <i>et al.</i> 2000:823.	Urban regeneration and revitalisation programmes to restore existing derelict urban centres and inner-city suburbs.	Brownfield regeneration
	Wang <i>et al.</i> , 2013:69.	Smart growth may reduce vehicle tailpipe emissions by considering land use mix, local transportation density and connectivity.	Mixed-land use
			Transportation modes
			Integrate transport network
	Frank <i>et al.</i> , 2006:2.	Higher densities, mixed-land uses and connectivity within urban areas encourage both transit ridership and pedestrian friendly transportation modes.	Urban densification
			Mixed-land use
			Transportation modes
New urbanism	Cozens & Hillier, 2008:52.	New urbanism aims to develop dense mixed-use neighbourhoods that emphasis pedestrian friendly transportation systems, while comprising diverse housing topologies.	Urban densification
			Mixed-land use
			Active transportation
			Housing typologies
	Alias <i>et al.</i> , 2011:79.	Inclusion of wider sidewalks, grid network layout, various housing topologies, commercial, businesses and social amenities situated in close proximity to encourage walking and cycling.	Housing typologies
			Mixed-land use
			Active transportation
	Hickichi, 2003:10.	Promotes conservation of agricultural land that are effectively integrated with surrounding neighbourhoods and towns in providing adequate green open spaces for public use.	Encourage green spaces
	Veras & Amorim, 2005:272.	Integration of development nodes through transportation corridors.	Transportation corridors
			Urban densification

Green urbanism	Hall & Porterfield, 2001:122.	Compact, high-density areas comprising a balance between public amenities, diverse housing and parks.	Housing typologies
		Integrate nodes with a corridor that functions as a continuous element that connects and articulates the metropolitan structure.	Encourage green spaces
			Transportation corridors
	Bohl, 2000:762.	Implement design-based strategies of conventional urban forms to halt further urban sprawl and revitalise urban and neighbourhood vitality.	Urban densification
			Brownfield regeneration
	Hikichi, 2003:2.	Development comprising social services, facilities and job opportunities within walking distance may decrease the number of long trips and encourage the use of pedestrian transportation.	Mixed-land use
			Link transportation and commercial nodes
			Walkability
	Congress for New Urbanism, 1996:99.	Encourages the use public transportation, since the development of more freeways induce longer trips that result in congestion and pollution.	Public Transportation
	Garde, 2020:454.	Development comprising diverse housing typologies, commercial activities, social amenities and public open spaces within a close walking distance may aid in the reduction of poor air quality.	Housing typologies
			Mixed-land use
			Encourage green spaces
			Walkability
	Lehmann, 2011:245.	Re-conceptualise existing urban areas and their associated systems of infrastructure to be more compact, mixed-use and polycentric.	Urban densification
			Mixed-land use
			Nodal hierarchy
	Lobejko <i>et al.</i> , 2015:23.	Introducing compact development patterns, urban regeneration and transformation of dilapidated Central Business District.	Urban densification
			Brownfield regeneration
		Implement walkable, mixed-use developments through transit-orientated neighbourhoods, that aims to curb urban sprawl and encourage a sense of community.	Active transportation
			Mixed-land use
	Jabareen, 2006:43.	Encourage of ecosystem services and urban greening, inducing the conservation of critical green infrastructure within urban areas.	Transportation modes
			Encourage green spaces
	Lehman, 2011:245.	Implementation of green infrastructure and green design principles within urban areas limit energy usage.	Implement green infrastructure
			Encourage green spaces
	Lehmann, 2008:418.	Employ compact development through densification strategies, promote infill development on underutilised "Brownfield" sites and implement urban renewal projects.	Urban densification
			Infill development
			Brownfield regeneration
	Handy, 2015:1.	Provide urban areas that focus on urban greening and mixed-use development, while providing multi modal transportation opportunities.	Implement green infrastructure
			Mixed-land use
			Transportation modes
			Urban densification

	Inturri & Ignaccolo, 2013:11.	Implement higher density neighbourhoods around green transportation nodes, comprising mixed use developments.	Mixed-land use
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Chapter 7 Assessing the implementation of spatial planning solutions to mitigate poor air quality on a municipal level

7.1 Introduction

This chapter aims to address research Objective 4:

4. To assess the implementation of spatial planning solutions to mitigate poor air quality on a municipal level.

The aim of the research is to evaluate the employment of a dispersion model as regulatory tool in modelling emissions within Sasolburg-Zamdela in determining whether spatial planning solutions may be implemented to mitigate poor air quality on a municipal level. The contribution of the identified sources will be estimated through emission factors and activity rates in AERMOD in simulating the existing air quality within the municipal area. Subsequently, the “urban development principles” identified in preceding Table 6-1 will be employed in developing three distinct development models for Sasolburg-Zamdela to investigate the applicability of spatial planning solutions in mitigating poor air quality.

7.2 Sasolburg-Zamdela

Sasolburg is situated in the centre of the world-renowned coalfields. During 1951, Sasolburg was developed by Max Kirchhofer for SASOL, the internationally renowned “oil from coal refinery”. The town aimed to function as both the residential and social centre of the SASOL employees, together with its associated companies. While limited housing was provided between 1952 and 1953, Sasolburg was proclaimed as a town in 1954, while the SASOL plant commenced with production in 1955 (Kirchhofer, 1982:1). Despite the fact that Sasolburg developed due to the SASOL plant, a number of by-products, inter alia, fertilisers, olefins, alcohols, tar products, waxes, gases, inorganic chemicals, rubber, plastics, etc. are manufactured in the area. Since its proclamation, Sasolburg developed gradually to the fourth largest town in the Free State (Metsimaholo Local Municipality SDF, 2016: 72). Sasolburg is regarded as a modern ‘Garden City’ that aimed to (i) establish a road network permitting unhindered traffic movement without intervening with occupational land, (ii) develop self-contained residential units that are protected from disturbing influences and (iii) create coherent urban spaces within the residential area and business centre (Brockett, 1996:174). In augmenting the workforce of SASOL, Zamdela was established to the southeast of Sasolburg as a modern town, comprising hostels and single residential units that were accompanied by “greenswards combining all parks, sports fields and other recreational facilities” (Kirchhofer, 1982:10). However, even though the intention of

Kirchhofer was to apply the same 'Garden City' design to Sasolburg and Zamdela, it was prevented by the National Party (Brockett, 1996:174). As a result, the Greater Sasolburg developed as a typical segregated urban area where Sasolburg and Zamdela were traditionally racially and physically segregated, with the vast SASOL industry and ash dumps located between the two precinct that enforced physical separation.

The Metsimaholo SDF reiterates the long-term expansion predicament of the Sasolburg and Zamdela precincts, owing to extremely rich and shallow laying coal deposits. The latter resulted in vast undermined areas that are not suitable for the establishment of housing structures and strategic areas identified by the mining companies for future underground mining activities. Consequently, limited developable land are available that restricts the expansion possibilities of the urban areas (Metsimaholo Local Municipality SDF, 2016:128). In addition to the preceding, the Greater Sasolburg area faces unprecedented development and irregular population growth due to its proximity with metros in the Gauteng and Northwest Provinces (Williamson, 2023:5). As a result, it is argued that influx of residents from neighbouring metropolitan areas is a major concern for the Municipality. The continuous influx of migrant workers that uses Sasolburg and Zamdela as satellite or "sleep towns" will have a significant burden on the municipality (Metsimaholo Local Municipality SDF, 2016:74). It is maintained that enormous pressure is placed on road networks, services, infrastructure and other urban amenities. Complicating the latter, is the extreme scarcity in developable land for neighbourhood extension, impacting severely on the delivery of housing in the municipality. Influx to the area and the inability to timely address housing needs, ultimately resulted in the development of informal urban areas and land invasion on properties not earmarked for residential purposes, gradually increasing in the municipality.

As discussed in Chapter 6, the latter emphasises that urban morphology may well play a significant role in poor air quality within the Greater Sasolburg area. Therefore, the location of the SASOL industry, incessant low-density residential expansion and limited developable urban land resulted not only in high-levels of urban informality, but also excessive commuting distances for residents. The importance of the Sasolburg-Zamdela case reflects the ongoing effect of urban morphology and its associated land uses on poor air quality in urban areas. The main concern is that limited attention is rendered towards the relationship of urban morphologies and its associated components that may affect poor air quality in urban areas; especially energy generation, transportation, mining and industrial activities, household air pollution, agriculture activities and waste management, as discussed in Chapter 4. Owing to the unique urban morphology, South African cities are regarded as among the most inefficient worldwide (SACN, 2016:10; Turok & Borel-Saladin, 2014:2). This notion supports the investigation of possible spatial planning solutions conducive to mitigate poor air quality South African, dense low-income areas.

7.3 Meteorological outline of the case study

Sasolburg-Zamdela is situated high above sea level and within a semi-arid region that are primarily dominated anti-cyclonic systems (Thomas, 2008:62). As a consequence, these systems present high incidences of stable atmospheric layers; especially during winter months that limit cloud cover, solar radiation and rainfall (Liebenberg-Enslin, 2014:22). Seasonal variations for weather conditions are profound. Summer months are generally hot and humid, owing to the presence of low-pressure systems; especially the easterly low that prevails between November and March. By contrast, winter months are cold and dry that are dominated by subtropical high-pressure systems. The change in seasonal patterns owing to adiabatic warming result in high levels of atmospheric stability that limits the dispersion of emission (Tyson *et al.*, 1996:267-268; Tyson & Preston-Whyte, 2000:229).

Therefore, the meteorological data collected from Lakes Software are employed for calculating the environmental conditions for 2016, in facilitating an extensive understanding of the dispersion potential of the case study.

7.3.1 Windfield

Jin *et al.* (2024:8) recognise that wind speed is a key factor responsible for influencing the mixing and dispersion of emission. Higher wind speeds are associated with greater dilution and transportation of emissions, resulting in lower ambient concentration. In contrast, lower wind speeds limit dispersion, resulting in reduced the dilution and elevated concentration of ambient emissions.

The mean wind speed per season for Sasolburg-Zamdela is illustrated in Figure 7-1 below. During summer months, wind patterns are characterised by strong and persistent winds predominantly originating from the north-northwest, north and north-northeast, ranging frequently between 4-8 m/s. Calm conditions are reported at 7.3%, suggesting that atmospheric stagnation is minimal during this period. Autumn presents changes in wind patterns with a notable shift toward a more evenly distributed wind direction. While the north-northwest direction remains dominant, there is an increase from the east and east-northeast directions. In comparison to summer, the wind speeds are lower that range mostly between 2-5 m/s, causing more stable atmospheric conditions. The latter is illustrated by the increase in calm conditions is to 12.1%. Winter is characterised by a predominance of winds from the north-northeast, northeast and north-northwest. Similar to winter, wind speeds are considered moderate, primarily between the 2-5 m/s range that result in the calmest conditions of all four seasons at 12.6%. Finally, spring demonstrates wind characteristics similar to summer, comprising strong and consistent winds from the north-northwest, north and north-northeast. Compared to autumn and winter, spring

experiences a higher frequency of strong winds exceeding 8 m/s, indicating active wind patterns with a calm condition frequency of 6.6%.

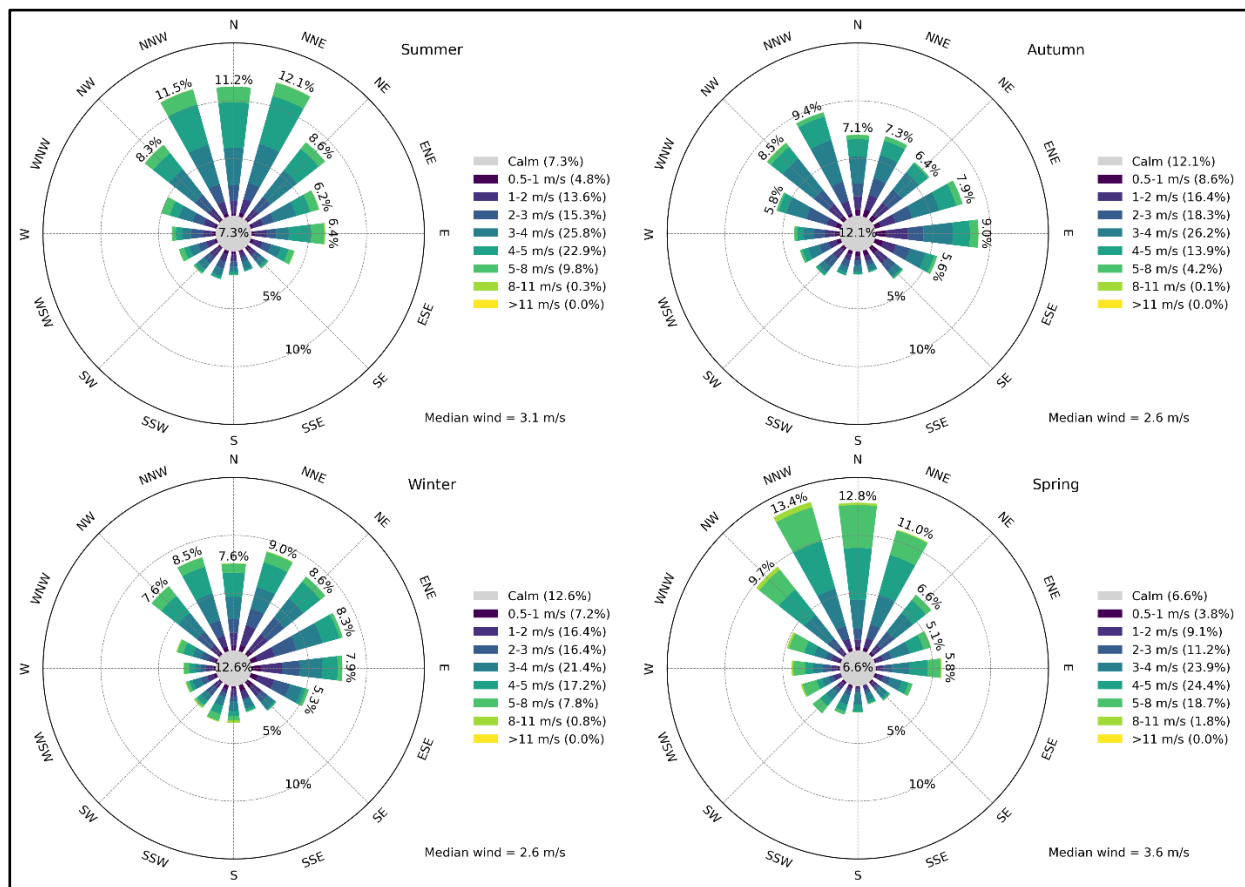


Figure 7-1: Mean seasonal wind roses employed in the analysis of Sasolburg-Zamdela

7.3.2 Variations in temperature, precipitation and relative humidity

Temperature not only has a significant influence in the formation and inversion of mixing layers, but also impacts the plume buoyance as a higher temperature variation between the plume and the surrounding air induces higher plume rise (Lake, 2020:23). The orange line in ensuing Figure 7-2 demonstrates the average monthly temperature for 2016 that follows a common seasonal pattern. Hottest temperatures are recorded during November, December, January and February, while coldest temperatures are experienced in May, June and July. The average monthly temperatures range between 8.0°C - 22.0°C.

Liu *et al.* (2020:2) reaffirm that precipitation is an imperative meteorological factor of PM concentration, indicating that the removal effect of precipitation on particles are influenced by the intensity of precipitation, raindrop diameter and particle size. Total precipitation per month is depicted by the respective bars in Figure 7-2 below for Sasolburg-Zamdela during 2016. Significant variations occur throughout the year with the highest rainfall experienced during

January and November, both exceeding 200mm in the respective months. Also, December comprises a total precipitation of 140mm. On the contrary, the lowest precipitation levels occur from May to August with almost negligible rainfall experienced in June and August. The transitional seasons, namely; March-April and September-October exhibit moderate precipitation that range between 30mm and 60mm.

Relative humidity shares an inverse relationship with temperature, suggesting that the increase in temperature will reduce the relative humidity and vice versa, in the event that moisture content remains constant. This signifies that warmer air is capable of retaining higher levels of water vapor and lowers the relative humidity, while cooler air retains less and raises the relative humidity (Khalaf & Altmimi, 2021:9). In response, the green on Figure 7-2 below illustrates the inverse relationship between the relative humidity and temperature for Sasolburg-Zamdela during 2016. The relative humidity is high during the precipitation season (January, February, November and December) and remains relatively stable throughout the year, peaking from May until June. This increase in the cooler month may be attributed to weakened evaporation rates and persistent moisture in the atmosphere. Nevertheless, mean monthly relative humidity ranges between 57% and 76%.

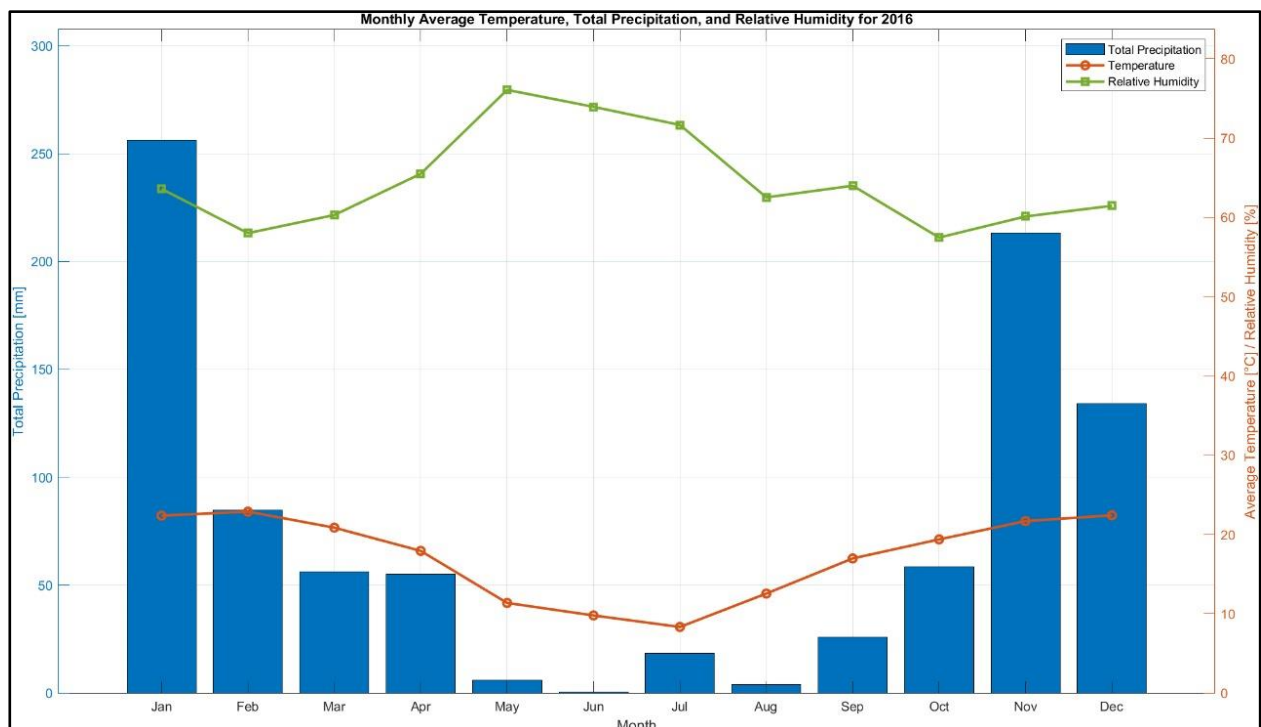


Figure 7-2: Monthly average temperature, precipitation and relative humidity employed in the analysis of Sasolburg-Zamdela

7.4 Investigating spatial planning solutions through the AERMOD model

For the purpose of determining the merits of contemporary spatial planning approaches as a solution to mitigate poor air quality, the research developed four development models, namely; (i) Baseline Model (ii) Realistic Development Model (ii), Extreme Development Model and (iv) Spatial Inclusion Development Model. In doing so, the impact of the identified poor air quality sources will be investigated in determining whether PM_{2.5} concentrations are reduced when applying the “urban development principles” identified in the literature. The ensuing section will discuss the compilation of each development model, together with the respective analyses.

7.4.1 Emission rates and dispersion in the baseline model

In determining and subsequently validating the accuracy of the PM_{2.5} concentrations for the identified poor air quality sources, the baseline model is modelled in verifying the existing impact of the identified poor air quality sources within Sasolburg-Zamdela. This is done as a point of reference whereby the ensuing development models will be compared to the baseline model in investigating the applicability of the “urban development principles” as a possible solution to mitigate poor air quality. For the purpose of the research, it is deemed feasible to harmonise the identified pollution sources, as identified in Table 3-1 Section 3.2.2, into various sectors responsible for poor air quality in Sasolburg-Zamdela. The reason for this is that the layout of the case study will be altered in each of the following development models by employing the identified “urban development principles”. When applying these principles, certain poor air quality sources that form part of a specific sector will be altered or removed. The aforementioned will be extensively discussed under each development model in the sections below. Ensuing Table 7-1 offers the identified sectors and their associated poor air quality sources in Sasolburg-Zamdela that will be employed in AERMOD for the baseline analyses.

Table 7-1: Identified sectors and associated poor air quality sources in Sasolburg-Zamdela for the baseline model

Sector	Emission pathway				
Park	No emission				
High Income, Low Density	Windblown dust	Cooking	Heating	Exhaust emissions	
High Income, High Density	Windblown dust	Cooking	Heating	Exhaust emissions	
Business Node	Windblown dust	Exhaust emissions			
Low Income, Low Density	Windblown dust	Cooking	Heating	Waste burning	Exhaust emissions
Low Income, High Density	Windblown dust	Cooking	Heating	Waste burning	Exhaust emissions
Informal Settlement	Windblown dust	Cooking	Heating	Waste burning	Exhaust emissions
Brownfield	Windblown dust	Waste burning			
Ash Dumps	Windblown dust				
Landfill Site	Windblown dust				
Hospital	Windblown dust	Exhaust emissions			
Light industrial	Windblown dust	Exhaust emissions			
SASOL Industry	Stacks	Windblown dust	Exhaust emissions		
Corridors	Exhaust emissions				

As discussed in Section 3.5 above, emission rates of various poor air quality sources are summated in order to obtain the total emission rate for a particular sector. Each respective sector is modelled in AERMOD to investigate the emission concentration for the 99th percentile and mean 24 hour averaging periods. Subsequently, the results are compared the AJ Jacobs monitoring station in Sasolburg (-26.822775 S, 27.826179 E) and previous studies (Chidhindi, 2022:93; Muyemeki, 2021:61) in validating the accuracy of the simulated concentrations within the baseline model. Figure 7-3 below represents the existing spatial pattern of Sasolburg-Zamdela, reflecting the identified sectors responsible for emitting PM_{2.5}.

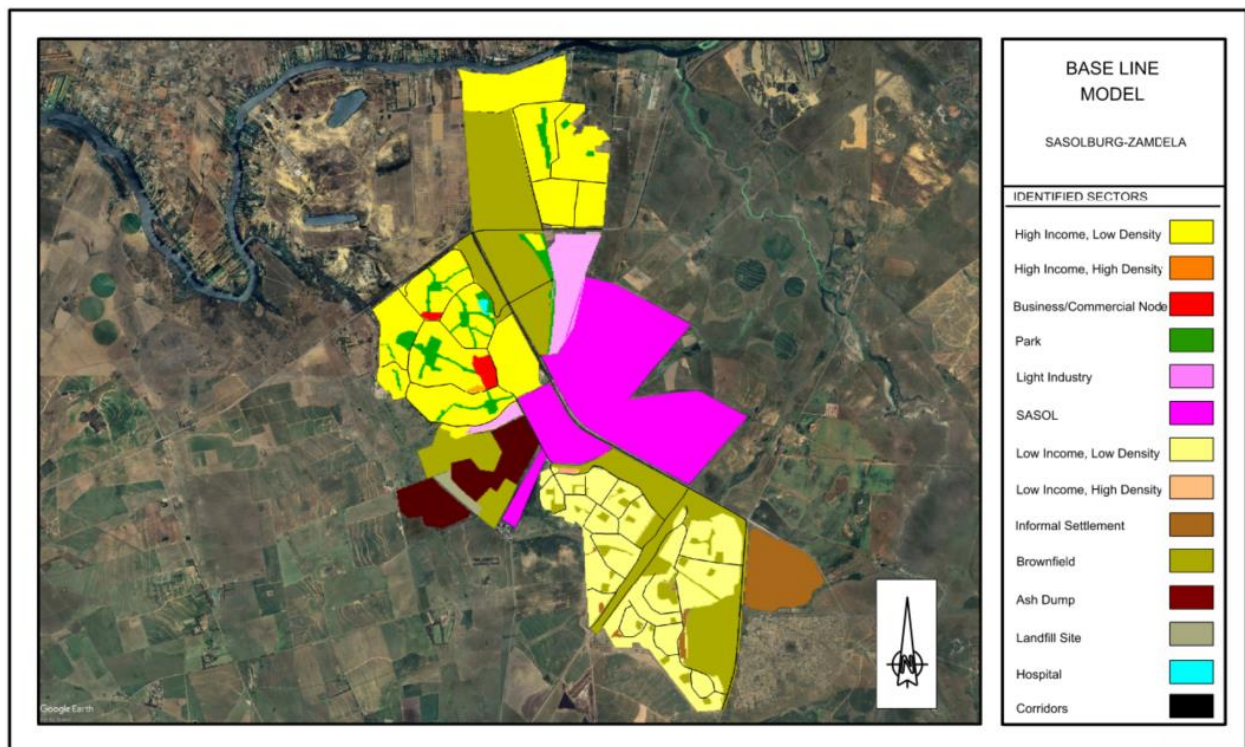


Figure 7-3: Spatial pattern of the baseline model

It should be noted that the existing urban footprint for the baseline model encompasses approximately 5 461 hectare, representing a density of 23 citizens per hectare within Sasolburg and 55 citizens per hectare in Zamdela. Owing to the segregated urban morphology, the total road length of the primary and secondary corridors is 87 km. The aforementioned is imperative, since these characteristics are amended when applying the “urban development principles” for each development model, influencing the overall emission concentrations.

As identified in Table 7-1 above, the emission rates of the identified poor air quality sources are summated and subsequently modelled under distinct sectors. Therefore, succeeding Table 7-2 presents emission concentration across the identified sectors with specific reference on the mean and extreme instances represented by the 99th percentile. These values are deemed imperative for assessing air quality and potential health risk, since they demonstrate a general

representation of poor air quality levels within the case study, together with the highest observed concentrations.

Table 7-2: Baseline model dispersion results for 24-hour average

Source Group: All	
99 th percentile	387 ug/m ³
Mean	131 ug/m ³
Source Group: Brownfield	
99 th percentile	5 ug/m ³
Mean	1 ug/m ³
Source Group: Hospital	
99 th percentile	0.00003 ug/m ³
Mean	0.00001 ug/m ³
Source Group: Industry	
99 th percentile	0.05 ug/m ³
Mean	0.01 ug/m ³
Source Group: Landfill	
99 th percentile	0.0000 ug/m ³
Mean	0.0000 ug/m ³
Source Group: Primary Corridor	
99 th percentile	0.5 ug/m ³
Mean	0.2 ug/m ³
Source Group: Secondary Corridor	
99 th percentile	24 ug/m ³
Mean	9 ug/m ³
Source Group: Sasolburg	
99 th percentile	51 ug/m ³
Mean	20 ug/m ³
Source Group: SASOL Industry	
99 th percentile	0.006 ug/m ³
Mean	0.001 ug/m ³
Source Group: Ash Dump	
99 th percentile	0.00001 ug/m ³
Mean	0.00000 ug/m ³
Source Group: Zamdela	
99 th percentile	378 ug/m ³
Mean	131 ug/m ³

Table 7-2 above specifies that existing emission concentrations over Sasolburg-Zamdela for all the sectors, representing a predicted 99th percentile value of 387 µg/m³ and mean value of 131 µg/m³. The main contributor to the overall concentration is "Zamdela" that exhibits a predicted 99th percentile value of 378 µg/m³ and a mean value of 131 µg/m³, owing to high levels of fugitive dust, waste burning, transportation, residential burning for heating and cooking. Also, "Brownfield" areas are mostly located within and around Zamdela, representing a predicted 99th percentile value of 5 µg/m³ and a mean value of 1 µg/m³. While these values are less in respect to the latter, the impact thereof is still noticeable in the urban area. Conversely, "Sasolburg" comprises a smaller predicted 99th percentile value of 51 µg/m³ and a mean value of 20 µg/m³. The major discrepancies between the two urban areas are the lack of available municipal infrastructure and services within Zamdela, resulting in burning of municipal solid waste and the use of dirty fuels for space heating and cooking. Furthermore, a high percentage of unvegetated land cover is common in Zamdela that increase the possibility of fugitive dust during dry conditions.

The "Industry" sector has a relatively low predicted 99th percentile value of 0.05 µg/m³ with a mean value of 0.01 µg/m³, since fugitive dust and transportation are calculated for this sector. However, the "SASOL Industry" demonstrates even lower pollution levels, with a predicted 99th percentile value of 0.006 µg/m³ and a mean value of 0.001 µg/m³, indicating the possibility of effective pollution control measures.

The "Primary Corridor" and "Secondary Corridor" sectors illustrate moderate PM_{2.5} levels. The "Secondary Corridor" exhibits significantly higher predicted 99th percentile and mean values of 24 µg/m³ and 9 µg/m³, respectively, in contrast to the predicted 99th percentile value of 0.5 µg/m³ and mean value of 0.2 µg/m³ for the "Primary Corridor". The preceding may be attributed to a lower number of vehicles travelling on the "Primary Corridor" and enhanced ventilation in comparison to enclosed areas. Also, higher levels of congestion and the number of stops on "Secondary Corridor" increase the idling time that directly produces higher emission from transportation.

Finally, the "Hospital", "Landfill" and "Ash Dump" sectors show predicted 99th percentile and mean values close to zero, signalling a low impact from these sectors. The reason for the negligible predicted emission concentrations may be attributed to the fact that the research only considers PM_{2.5} for the case study analyses. Furthermore, the low contribution of the "Ash Dump" sector is attributed to the rehabilitation of the area that are mostly covered by vegetation.

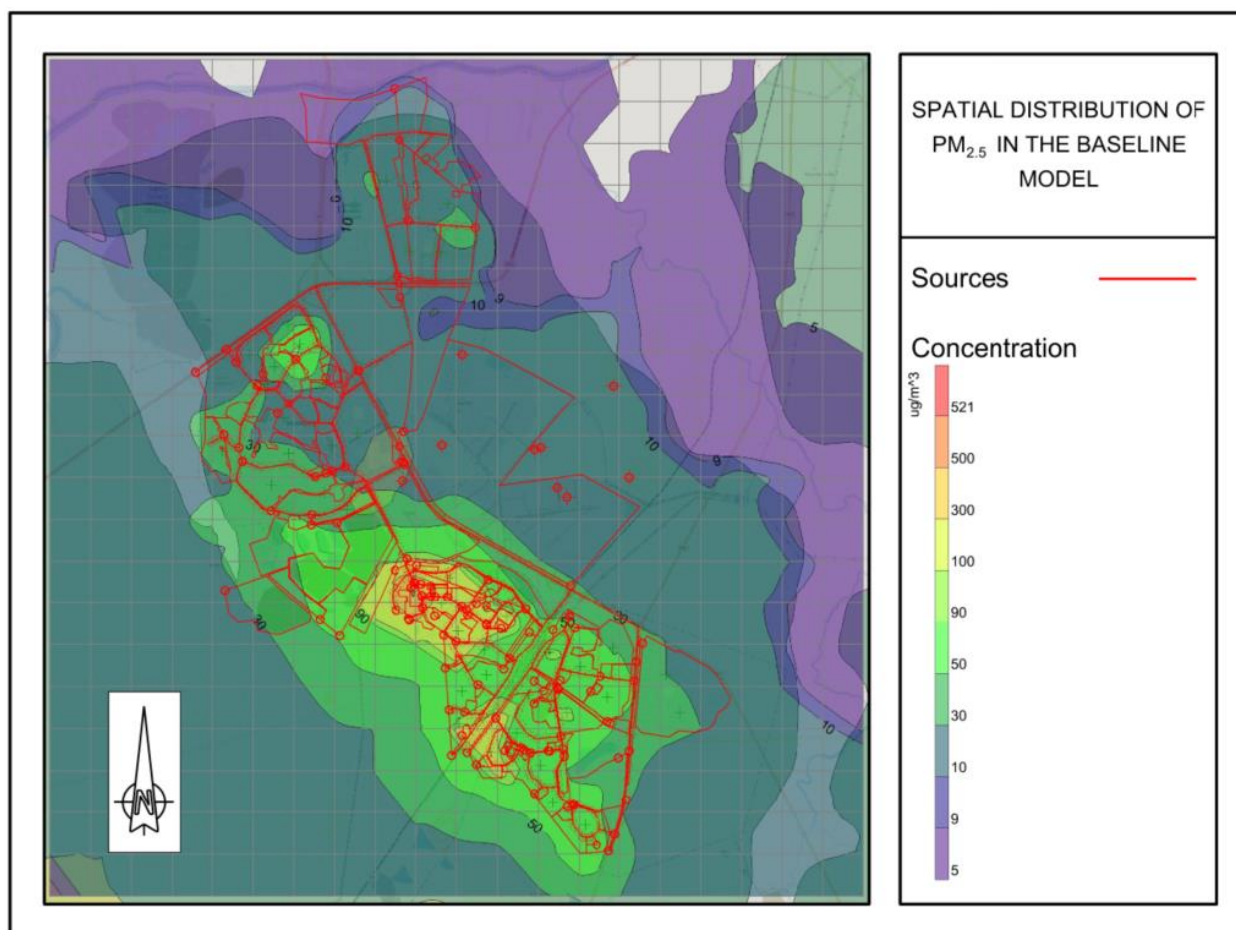


Figure 7-4: Spatial distribution of PM_{2.5} (µg.m³) over the baseline model for all sectors

Preceding Figure 7-4 illustrates that the highest predicted PM_{2.5} concentrations are observed over the northeastern and southern portions of Zamdela. As discussed above, this is attributed by the lack of municipal infrastructure and services, causing households to rely on dirt fuels for cooking and heating, together with combustion of municipal solid waste. Additionally, the location of Zamdela in relation to the SASOL Industry is imperative in the accumulation of PM_{2.5} concentrations. The latter is confirmed by Figure 7-1 above, indicating that the dominant wind directions of Sasolburg-Zamdela originate from a northwest, north and northeast direction. As a consequence, emissions from the industrial areas situated north of Zamdela are transported within the urban area that contribute to higher concentrations.

Sasolburg shows an apparent decline in PM_{2.5} concentrations ranging between 30 and 90 µg/m³, owing to enhanced municipal services and infrastructure that lower emission rates and increased vegetation that assist with the deposit of PM. Similar to Zamdela, the highest concentrations are observed over the southern portions of Sasolburg, supporting the notion of emission transportation through the dominant northerly winds.

7.4.2 Emission rates and dispersion in the realistic development model

In determining whether spatial planning solutions may be implemented to mitigate poor air quality, the “urban development principles”, identified in Table 6-1 above, are employed in the following development model. This is done by restructuring the layout of Sasolburg-Zamdela for each development model and subsequently calculating the amended pollution sources for each sector. In the instance for the following development model, the “Informal” sector is excluded from the calculations, since all developable areas within the case study are deemed formal, comprising adequate municipal services and infrastructure. In a similar manner, all “Low Income” sectors are considered formal that comprise municipal services and infrastructure. It should be noted that even though these areas are regarded formal, calculations for space heating and cooking are still considered in the emission calculations. However, dirty fuels are mostly reduced and the primary source for space heating and cooking is LP Gas. Moreover, the “Brownfield” and “Ash Dump” sectors are substituted with the “Park” sector that emits zero emissions, while the “TOD” sector incorporates high-density residential elements, which includes space heating and cooking in addition to existing activities. Since the layout of each development model is different, the “Corridor” sector is amended for each respective model in respect to the residential block and TODs. Finally, emission rates for “Light Industrial”, “SASOL Industry” and “Landfill Site” sectors are maintained considering that “urban development principles” cannot directly influence the release of emission. Table 7-3 below presents the amended sectors and their associated poor air quality sources for the three ensuing development models, namely; realistic development model, extreme development model and spatial inclusion model. These sectors will be employed in AERMOD for dispersion modelling in the respective development models.

Table 7-3: Amended sectors for the development models

Sector	Emission pathway			
Park	No emission			
Low density	Windblown dust	Cooking	Heating	Exhaust emissions
High density	Windblown dust	Cooking	Heating	Exhaust emissions
TOD	Windblown dust	Exhaust emissions	Cooking	Heating
Light industrial	Windblown dust	Exhaust emissions		
SASOL Industry	Stacks	Windblown dust	Exhaust emissions	
Landfil site	Windblown dust	Exhaust emissions		
Hospital	Windblown dust	Exhaust emissions		
Corridors	Exhaust emissions			

In maintaining consistency throughout the development models, the 99th percentile and mean 24-hour averaging periods for 2016 are modelled with a receptor grid of 800m x 800m over the case study domain and the discrete cartesian receptors within the neighbourhoods. The following Figure 7-5 indicates the layout of the realistic development model for Sasolburg-Zamdela that reflects the amended sectors responsible for emitting PM_{2.5}.

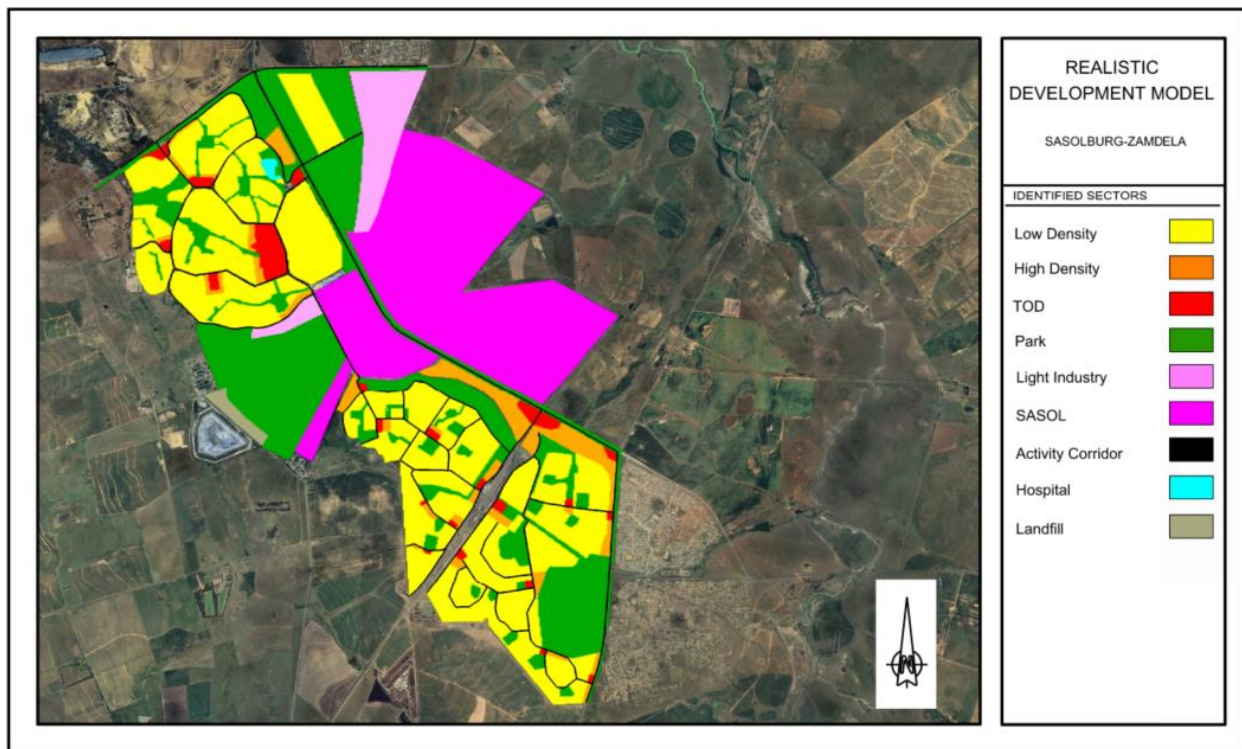


Figure 7-5: Spatial pattern of the realistic development model

Figure 7-5 above shows the proposed layout for the realistic development model that encompasses a total urban footprint of 4 064 hectare. The densities employed for this development model are considered moderate in terms of European standards (Romanova, 2018:2), representing (i) 180 citizens per hectare for high-density residential areas in Sasolburg and Zamdela, (ii) 23 citizens per hectare and 55 citizens per hectare for low-density residential areas Sasolburg and Zamdela, respectively, (iii) and 80 citizens per hectare for TODs in both in Sasolburg and Zamdela. This was done to incorporate the existing densities within the low-density residential areas, while increasing densities for the high-density residential area and incorporating high-density development at strategically located TODs. Furthermore, the total road length for the primary and secondary corridors is approximately 77 km. It should be noted that, even though the layout is similar than the urban development pattern of the baseline model, the total urban footprint has decreased with approximately 24% and corridor length with approximately 10 km.

As discussed in Section 7.4.2 above, the emission rates are re-calculated for each sector, owing to the amendments made to the layout of the development model. Moreover, the emission rates were reduced by 50% for the “Primary Corridor” and “Secondary Corridor” sectors, since vehicle miles travelled may be reduced by up to 50% with the implementation of effective TODs at adequate locations (Cervero & Arrington, 2008:9). Ensuing Table 7-4 presents emission concentrations for the amended sectors with specific reference to the 99th percentile and mean 24-hour averaging periods for 2016.

Table 7-4: Realistic development model dispersion results for 24-hour average

Source Group: All	
99 th percentile	334 ug/m ³
Mean	114 ug/m ³
Source Group: Hospital	
99 th percentile	0.00003 ug/m ³
Mean	0.00001 ug/m ³
Source Group: Industry	
99 th percentile	0.04 ug/m ³
Mean	0.01 ug/m ³
Source Group: Landfill	
99 th percentile	0.0000 ug/m ³
Mean	0.0000 ug/m ³
Source Group: Primary Corridor	
99 th percentile	0.4 ug/m ³
Mean	0.2 ug/m ³
Source Group: Secondary Corridor	
99 th percentile	24 ug/m ³
Mean	8 ug/m ³
Source Group: Sasolburg	
99 th percentile	325 ug/m ³
Mean	111 ug/m ³
Source Group: SASOL Industry	
99 th percentile	0.06 ug/m ³
Mean	0.01 ug/m ³
Source Group: Zamdela	
99 th percentile	324 ug/m ³
Mean	106 ug/m ³

Following the implementation of the “urban development principles”, the realistic development model presents a decrease in the overall predicted 99th percentile value of 334 µg/m³ and a mean of 114 µg/m³, suggesting a slight improvement in air quality. In contrast to the baseline model, the realistic model presents a more equal distribution predicted PM_{2.5} concentration in the model domain with “Sasolburg” experiencing a predicted 99th percentile value of 325 µg/m³ and a mean of 111 µg/m³ and “Zamdela” a predicted 99th percentile value of 324 µg/m³ and a mean of 106 µg/m³. Even though “Zamdela” shows a decrease in predicted concentrations with the implementation of the “urban development principles”, “Sasolburg” experiences a significant increase. This may be attributed to the increase of high-density residential areas and TODs within low-density neighbourhoods. The population accommodated within these high-density areas are

relocated from the segregated urban areas north of Sasolburg, making the overall population density higher when compared to the baseline model. Also, it appears that the existing parks within “Sasolburg” are located within the centre of the neighbourhood cells, limiting the buffer function presented by vegetated areas. In contrast, Zamdela comprises parks adjacent or around high activity land uses and corridors that may well lessen the impact of PM_{2.5} emissions in the neighbourhoods. The "Industry", "SASOL Industry", "Hospital" and "Landfill" sectors demonstrate a minimal decrease in concentrations in relation to the baseline model. The latter is expected since no change in the emission rates for the sectors are made for the recalculation of the development model.

Finally, the Primary Corridor” and “Secondary Corridor” experience a slight decrease in the predicted 99th percentile and mean values. Even though the decrease may appear insignificant, it shows a positive correlation with the implementation of TODs to reduce PM_{2.5} emissions from vehicles, since the total length of corridors in the realistic development model is reduced by approximately 10 km. Furthermore, the implementation of strategically located TODs in relation to business activities and residential areas may well increase pedestrian orientated transportation that directly reduce transportation emission.

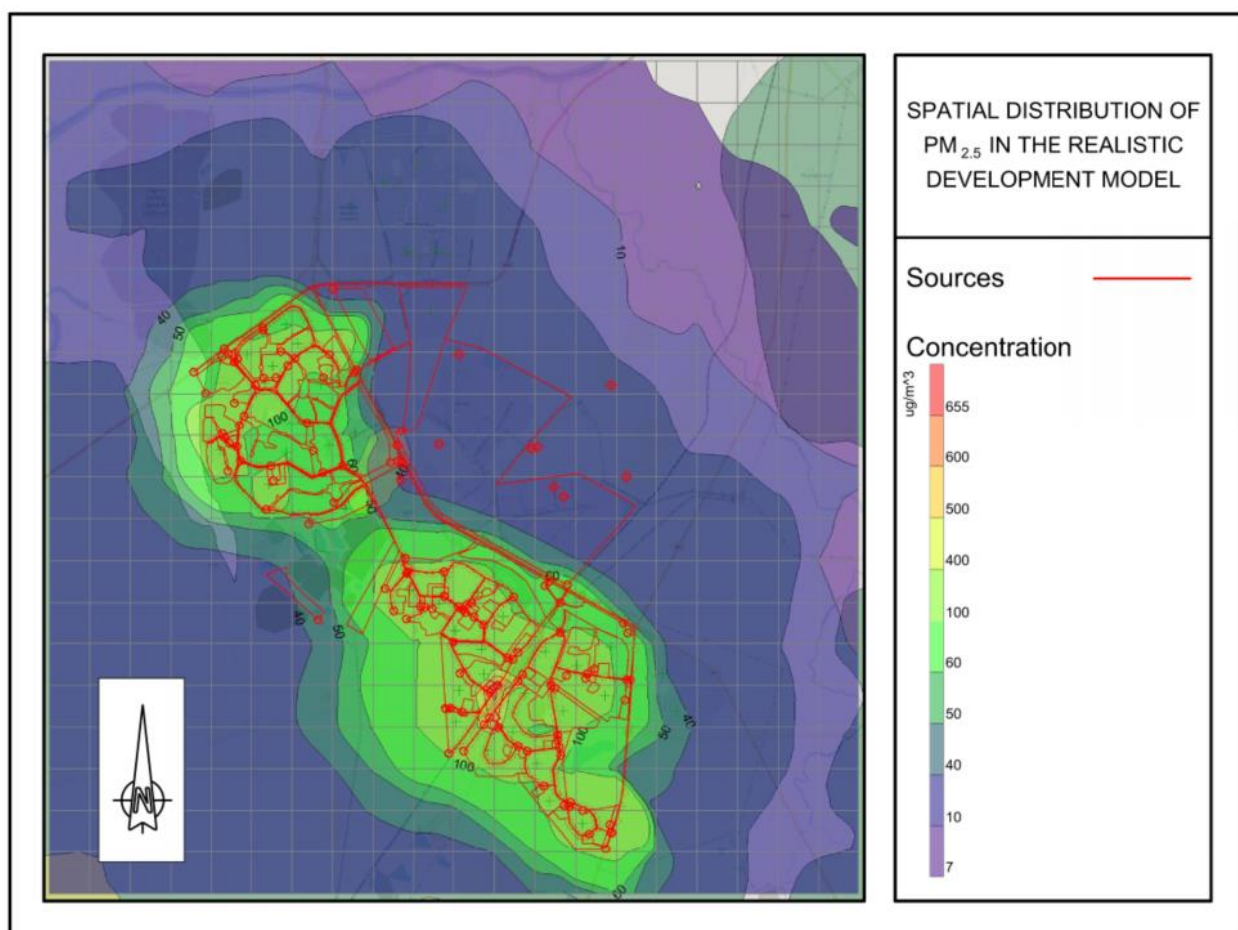


Figure 7-6: Spatial distribution of PM_{2.5} (µg.m³) over the realistic development model for all sectors

The spatial distribution for the concentration of PM_{2.5} emissions over the realistic development model is presented in preceding Figure 7-6. In comparison to the baseline model, lower overall PM_{2.5} concentrations are prevalent; especially in the core areas of Sasolburg and Zamdela. While PM_{2.5} concentration peaks at approximately 655 µg/m³ in Zamdela which is higher than the baseline model, the spatial distribution shows signs of being more restricted to a specific location with lower levels of PM_{2.5} concentrations in the surrounding area. Therefore, the predicted concentrations exhibit within Zamdela are less intense as an increased number of areas comprise 100 µg/m³ in respect to 300 µg/m³ in the baseline model. However, even though the eastern portion of Sasolburg and southern portion of Zamdela continue to experience high levels of predicted PM_{2.5} concentrations in localised areas, an improved level of dispersion is sustained in the surrounding areas. Additionally, the primary and secondary corridors contribute to elevated levels of PM_{2.5} concentrations, however, the intensity adjacent these corridors seem lower in comparison to the baseline model.

7.4.3 Emission rates and dispersion in the extreme development model

As discussed in Section 7.4.2, the “urban development principles” are employed in a similar manner in the extreme development model than the realistic development model by excluding the “Informal”, “Low Income”, “Brownfield” and “Ash Dump” sectors from the layout. The “TOD” sector still incorporates high-density residential elements, while the “Corridor” sector is amended accordingly in order to accommodate the layout and location of the TODs. Moreover, the emission rates remain the same for “Light Industrial”, “SASOL Industry” and “Landfill Site” sectors as deliberated above. Finally, the same 24-hour averaging periods for 2016 are modelled with the selected receptor grid and discrete cartesian receptors, identical to the preceding development model. The layout of the extreme development model for Sasolburg-Zamdela is illustrated in ensuing Figure 7-7.

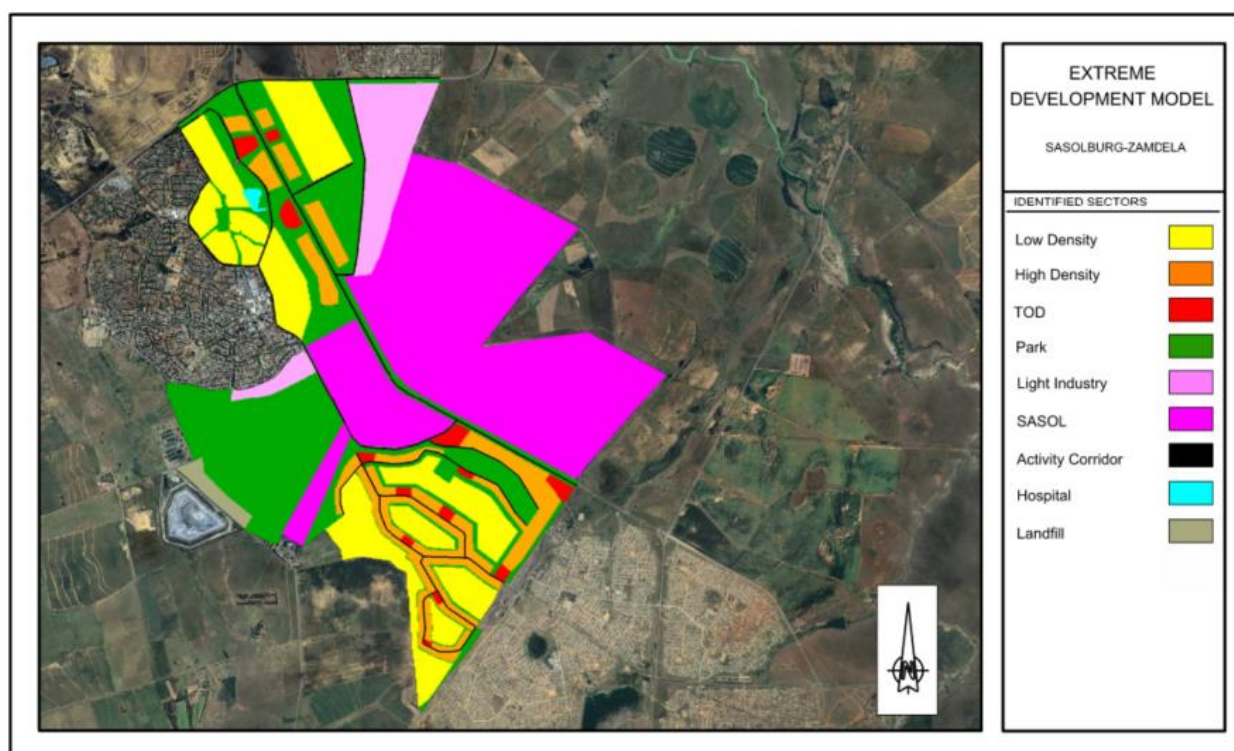


Figure 7-7: Spatial pattern of the extreme development model

As demonstrated in Figure 7-7 above, the proposed layout of the extreme development model comprises a total urban footprint of approximately 2 918 hectare, decreasing the area with approximately 53% in comparison to the baseline model. This is conducted by employing a high-densities in terms of European standards (Romanova, 2018:2), for instance; (i) 300 citizens per hectare for high-density residential areas in Sasolburg and Zamdele, (ii) 23 citizens per hectare and 55 citizens per hectare for low-density residential areas Sasolburg and Zamdele, respectively, (iii) and 100 citizens per hectare for all TODs. The latter is considered an imperative measure in investigating whether poor air quality may well be mitigated when the “urban development principles” are implemented in an excessive manner. It should be highlighted that an additional measure in the extreme development model is the provision of green infrastructure between high pollution sectors and residential neighbourhood in minimising the impact. The latter is highlighted in Figure 7-7 above where parks are located behind TODs and high-density residential areas, separating low-density areas with areas responsible for excessive emission. Furthermore, following the implementation of these extreme densification measures, the total road length for the primary and secondary corridors is approximately 42 km, decreasing the total road length with roughly 45 km.

As discussed in Section 7.4.2 above, each sector is re-calculated in assigning amended emission rates for the respective activities. Similar to the realistic development model, the emission rates are reduced by 50% for the “Primary Corridor” and “Secondary Corridor” sectors as suggested by Cervero and Arrington (2008:9). Emission concentrations in the extreme development model are

presented in Table 7-5 below with reference to the 99th percentile and mean 24-hour averaging periods for 2016 of amended sectors.

Table 7-5: Extreme development model dispersion results for 24-hour average

Source Group: All	
99 th percentile	40 ug/m ³
Mean	15 ug/m ³
Source Group: Hospital	
99 th percentile	0.00009 ug/m ³
Mean	0.00003 ug/m ³
Source Group: Industry	
99 th percentile	0.09 ug/m ³
Mean	0.04 ug/m ³
Source Group: Landfill	
99 th percentile	0.0008 ug/m ³
Mean	0.0002 ug/m ³
Source Group: Primary Corridor	
99 th percentile	1 ug/m ³
Mean	0.4 ug/m ³
Source Group: Secondary Corridor	
99 th percentile	22 ug/m ³
Mean	7 ug/m ³
Source Group: Sasolburg	
99 th percentile	30 ug/m ³
Mean	13 ug/m ³
Source Group: SASOL Industry	
99 th percentile	0.012 ug/m ³
Mean	0.002 ug/m ³
Source Group: Zamdela	
99 th percentile	24 ug/m ³
Mean	8 ug/m ³

The adoption of excessive densification and green infrastructure in the extreme development model show a significant reduction in both the 99th percentile and mean values when compared to the baseline model. The overall predicted 99th percentile value of 40 µg/m³ and a mean of 15 µg/m³, representing an 89.6% decrease in the predicted 99th percentile and an 88.8% decrease in the mean value. In contrast to the realistic development model, both residential areas show a major reduction in predicted PM_{2.5} concentrations, depicting a decrease of 40.6% in the 99th percentile and 36.3% in the mean concentration for “Sasolburg” and a reduction of 93.8% in the 99th percentile and 93.6% in the mean value for “Zamdela”. It may be argued that the location of

high-density residential development in close proximity to major transportation nodes and corridors show a positive correlation in reducing PM_{2.5} emission. The latter is supported though the relocation of the majority of the urban population in high residential neighbourhoods adjacent to high activity corridors as depicted in preceding Figure 7-7.

In the same manner as the realistic development model, the "Industry", "SASOL Industry", "Hospital" and "Landfill" sectors experience a slight decrease in both the 99th percentile and mean value. This may be accredited to the implementation of adequate green infrastructure principles, functioning as a buffer that absorbs the particulates and reduce its dispersion.

With reference to the "Secondary Corridor" sector, a moderate reduction is shown of 11.6% for the 99th percentile and 12.6% for the mean value. While the improvement within the "Secondary Corridor" sector does not seem noticeable, it is imperative to refer to the reduction in road length of approximately with 45 km. Despite the fact that public transportation modes will increase with the implementation of TOD and densification principles, the proximity of residential, retail, business and social activities may well decrease the dependency of privately owned vehicles, while enhancing pedestrian orientated transportation. In contrary to the latter, the "Primary Corridor" sector demonstrates a subtle increase in both the 99th percentile and mean values. The aforementioned is expected owing to the prevalent segregated nature of the extreme development model where Sasolburg and Zamdela are still separated. Although a higher ridership of public transportation is attained through TOD and densification principles, the total kilometres travelled between Sasolburg and Zamdela in this development model are still excessive.

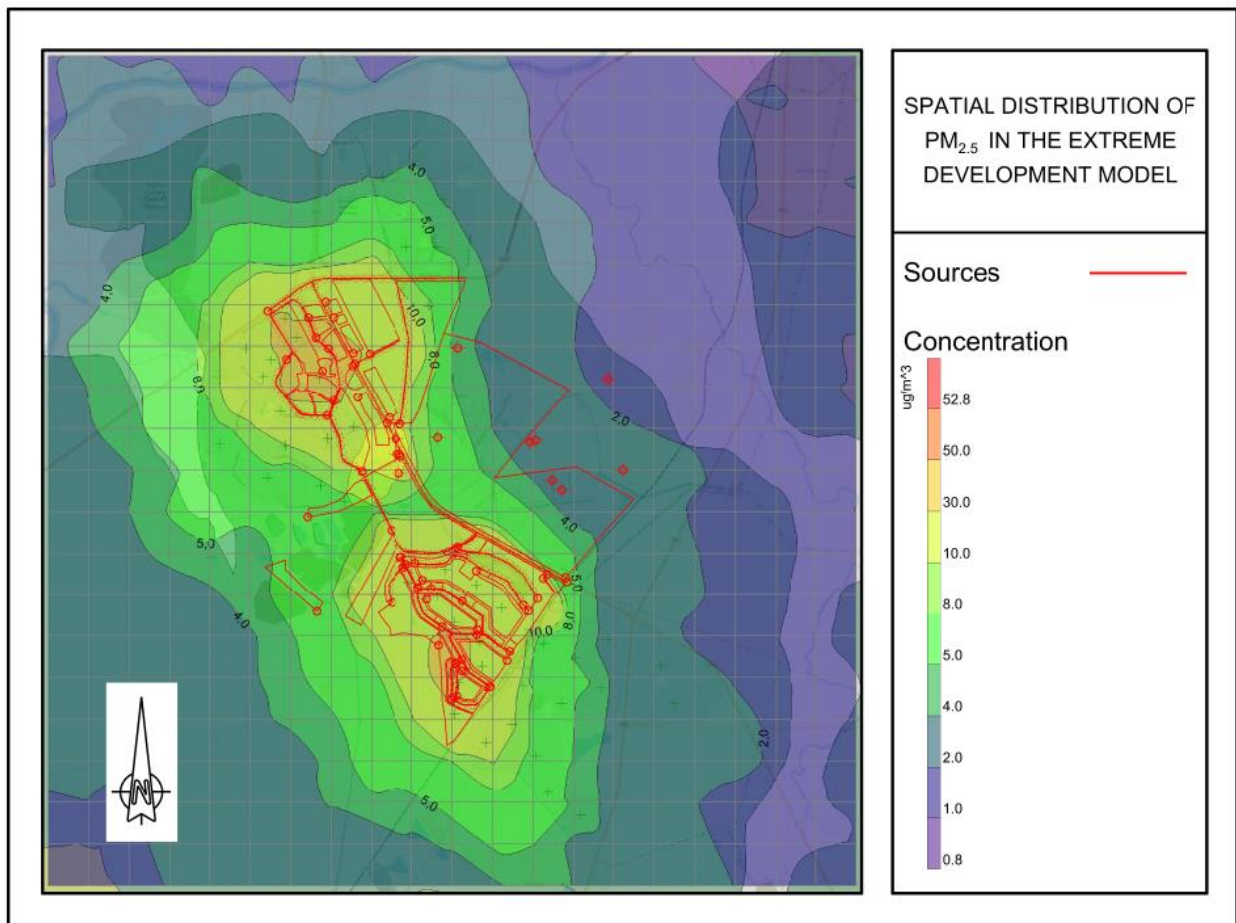


Figure 7-8: Spatial distribution of PM_{2.5} (µg.m³) over the extreme development model for all sectors

As depicted in Figure 7-8 above, the spatial distribution for the concentration of PM_{2.5} emissions for the extreme development model is outlined. As opposed to the base line and realistic development model, the extreme development model presents a more moderated and evenly dispersed PM_{2.5} concentration pattern. Albeit that the overall concentrations are significantly lower in relation to the previous development model, the highest concentration levels of between 30-50 µg/m³ are prevalent within the central urbanised areas of Sasolburg and Zamdela; particularly adjacent to high activity corridors and TODs. Also, the extreme development model exhibits a distinct concentration gradient from both the urban centres to the urban fringe where values fall below 5 µg/m³ and decrease outward. The aforementioned may be influenced by the concentration of high-density land uses within the urban centres, while low-density neighbourhoods gradually transition into low intensity poor air quality areas that enhance the natural dispersion of PM_{2.5} emission.

7.4.4 Emission rates and dispersion in the spatial inclusion development model

In preparing the layout for this development model, a spatial inclusion approach is adopted in order to provide a contemporary urban form that is integrated and effective. In doing so, Figure

7-9 below presents an alternative urban form for Sasolburg that does not comprise a dense, low-income areas situated in close proximity to industrial areas. As an alternative, the population of Zamdela are accommodated in residential areas that are considered more suitable for spatial inclusion. This is attained by locating high-density residential areas along the activity corridors that are adequate services by ideally located TODs. Moreover, low-density residential areas are separated by green infrastructure at the rear of the high-density residential areas. This approach ensures that the majority residents, either in low or high-density residential areas, have sufficient opportunity to use alternative transportation modes that private vehicles. Therefore, similar to the realistic and extreme development model, “Informal”, “Low Income”, “Brownfield” and “Ash Dump” sectors are excluded from the layout, while the “TOD” sector still incorporates high-density residential elements. In a similar manner, the emission rates for the “Light Industrial”, “SASOL Industry” and “Landfill Site” sectors will be maintained. Finally, the 24-hour averaging periods for 2016 are modelled using the selected receptor grid and discrete cartesian receptors, consistent with the preceding development models. The following Figure 7-9 illustrates Figure 7-7the layout of the spatial inclusion development model for Sasolburg-Zamdela.

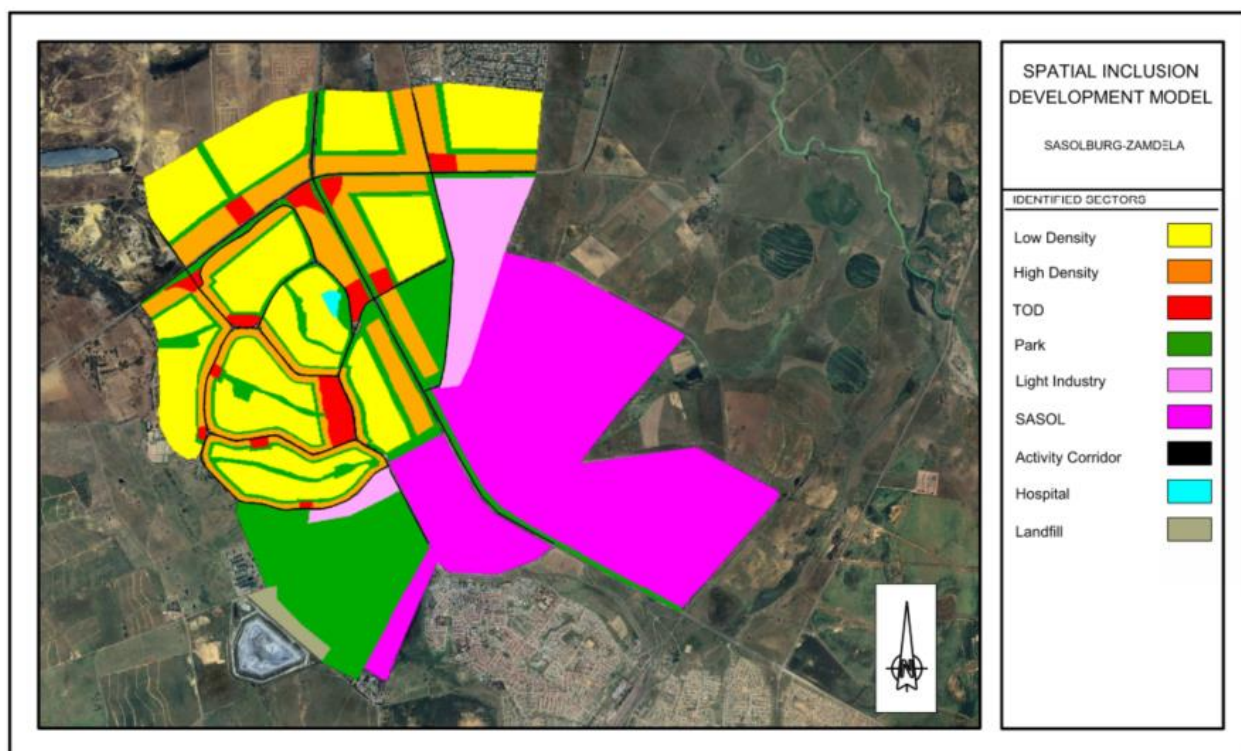


Figure 7-9: Spatial pattern of the spatial inclusion development model

The proposed layout of the spatial inclusion development model, as indicated in preceding Figure 7-9, encompasses a total urban footprint of approximately 3 596 hectare. The coverage exceeds that of the extreme development model, however, it remains significantly lower in comparison to the base line and realistic development models. In doing so, the total urban footprint is reduced with approximately 34% as opposed to the baseline model. The increase in urban footprint may

be attributed to the implementation of lower densification strategies based on European standards (Romanova, 2018:2), namely; (i) 180 citizens per hectare for high-density residential areas (ii) 23 citizens per hectare for low-density residential areas (iii) and 80 citizens per hectare for TODs. The research considered these residential densification levels into the restructuring of the case study as they are deemed more suitable in the South African context. The implementation of the spatial inclusion development approach is twofold, firstly by investigating the impact of spatially segregated South African urban areas on poor air quality; particularly in dense, low-income areas and secondly to explore the impact on air quality of new extensions to existing urban areas. Similar to the extreme development model, green infrastructure is adequately provided to minimise the impact of poor air quality. Finally, the incorporation of the spatial inclusive development model provides a more spatially integrated urban form that reduces the total road length for the primary and secondary corridors from roughly 87 km in the base line development model to approximately 45 km.

The re-calculation of the emission rates for each sector is consistent with the preceding development models as deliberated in Section 7.4.2. In accordance with the realistic and extreme development model, emission rates for the “Primary Corridor” and “Secondary Corridor” sectors are reduced by 50%, as argued by Cervero and Arrington (2008:9). Consequently, emission concentrations of the amended sectors for the 99th percentile and mean 24-hour averaging periods for 2016 are presented in ensuing Table 7-6 for the spatial inclusion development model.

Table 7-6: Spatial inclusion development model dispersion results for 24-hour average

Source Group: All	
99 th percentile	194 ug/m ³
Mean	81 ug/m ³
Source Group: Hospital	
99 th percentile	0.00009 ug/m ³
Mean	0.00003 ug/m ³
Source Group: Industry	
99 th percentile	58 ug/m ³
Mean	21 ug/m ³
Source Group: Landfill	
99 th percentile	0.0008 ug/m ³
Mean	0.0002 ug/m ³
Source Group: Primary Corridor	
99 th percentile	8 ug/m ³
Mean	3 ug/m ³
Source Group: Secondary Corridor	
99 th percentile	17 ug/m ³

Mean	6 ug/m ³
Source Group: Sasolburg	
99 th percentile	188 ug/m ³
Mean	78 ug/m ³
Source Group: SASOL Industry	
99 th percentile	0.012 ug/m ³
Mean	0.002 ug/m ³

Even though the emission concentrations of the spatial inclusion development model exceed those of the extreme development model, the reduction in overall emission concentration is still significant when compared to the base line development model. With reference to the baseline model, there is a clear reduction for the overall concentrations in both the predicted 99th percentile value of 194 ug/m³ and mean value of 81 ug/m³, demonstrating a decrease of 49.9% and 38.4%, respectively. Although the PM_{2.5} concentrations in Sasolburg may appear excessive with a predicted 99th percentile value of 188 ug/m³ and mean value of 78 ug/m³, it should be noted that the entire urban population are located within these residential areas. In considering the aforementioned, the PM_{2.5} concentrations for residential areas, namely; “Sasolburg” and “Zamdela” sectors in the baseline model, show an accumulated predicted 99th percentile value of 429 ug/m³ and mean value of 151 ug/m³, representing a decrease in emission concentrations of 56.1% and 48.6%. Owing to the significant reduction in PM_{2.5} concentrations, the spatial inclusion development model appears to be the most effective scenario to mitigate poor air quality. This may be resultant from the less stringent densification principles adopted in the spatial inclusion development model.

Albeit the "SASOL Industry", "Hospital" and "Landfill" sectors present similar concentrations in both the predicted 99th percentile and mean value in the realistic and extreme development models, the “Industry” sector experience an increase in the predicted 99th percentile and mean values. Even though the emission rate of this sector remained consistent through the various development models, the increase may be caused by the location of new residential areas north and south of the light industrial area north of Eric Louw Way. Given that the concentrations are calculated for a 24-hour averaging period, the residential areas surrounding the industrial area may well increase the mean concentration. As a consequence, the latter highlights the significance of locating residential areas away from industrial areas.

A notable observation in the spatial inclusion development model is the increase in PM_{2.5} concentrations in the “Primary Corridor” sector in both the 99th percentile and mean value. This increase may be caused by the change in land uses adjacent to these corridors that influence the dispersion efficiency, since the spatial inclusion development model incorporated vast high-density residential areas opposite the “Primary Corridor” sectors. Also, the aim of high activity

corridors is to accommodate a large number of vehicles where pedestrian orientated transportation is limited, contributing to the overall ridership. In contrast to the “Primary Corridor” sector, the “Secondary Corridor” sector experiences a significant decrease in $PM_{2.5}$ concentrations for the spatial inclusion development model with the predicted 99th percentile concentration decreasing from 24 $\mu g/m^3$ in the baseline model to 17 $\mu g/m^3$, reflecting a 31.7% reduction. Similarly, the predicted mean value diminished from 9 $\mu g/m^3$ to 6 $\mu g/m^3$, indicating a 28.1% reduction. The reason for this may be resultant from the provision of sufficient pedestrian orientated transportation infrastructure that encourages walking and cycling from residential neighbourhoods to TODs.

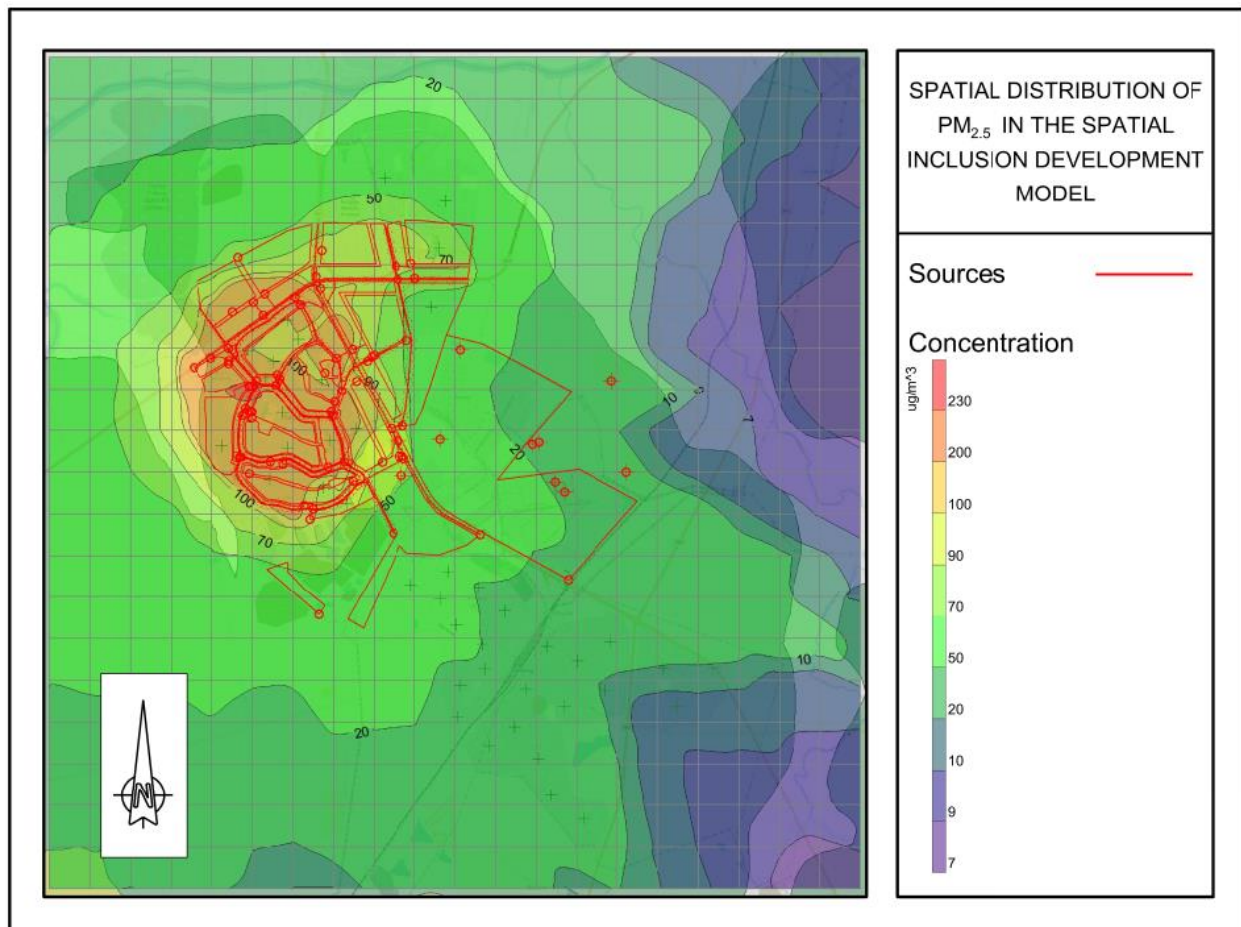


Figure 7-10: Spatial distribution of $PM_{2.5}$ ($\mu g.m^3$) over the extreme development model for all sectors

The spatial distribution of the $PM_{2.5}$ emission concentrations for the spatial inclusion is illustrated in preceding Figure 7-10, demonstrating a homogeneous dispersion that are concentrated at the core of the development model. The aforementioned is expected, considering that the compact layout of the development model aims to minimise the impact of the urban footprint by locating residential, retail and transportation activities in close proximity. In contrast to the previous development models, the spatial inclusion development model maintains the high 100 $\mu g/m^3$ $PM_{2.5}$ concentrations over the high densification areas, while strongly decreasing to between 50-

70 $\mu\text{g}/\text{m}^3$ over the low-density residential areas on the urban fringe. Even though the proposed layout for this model is not as effective of the extreme development model, the overall concentrations remain significantly lower than the base line and realistic development model. Moreover, the proposed layout for the spatial inclusion development model aims to contain urban sprawl by locating high-density residential areas and TODs adjacent to high activity corridors. Albeit that green infrastructure is implemented as a means to alleviate poor air quality, the extent thereof is less extensive when compared to the extreme development model. Consequently, it is argued that the implementation of larger green infrastructure areas between high pollution areas may contribute to a reduction in $\text{PM}_{2.5}$ concentrations or facilitate improved dispersion within the urban centre.

7.5 Integrated analysis of the spatial planning solutions

Ensuing Figure 7-11 compares the concentration of $\text{PM}_{2.5}$ in the different development models employed in the case study analysis. While spatial planning solutions were employed in the realistic development model, the reduction of $\text{PM}_{2.5}$ is not significant when compared to the baseline model. This may be attributed to the relatively low-densities and small TODs employed that maintains the segregated urban form where high dependency of vehicles is still prevalent. In contrast, a significant reduction in $\text{PM}_{2.5}$ concentrations is experienced in the extreme and spatial inclusion development model. This is attributed to the location of large areas adjacent to transportation corridors for high-density development that improves pedestrian orientated transportation. Moreover, the provision of higher-density development result in a smaller urban footprint, enabling local municipalities to effectively provide infrastructure and services that reduces household burning and waste burning. The extent and number of green infrastructure are accentuated in these models when compared to the baseline model. Explicit design thereof is incorporated by strategically locating green areas or corridor between primary poor air quality sources and residential neighbourhoods, functioning as an effective buffer for $\text{PM}_{2.5}$. Additionally, the provision of large TODs at strategic locations not only provide nodes that comprise mix, land use development at higher densities, but also enhances the accessibility of Sasolburg-Zamdela through pedestrian orientated development. By integrating the TODs and green corridos result in a more integrated and compact urban form that enhances walkability and cycling that reduced the need for vehicles and create a healthy living environment.

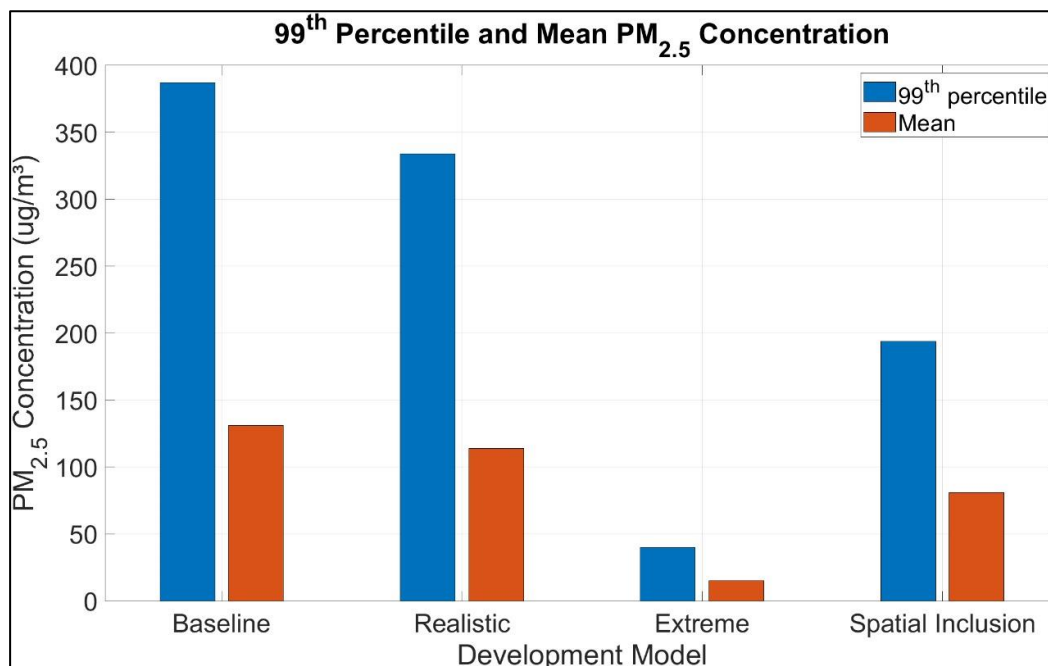


Figure 7-11: Comparative illustration of all source categories for the 99th percentile and mean PM_{2.5} concentrations of the various development models

7.6 Conclusion

The effectiveness of contemporary spatial planning approaches as a solution to mitigate poor air quality in South African dense, low-income areas was assessed through the employment of the purposefully selected “urban development principles”. The analysis was conducted through the implementation of various development scenarios in AERMOD view to determine their impact on emission concentration levels over Sasolburg-Zamdela. The incorporation of densification strategies promoted the agglomeration of efficient land uses to halt excessive urban sprawl that reduces the urban footprint and subsequent impact on air quality. The latter is supported by Holden and Norland (2005:2148), reiterating that concentrated spatial development patterns that are adequately integrated may be employed to lessen energy demand and emission. The reduction in emission concentrations in the three development models may well be attributed to a more compact urban approach, resulting in improved service and infrastructure delivery in marginalised areas that alleviate the reliance of dirty fuels. The aforementioned is deemed feasible as Zamdela experienced high levels of PM_{2.5} concentrations in the baseline model, that were significantly reduced in the subsequent development models through the facilitation of high-density, mixed-land use development patterns that limit incessant urban sprawl that result in long travel distances and excessive transportation networks. In the baseline model,

The analysis of the development models illustrated that the implementation of TODs is considered an imperative solution in mitigating poor air quality by encouraging pedestrian orientated development and alternative transportation modes, reducing the dependency of private vehicle

use. This notion is supported by Salat and Ollivier (2017:7), validating that well-designed TODs that support residential areas, business activities and social amenities establish spatial patterns which encourage the use of alternative transportation modes. Additionally, efficient public transportation decreases the number of privately owned vehicles on transportation networks that reduce congestion-related emission. The analysis of the development models illustrated that the incorporation of these “urban development principles” is validated, since the total road length in the extreme and spatial inclusion development model decreased by approximately 50% in comparison to the baseline model, thus lowering associated PM_{2.5} emission concentrations. The notion of sustainable urban forms is not only the provision of compact development that promotes walkable, mixed-use developments through transit-orientated neighbourhoods, but also the facilitation of green infrastructure that decreases poor air quality and mitigate severe urban climates (Jabareen, 2006:43). By doing this, green infrastructure; especially in the extreme development model, contributed to the reduction of PM_{2.5} concentrations as it functions as a barrier that capture PM. Also, the provision of effective green infrastructure within urban areas mitigates exiting brownfield areas that are associated with high levels of fugitive dust emission. The analysis of the development models indicates that in the instances where green infrastructure was incorporated adjacent to high activity corridors and high pollution areas resulted in the reduction of PM_{2.5} concentrations.

In this respect, the research argues that the implementation of contemporary spatial planning approaches may well be implemented as a solution to mitigate poor air quality in South African dense, low-income areas. However, it is further argued that a collective impact approach should be considered when addressing complex urban challenges; especially in the South African context, as reiterated by Spiekermann and Wegener (2018:68). In concluding the research, the following chapter will discuss each research objective in comparison with the research conducted in each chapter, together with the contribution of the research.

Chapter 8 Conclusion

8.1 Introduction

This chapter presents the key findings that originated from the research necessary to attain the research aim identified in Chapter 1, namely:

To investigate the nature of the relationship between South African dense, low-income areas and poor air quality and its mitigation through spatial planning solutions.

The aim of this chapter is to concisely present the findings of the preceding chapters required to attain the aforementioned research aim. Section 8.2 will present an extensive discussion of the research results, correlating to the research objectives (Section 1.2) to illustrate a specific connection to the aim of the research. Subsequently, Section 8.3 will present the contributions of the research to the spatial planning theoretical discourse, together with air quality management and spatial planning practices, considering the thematic analysis and the results of the case study analysis.

8.2 Conclusion of research results

The following section discusses the research objective, highlighted in Section 1.2, and how they are addressed in order to attain the research aim. A synopsis of the research objectives in reflection with their corresponding conclusions are illustrated in the ensuing Table 8-1.

Table 8-1: Summary of the key findings in relation to the respective research objectives.

Conclusions relating to research Objective 1: To identify, analyse and evaluate specific contributing drivers of poor air quality in South African dense, low-income areas.

Chapter 4 used a thematic analysis in an attempt to identify the most prominent poor air quality sources contributing to poor air quality within urban areas. Owing to high levels of urbanisation globally, poor air quality poses health concerns, increasing the impact on healthcare systems and productivity of the working force. Spatial planning and segregation policies have a lasting effect on South African urban areas where spatial and racial segregation of different racial groups were located on the urban periphery, usually on undeveloped land and away from economic centres. In an effort to compile an emergent inventory, the research identified energy

generation (Section 4.2.1), transportation (Section 4.2.2), mining and industries (Section 4.2.3), household air pollution (Section 4.2.4), agriculture (Section 4.2.5) and waste management (4.2.6) as the main sectors contributing to poor air quality.

The purposefully selected “contributing drivers of poor air quality” were employed in Section 4.3 by investigating whether the sources are effectively managed in current South African AQM practices. This was done through the employment of the assessment matrix by investigating the South African AQMPs by nominating interfaces between the AQM steps and “contributing drivers of poor air quality”. The assessment revealed an insufficient representation of the AQM lifecycle, since in the most instances the “inventory” step obtained higher values than the subsequent management steps (Section 4.3.1). This signified that the subsequent AQM steps; especially “dispersion” and “monitoring” are neglected during the preparation of AQMPs. Additionally, the assessment indicated that in all instances not one poor air quality source was considered by an equal number in the “inventory” and “mitigation” step. The significant gap between the “inventory” and subsequent AQM steps illustrated the emphasis on the identification of poor air quality sources rather than implementing measures to improve poor air quality, questioning the capability of South African AQMPs to address poor air quality.

- South African urban areas and specifically dense, low-income areas have a significant impact on poor air quality.
- The main contributing sectors of poor air quality in South Africa are energy generation, transportation, mining, industries, household air pollution, agriculture and waste management.
- The assessment of the AQMPs illustrated a disconnect between the identification of poor air quality sources and the subsequent AQM steps.

Conclusions relating to research Objective 2: To examine the level of interface between the South African air quality and spatial planning directives.

Chapter 5 examined the level of alignment between existing South African spatial planning and AQM practices. The Municipal Systems Act (MSA) of 2000 was introduced to empower local governments by promoting IDP as a mandatory tool for coordinating sectoral strategies, including spatial planning and air quality management (AQM). This approach aimed to replace the fragmented planning policies with a unified framework aligned with national priorities (Simphiwe, 2014). However, challenges persist in aligning sectoral plans within IDPs. Critics (Harrison, 2006; SACN, 2020) argue that IDPs often lack clear goals, conflict with other

planning instruments, and serve as mere compliance exercises without meaningful sectoral integration. The Public Affairs Research Institute (2018) highlights that the independent development of sectoral policies leads to inefficient budgeting and disconnected implementation, weakening the link between spatial planning and AQM. The misalignment stems from policy fragmentation: spatial planning is driven by economic development priorities in policies such as the NDP, IUDF, and NSDF, while AQM is regulated by the AQA and the National Framework for Air Quality Management, which set pollution control standards but lack integration with land use planning (Naiker et al., 2012). Additionally, key environmental legislation (e.g., NEMA, AQA) does not explicitly reference spatial planning, and SPLUMA fails to acknowledge AQM policies directly. Despite references to sustainability (e.g., low-carbon economy, green cities, sustainable transport) in strategic frameworks, these policies do not emphasise poor air quality management explicitly. This siloed approach to policymaking hinders effective integration between spatial planning and AQM, reducing the potential for sustainable urban development.

While misalignment between spatial planning and air quality management (AQM) policies remains prevalent, the 2016 Strategy for Air Pollution in Dense, Low-Income Settlements marks a paradigm shift by explicitly recognizing the role of spatial planning in AQM (Department of Environmental Affairs, 2016). The strategy emphasises the need for coordination between municipal spatial planning and air quality departments to ensure effective policy implementation. The disconnection between spatial planning and AQM in South Africa largely stems from the development of policy directives at different times, resulting in a lack of explicit cross-references. SPLUMA broadly mentions environmental legislation but does not directly address AQM, while the AQA focuses on industrial emissions without integrating spatial planning considerations. This siloed approach reflects historical policy priorities rather than a cohesive, updated strategy. The current AQM framework under the AQA is too narrow, prioritizing command-and-control measures for industrial pollution while neglecting key sectors like energy, transportation, and urban planning, which significantly impact air quality. Addressing this gap requires a more holistic approach where air quality objectives are integrated into sectoral plans; particularly SDFs. To enhance alignment between spatial planning and AQM, IDPs should be strengthened as a mechanism for integrated development, ensuring a more coordinated approach. A well-integrated strategy would not only promote sustainable urban development but also lead to improved air quality outcomes, benefiting communities across South Africa.

- Misalignment between spatial planning and AQM owing to conflicting objectives and siloed approaches.

- Spatial planning is generally economically driven, while AQM focusses on environmental conservation.
- A holistic, updated approach is required by integrating air quality goals into municipal SDFs.

Conclusions relating to research Objective 3: To investigate whether contemporary spatial planning may be conducive to mitigate poor air quality.

Chapter 6 investigated contemporary spatial planning approaches, namely; compact city, TOD, smart growth, new urbanism and green urbanism with specific reference in their ability to address poor air quality. The research identified that the contemporary spatial planning approaches will arguably serve as a solution to mitigate poor air quality within South African dense, low-income areas by emphasising urban compactness and densification in reducing urban sprawl (Section 6.2.1), implementing an integrated transportation system to link various urban nodes to reduce private vehicle use (Section 6.2.2), encouraging high density, mixed-use development in proximity to transportation facilities (Section 6.2.3), providing mixed housing typologies at appropriate densities in dilapidated urban regions to encourage active transportation (Section 6.2.4) and promoting urban greening and green infrastructure within urban areas to reduce exposure to poor air quality (Section 6.2.5).

However, the research additionally argued that the employment of the aforementioned spatial planning approaches in isolation will in all probability fail, owing to the nature and form of contemporary South African urban areas. The latter is supported by Spiekermann and Wegener (2018:68), recognising that multiple approaches should be considered when resolving complex urban challenges. As a consequence, the research (Section 6.3) suggested that the implementation of the contemporary spatial planning approaches as a collective and unique approach for mitigating poor air quality in South African urban areas is reasonable, stressing that each attribute possess significant qualities and advantages independently.

Chapter 6 marked the conclusion of the thematic analysis of the research by exploring the contemporary spatial planning approaches, derived as “urban development principles”, that may well be employed as a solution to mitigate poor air quality within South African dense, low-income areas. The latter was ensuing deployed in the development of the emerging assessment tool to conduct the empirical phase.

- The research investigated contemporary spatial planning approaches and identified that compact city, TOD, smart growth, new urbanism and green urbanism may mitigate poor air quality.
- The isolated implementation of these approaches in South African urban areas will most likely fail, owing to the unique urban morphology.
- The research suggests a collective impact approach of the identified “urban development principles” in addressing complex urban challenges on a site-specific basis.

Conclusions relating to research Objective 4: To assess the implementation of spatial planning solutions to mitigate poor air quality on a municipal level.

In exploring the feasibility of spatial planning solutions to mitigate poor air quality, Chapter 7 explored whether “urban development principles” may be employed in Sasolburg-Zamdela to mitigate poor air quality. This was done by initially using AERMOD in preparing the baseline model of the case study through AERMET that is responsible for processing the meteorological data and AERMAP that processes landscape data. Subsequently, the data input files for AERMOD were prepared by incorporating the calculated emission rates of the identified poor air quality sectors. For the purpose of this research, the desktop survey identified that AREA_POLY, AREA_LINE and POINT as the most appropriate source types to be incorporated in the model. In validating the accuracy of the data, the aforementioned were employed in the baseline model and the emission concentrations results were compared to previous studies (Section 7.4.1).

Following the analysis of the baseline model, the emission concentrations for certain sectors were recalculated in reference to the implementation of the “urban development principles” for each scenarios and employed in the subsequent development models, in particular; realistic development model (Section 7.4.2), extreme development model (Section 7.4.3) and spatial inclusion development model (Section 7.4.4). The analysis demonstrated that the “urban development principles” may well be implemented to remedy poor air quality, since the reduction of PM_{2.5} concentrations were attained in all three development models. In relation to the baseline model, the overall predicted 99th percentile emission concentrations were reduced in the realistic development model by 13.7% (Section 7.4.2), in the extreme development model by 89.6% (Section 7.4.3) and in the spatial inclusion development model by 49.9% (Section 7.4.4). The development models incorporated a more compact development approach by locating high density, mixed-land use development in proximity to TODs and high order

transportation corridors, resulting in agglomeration of land uses that curb incessant urban sprawl. This approach reduced the total urban footprint and length of transportation corridors that facilitate the provision of effective services and infrastructure, lessening the impact of the urban areas on poor air quality.

Chapter 7 concluded by highlighting that South African urban areas present unique challenges owing to the spatially segregated land use patterns that are still prevalent. As a result, the research reiterated the importance to implement the contemporary spatial planning approaches as a collective impact approach to address poor air quality in South African dense, low-income areas, as suggested by Spiekermann and Wegener (2018:68).

- The development models were developed through employing the “urban development principles” as means to investigate the feasibility of spatial planning solutions to mitigate poor air quality in Sasolburg-Zamdela.
- In comparison to the baseline model, all three development models illustrated a reduction in 99th percentile and mean PM_{2.5} concentrations, highlighting the effectiveness of spatial planning solutions.
- The most significant solutions are high-density, mixed-land use development that are effectively integrated with transportation corridors and associated TODs. The provision of green infrastructure through the development models and between primary poor air quality sources and residential neighbourhoods is considered imperative.
- Considering the complex nature of South African urban areas, the character of a specific site should be considered in identifying the most suitable spatial planning solution, refraining from a generic or umbrella approach.

8.3 Contribution of the research

The ensuing section offers contributions of the research relevant to the South Africa context in addition to expanding the global knowledge.

8.3.1 Contribution in relation to the South African context.

i. Identify and implement an emission inventory applicable to South Africa

While significant efforts were made with the promulgation of the AQA (2004) to attain environmental protection by implementing associated laws and frameworks, regulations and air quality standards for monitoring and mitigation strategies, scholars argue that the South African urban areas still experience high levels of poor air quality. The research argues that existing South African AQM fraternity employs emission inventories that are developed at a global scale and are not specific for African regions that may result in discrepancies of emission factors and distribution of poor air quality sources. The research highlights the importance of effectively identify poor air quality sources in providing emission inventories as an imperative tool to accurately quantify pollutant emissions, comprehend their sources and develop appropriate strategies. While not exhaustive, the inventory list compiled from the thematic analysis may well be employed as a means to aid municipalities in introducing or updating their existing emission inventories components in the preparation of AQMPs. It is critical to note that the provided inventory list represents a summary of all the possible poor air quality sources in South Africa and ought to be applied on merits when preparing AQMPs; especially as a 100% incidence of all source in all locations is unlikely. In addition, the research emphasises the significance of establishing a comprehensive inventory list as it is perceived integral in developing effective emission control strategies for identified poor air quality sources (Gulia *et al.*, 2015:292).

ii. Emphasis on the identification of specific poor air quality sources rather than sectors

The assessment of the AQMPs identified that in both the “inventory” and “mitigation” components, the AQMPs addressed the majority of the sectors identified within the literature, however, the associated poor air quality sources addressed within the sectors are insufficient. The research, therefore, advocates that prominence should be placed on the detailed description of the poor air quality sources within the sectors, ceasing the use of generic emission inventories. Johnson *et al.* (2011:xi), in endorsing the latter, affirm that accurate source identification and quantification provide a means to introduce effective policy measures, attaining the reduction poor air quality.

iii. Review existing frameworks for the compilation of AQMPs

The NEMA (2004) and Manual for Air Quality Management and Planning (2008) require that an effective AQMP should comprise certain AQM components, however, limited

guidance is available in providing an extensive explanation of the ideal methodology to properly define and implement these components. In reference to the latter and the assessment conducted in Section 4.3, the research questions the capability of existing South African AQMPs to address poor air quality. While it is acknowledged that certain AQMPs may well mitigate poor air quality in certain areas; especially the identified high priority areas, the quality and detail of the majority AQMPs are considered insufficient. It is recommended that the five AQM steps investigated in Section 3.2.1 may well be applied as an emergent approach to compile exhaustive South African AQMPs. However, future research should be conducted to introduce a comprehensive AQM framework for the public and private authorities, providing objectives for each management step and specific means in attaining them.

iv. Effectively integrate spatial planning and air quality management in South Africa

Even though the IDP's function is to attain integrated development, effective alignment between sector plans appears lacking owing to conflicting goals of other spatial planning instruments, unclear aims and insufficient consultation from various sectors and stakeholders during the compilation of the plan. In addition, South African spatial planning is mostly guided by development policies, inter alia; NSDF, NDP and IUDF that emphasise inclusive economic and social development that are typically in conflict with air quality objectives. In contrast, AQM is predominantly regulated by the AQA and the National Framework for Air Quality Management that introduce minimum standards and provide comprehensive guidelines for managing air pollutants. The research contributes by highlighting the lack of integration between spatial planning and AQM in South Africa, despite its requirements by South African policy directives. Accordingly, it is suggested that during the compilation of SDFs, an holistic approach should be adopted by consulting AQM stakeholders to incorporate air quality objectives within the frameworks. It should be noted that the integration between spatial planning and AQM was investigated through existing South African spatial planning and AQM policy directives. As a result, it is recommended that future research should be done to determine the legislative requirements for compiling SDFs and AQMPs in highlighting specific instances where integration may be attained.

v. Integrating air quality impact assessment reports and trade-offs into the development process

The promulgation of the AQA during 2004 presented a major paradigm shift in air quality management by introducing air quality impact assessment reports. This was done to determine and quantify the potential environmental and health impacts of an existing or

proposed development in order to mitigate potential consequences. However, in South Africa it appears that emphasis is placed on primary poor air quality sources, for instance; the development or expansion of mines and power plants. Therefore, the research contributes by highlighting the importance of incorporating air quality impact assessment reports in the spatial planning process on a municipal level in determining the impact of a proposed development. Environmental impact and traffic impact reports are compulsory supporting documents required for new township establishment applications (residential, business or industrial) within local municipalities in determining the impact of the proposed development. The inclusion of air quality impact assessment reports into the spatial planning process may aid in identifying ideal locations prior to development, situating residential areas away from primary pollution sources. Moreover, the inclusion of these reports may assist local municipalities to address poor air quality by negotiating trade-offs with private developers to implement appropriate mitigation measures, for example; provision of green infrastructure, integrated land use patterns, ideal building morphologies and energy efficient technologies.

vi. Establish a contemporary spatial planning theory applicable to South African urban areas

The research highlighted that South African urban areas comprise an unique spatial form owing to the segregated spatial planning policies. These policies resulted in fragmented urban areas that comprise dual cities where marginalised groups were located on the urban periphery that resulted in long commuting distances. Regardless of the intentions to address these spatial imbalances, scholars (Pieterse, 2004:81-104; Turok, 2001:2349) argue that the South African urban areas remain fragmented, segregated and unequal. The reason for this may be the implementation of generic international spatial development models without considering the complex and unique nature of South African urban areas. In response, the research contributes by providing a collective impact approach that identifies specific “urban development principles” in developing a development model applicable to South Africa. In doing so, it is suggested that the adoption of generic spatial planning approaches on a national, provincial or local level should be avoided and rather consider “urban development principles” that are relevant to address specific spatial development challenges.

vii. Consideration of spatial planning solutions to mitigate poor air quality

The case study analysis (Section 7.4) confirmed that spatial planning solutions may well be employed to mitigate poor air quality in South African dense, low-income areas. Through employing specific “urban development principles”, the overall predicted 99th

percentile emission concentrations for PM_{2.5} were reduced in all three development models, particularly; in the realistic development model by 13.7% (Section 7.4.2), in the extreme development model by 89.6% (Section 7.4.3) and in the spatial inclusion development model by 49.9% (Section 7.4.4). While AQM may implement certain mitigation strategies for pollution sources, the research highlights, in a novel approach through incorporating development models in dispersion modelling, the importance of incorporating spatial planning solutions with AQM. The collaboration between the two fraternities' results in addressing the complex nature of poor air quality in urban areas through providing unique perspectives and methodologies.

viii. Consideration of dispersion modelling in spatial planning practices

The investigation of contemporary spatial planning approaches as a means to improve poor air quality (Section 6.2) argued that spatial planning solutions may well be implemented to mitigate poor air quality within urban areas, however, the extent or feasibility thereof were not validated. Therefore, the research employed an innovative approach by utilising dispersion modelling (AERMOD) to investigate the applicability of the spatial planning approaches as suggested in literature. In doing so, the research contributes to spatial planning fraternity by recommending the employment of dispersion models as a means to verify whether policies or frameworks will be effective prior to its implementation. Consequently, the use thereof may be regarded as an adequate tool for policy makers on various spheres of government. In addition, it is suggested that a dispersion model may be utilised by spatial planners as a "pre-planning tool" prior to the development of new extensions or towns. The model will assist by validating the effectiveness of proposed extensions through the investigation of a specific layout before the development commences, ensuring the correct agglomeration and location of land uses.

ix. Introduce alternative urban development principles for South African urban areas to mitigate poor air quality

As discussed above, the current spatial patterns of South African urban forms provide various challenges; especially to air quality. During the previous regime, spatial planning practices located marginalised groups on the urban periphery, adjacent to high pollution areas, inter alia; noxious industries, mining activities and landfill sites. The research recommends that in instances of existing proximity of residential areas to high pollution areas, effective green infrastructure should be provided between the areas in mitigating the impact. These areas may serve as a secondary function by designing green corridors to encourage pedestrian orientated development.

The preparation of the baseline model (Section 7.4.1) demonstrated the low residential densities in South African urban areas (Sasolburg 23 citizens/hectare and Zamdela 55 citizens/hectare) in relation to international standards. Romanova (2018:2) indicates that the recommended densities in urban areas are 130 – 220 citizens/hectare for high density areas and 70 – 110 citizens/hectare for low density areas. Even though Zamdela is classified as a high-density area in terms of South African standards, the density is still less than the low-density standards for international urban areas. Considering that the majority poor air quality sources in dense, low-income areas are attributed to the lack of infrastructure and services, the research recommends the location of new high rise, high-density residential buildings in close proximity to activity corridors. Not only will this encourage pedestrian orientated transportation modes, but also minimise the urban footprint that assist in the provision of adequate infrastructure of services owing to shorter road networks, water pipelines, electrical grids and waste services.

Considering that South African urban areas developed in a “tentacle pattern”, the research recommends the introduction of strategically designed TODs in relation to existing residential areas. The TODs should function as a mixed-use area, comprising diverse housing typologies, green infrastructure, commercial and retail activities, together with public and social facilities. In doing so, TODs; especially within low-income areas, will promote economic revitalisation through enhanced accessibility to economic opportunities, while reducing household transportation expenses. The case study analysis (Section 7.4) indicated that the incorporation of TODs will most likely result in the increase of PM_{2.5} emission concentration on high order transportation corridors owing to the increase in public transportation ridership. In addressing the latter, the research recommends the incorporation of green corridors between residential areas and transportation corridors to function as a buffer.

The research accepts that South African urban areas differ in scale and layout, suggesting that an “umbrella” approach should be avoided. Consequently, it is suggested that the “urban development principles” may well be employed as a guideline when considering spatial planning solutions to address poor air quality within a specific South African urban area.

8.3.2 Contribution in relation to expanding the global knowledge

x. Consider urban development principles to mitigate poor air quality in African urban areas

African urban areas currently experience major urban development challenges resultant from high population growth, unplanned urbanisation and unsustainable lifestyles (United Nations Environment Programme, 2022:9). Similar to South Africa, urban areas in African nations were shaped by complex historical, social and economic factors, representing a comparable “tentacle pattern” (Berger *et al.*, 2010:4). For this reason, the research endorses that the “urban development principles” may be employed in African urban areas to reduce poor air quality. While the research accepts that the urban areas are not identical, it is recommended that the “urban development principles” may be used as a point of reference, since urban areas in African nations share similar characteristics than those of South Africa, for example; segregated urban areas that are connected with high order transport corridors, together with sprawling informal urban areas that lack sufficient infrastructure and services. Moreover, the proposed “urban development principles” may be augmented by individual nations to ensure the principles are tailored to address specific urban challenges.

xi. Introduce dispersion modelling in international spatial planning practices

Spatial planning is regarded as a dynamic discipline that plays an imperative role in shaping future urban areas, since it attempts to facilitate holistic urban development that promotes economic growth, while conserving citizen health (Alhassani *et al.*, 2024:2). For decades, speculative spatial planning models have been introduced in an attempt to provide efficient urban areas, however, the utopian ideals and extreme visions failed as a result of growing urban challenges (Koning & Van Dijk, 2024:136). In response, spatial planners are prompted to investigate alternative approaches by considering contemporary methodologies from diverse disciplines when planning urban areas (Jaoude *et al.*, 2022:467). Accordingly, the research recommends dispersion modelling as an appropriate “pre-planning” tool that may be used by spatial planners to investigate the impact of proposed developments on air quality prior to their implementation. This is considered an adequate tool as the development parameters, inter alia; density, building height, building orientation, coverage and agglomeration of land uses, may be tested in various scenarios to determine the most suitable design or layout.

8.4 Assumptions and limitations

The ensuing are assumptions made and limitations of the research.

- i. The research acknowledges that the poor air quality sources used to analyse the AQMPs are derived from international and local documentation and not all the identified sources will be prevalent within a specific municipality, for example; emissions from ports are unlikely in urban areas located inland. Even though the AQMPs did not recognise all the identified poor air quality sources in the inventory step, the research assumes that the respective source should be considered within the subsequent AQM steps.
- ii. The case study analysis was conducted during 2016, since the recently prepared Metsimoholo SDF and municipal census were approved in 2016. Therefore, the research used the total population from these datasets for calculating the emission concentrations. As a result, the research maintained the same population size over the different development scenarios and did not consider any urbanisation trends.
- iii. Considering that the research is a preliminary approach to employ dispersion modelling as a means to verify the effectiveness of spatial planning solutions to mitigate poor air quality, the research deemed it appropriate to only model a one-year period. This approach was considered feasible, since it illustrated the change in emission concentrations over diurnal and season variations.
- iv. While traffic count data were used from previous studies in Zamdela, the accuracy of the data is not validated as the researcher conducted traffic counts on one intersection. However, since the intersection is located on the main entry point between Sasolburg and Zamdela, the research argues that the traffic represents the majority of vehicles in Zamdela. While the research accepts the South African Trip Data Manual as accurate for the activities identified in Sasolburg, the model split was not indicated. Therefore, realistic assumptions were made regarding the type of vehicles for households and the frequency of delivery vehicles to the business nodes.
- v. Owing to computation capabilities and time constraints, an 800m x 800m receptor grid were set over the case study domain, together with discrete cartesian receptors within the neighbourhoods. When a finer receptor grid was employed in AERMOD, computational limits were reached and the model failed. In reference to Section iii above, the approach was considered feasible in investigating the implementation of spatial planning solutions as a means to mitigate poor air quality.
- vi. As a point of departure, the implementation of the spatial planning solutions was employed on a city scale that included the entire urban area. While the research acknowledges that this approach may be unrealistic in South Africa owing to various economic and social factors, the aim of the research was to verify the feasibility of spatial planning solutions as

a means to mitigate poor air quality. Considering the latter is verified, the research acknowledges that the spatial planning solutions may be refined and implemented on a neighbourhood scale in order to address site-specific challenges.

8.5 Conclusion

Even though South Africa urban areas still face major challenges urban areas provide significant opportunities in providing a sustainable future for citizens. The precedingly highlights the major responsibility of various stakeholders to ensure sustainable, inclusive and productive economic and urban growth. In doing so, innovative approaches through the collaboration of diverse disciplines are required in ensuring healthy urban areas. In concluding the research, it is recommended that spatial planning solutions can be considered as a means to mitigate poor air quality in South African dense, low-income areas. The implementation of dispersion modelling offers the compilation of possible urban development scenarios to facilitate adaptive strategies that enhance resilience in contrast to uncertainties.

Bibliography

Abrahams, C., Everatt, D., Heever, A.v.d., Mushongera, D., Nwosu, C., Pilay, P., . . . Turok, I. 2018. *South Africa: National Urban Policies and City Profiles for Johannesburg and Cape Town*. Johannesburg, South Africa.

Adesina, J.A., Piketh, S.J., Burger, R.P. & Mkhathshwa, G. 2022. Assessment of criteria pollutants contributions from coal-fired plants and domestic solid fuel combustion at the South African industrial highveld. *Cleaner Engineering and Technology*, 6(1), art100358. doi:10.1016/j.clet.2021.100358.

Adil'bayeva, T.E., Talovskaya, A.V., Yazikov, Y.G. & Matveenko, I.A. 2016. *The level of air pollution in the impact zone of coal-fired power plant (Karaganda City) using the data of geochemical snow survey (Republic of Kazakhstan)*. Paper presented at the IOP Conference Series: Earth and Environmental Science, 2016/09/01. <https://dx.doi.org/10.1088/1755-1315/43/1/012040> <https://iopscience.iop.org/article/10.1088/1755-1315/43/1/012040> Date of access: 24 Jul. 2019.

Aggarwal, A., Haritash, A. & Kansal, G. 2014. Air pollution modelling - A review. *International Journal of Advanced Technology in Engineering and Science*, 2(6):255-264.

Agren, C. 2009. Long Range Transboundary Air Pollution. In Kutting, G.M., ed. *Conventions, Treaties and other Responses to Global Issues*. Abu Dhabi, United Arab Emirates: EOLSS Publications. pp. 253-274.

Ahlfeldt, G.M. & Pietrostefani, E. 2017. *The Compact City in Empirical Research: A Quantitative Literature Review*. Cork, Ireland.

Air Pollution Prevention Act 45 of 1965.

Alberts, R.C., Retief, F.P., Cilliers, D.P., Roos, C. & Hauptfleisch, M. 2021. Environmental impact assessment (EIA) effectiveness in protected areas. *Impact Assessment and Project Appraisal*, 39(4):290-303.

Alessi, M. 2015. *The first truly global international climate change agreement*. <https://climatepolicyinfohub.eu/history-un-climate-negotiations-part-1-1980s-2010.html> Date of access: 20 Apr. 2021.

Alexander, D. & Tomalty, R. 2002. Smart growth and sustainable development: Challenges, solutions and policy directions. *Local environment*, 7(4):397-409.

- Alhassani, S.S., Alzubaidi, R.M. & Hussien, A.A. 2024. Navigating Uncertainties: A Scoping Review of Risks in Urban Planning. *Future Cities and Environment*, 10(1), art10. doi:10.5334/fce.230.
- Alias, A., Ali, A.S. & Wai, C.K. 2011. New urbanism and township developments in Malaysia. *Urban Design International*, 16(1):76-93.
- Allen, H. 2013. *Africa's First Full Rapid Bus System: the Rea Vaya Bus System in Johannesburg, Republic of South Africa*. Nairobi.
- Al-Thani, H.G. & R.J., I. 2024. Policies and Regulations for Sustainable Clean Air: A Comprehensive Overview. In Ogwu, M.C. & Izah, S.C., eds. *Sustainable Strategies for Air Pollution Mitigation*. New York, United States of America: Springer. pp. 409-437.
- Altieri, K.E. & Keen, S.L. 2019. Public health benefits of reducing exposure to ambient fine particulate matter in South Africa. *Science of the Total Environment*, 684(1):610-620.
- Amati, M. & Yokohari, M. 2007. The establishment of the London greenbelt: reaching consensus over purchasing land. *Journal of Planning History*, 6(4):311-337.
- Ambarwati, L. & Indriastuti, A.K. 2019. Improvement of Public Transport to Minimize Air Pollution in Urban Sprawl. *International Journal of GEOMATE*, 17(59):43-50.
- Amster, E. & Levy, L.C. 2019. Impact of coal-fired power plant emissions on children's health: a systematic review of the epidemiological literature. *International journal of environmental research and public health*, 16(1), e2008. doi:10.3390/ijerph16112008.
- Aneja, V.P., Schlesinger, W.H. & Erisman, J.W. 2009. Effects of agriculture upon the air quality and climate: research, policy, and regulations. *Environmental Science & Technology*, 43(12):4234–4240.
- Arbury, J. 2005. *From Urban Sprawl to Compact City – An analysis of urban growth management in Auckland*. Auckland: University of Auckland. (Thesis - PhD).
- Arku, R.E., Vallarino, J., Dionisio, K.L., Willis, R., Choi, H., Wilson, J.G., . . . Ezzati, M. 2008. Characterizing air pollution in two low-income neighborhoods in Accra, Ghana. *Science of the total environment*, 402(2-3):217-231.
- Asha, A. & Makalela, K. 2020. Challenges in the implementation of integrated development plan and service delivery in Lepelle-Nkumphi municipality, Limpopo province. *International Journal of Economics and Finance Studies*, 12(1):1-15.

- Averill, J.B. 2002. Matrix analysis as a complementary analytic strategy in qualitative inquiry. *Qualitative health research*, 12(6):855-866.
- Badach, J., Wojnowski, W. & Gębicki, J. 2023. Spatial aspects of urban air quality management: Estimating the impact of micro-scale urban form on pollution dispersion. *Computers, Environment and Urban Systems*, 99(1), art101890. doi:10.1016/j.compenvurbsys.2022.101890.
- Baffi, S., Turok, I. & Vacchiani-Marcuzzo, C. 2018. The south African urban system. *International and transnational perspectives on urban systems*, 1(1):285-314.
- Balmer, M. 2007. Household coal use in an urban township in South Africa. *Journal of Energy in Southern Africa*, 18(3):27-32.
- Banica, A. & Istrate, M. 2016. Recent Dynamics of Air Pollution from Thermal Power Plants – Evidence from Romania, Bulgaria and Greece. *Journal of environmental protection and ecology*, 17(3):831-839.
- Barnes, A. & Nel, V. 2017. Putting Spatial Resilience into Practice. *Urban Forum*, 28(1), art6. doi:10.1007/s12132-017-9303-6.
- Barnes, B., Mathee, A., Thomas, E. & Bruce, N. 2009. Household energy, indoor air pollution and child respiratory health in South Africa. *Journal of Energy in Southern Africa*, 20(1):4-13.
- Barnes, J.H., Hayes, E.T., Chatterton, T.J. & Longhurst, J.W. 2014. Air quality action planning: why do barriers to remediation in local air quality management remain? *Journal of Environmental Planning and Management*, 57(5):660-681.
- Barnwell, L. 2009. *Industrial Perspectives on the Implementation of the Air Quality Act (AQA) (Act No. 39 of 2004)*. Westville: University of KwaZulu-Natal. (Thesis - MA).
- Batty, M. 2010. Complexity in city systems: Understanding, evolution, and design. In De Roo, G. & Silva, E.A., eds. *A planner's encounter with complexity*. London: Routledge. pp. 99-122.
- Bauer, S.E., Tsigaridis, K. & Miller, R. 2016. Significant atmospheric aerosol pollution caused by world food cultivation. *Geophysical Research Letters*, 43(10):5394-5400.
- Bel, G. & Holst, M. 2018. Evaluation of the impact of bus rapid transit on air pollution in Mexico City. *Transport Policy*, 63(1):209-220.
- Beltran, D., Belalcazar, L.C. & Rojas, N. 2012. *Spatial distribution of non-exhaust particulate matter emissions from road traffic for the city of Bogota–Colombia*. Paper presented at the 20th

International Emission Inventory Conference, Tampa.

<https://www3.epa.gov/ttn/chief/conference/ei20/index.html> Date of access: 30 Jul 2019.

Belzer, D. & Autler, G. 2002. *Transit oriented development: moving from rhetoric to reality*. Washington, DC.

Benaquisto, L. & Given, L. 2008. Codes and Coding. In Given, L.M., ed. *The SAGE encyclopedia of qualitative research methods*. Thousand Oaks: SAGE Publications Inc. pp. 86-95.

Bereitschaft, B. & Debbage, K. 2013. Urban form, air pollution, and CO2 emissions in large US metropolitan areas. *The Professional Geographer*, 65(4):612-635.

Berger, P., Pech, N., Descroux, T., Le Gac, M. & Boisset, C. 2010. *Corridor design in town planning: sustainable planning for large cities in developed countries*.

<http://www.codatu.org/wp-content/uploads/Corridor-designs-in-town-planning-Patrice-BERGER-Nicolas-PECH-Thibaut-DESROUX-Marie-LE-GAC-Claire-BOISSET> Date of access: 28 Nov. 2024.

Bertolini, L. 1999. Spatial development patterns and public transport: the application of an analytical model in the Netherlands. *Planning practice and research*, 14(2):199-210.

Bertolini, L., Carey, C. & Renne, J.L. 2009. Introduction. In Curtis, C., Renne, J.L. & Bertolini, L., eds. *Transit Oriented Development: Making it Happen*. Farnham: Ashgate Publishing Company. pp. 2-12.

Bibri, S.E., Krogstie, J. & Kärrholm, M. 2020. Compact city planning and development: Emerging practices and strategies for achieving the goals of sustainability. *Developments in the built environment*, 4(1), art100021. doi:10.1016/j.dibe.2020.100021.

Binns, T. & Nel, E. 2002. Tourism as a local development strategy in South Africa. *Geographical Journal*, 6(1):14-29.

Blair, E. 2015. A reflexive exploration of two qualitative data coding techniques. *Journal of Methods and Measurement in the Social Sciences*, 6(1):14-29.

Bochner, B.S., Lewis, C.A., Rabinowitz, R.L., Higgins, L.L. & Zietsman, J. 2002. *Introducing Smart Growth to Texas: Research Report*. Texas, United States of America.

Bodansky, D.M. 2010. *The Art and Craft of International Environmental Law*. Cambridge, MA: Harvard University Press.

Bohl, C.C. 2000. New urbanism and the city: Potential applications and implications for distressed inner-city neighborhoods. *Housing Policy Debate*, 11(4):761-801.

Bond, A., Pope, J., Morrison-Saunders, A. & Retief, F. 2022. Exploring the relationship between context and effectiveness in impact assessment. *Environmental Impact Assessment Review*, 97(1), art106901. doi:10.1016/j.eiar.2022.106901.

Borge, R., Lange, S. & Kehew, R. 2023. Analysis of air quality issues and air quality management status in five major African cities. *Clean Air Journal*, 33(2):74-93.

Borrego, C., Martins, H., Tchepel, O., Salmim, L. & Monteiro, A. 2006. How urban structure can affect city sustainability from an air quality perspective. *Environmental Modelling & Software*, 21(1):461-467.

Bosman, C. 2003. *New legal implication on South Africa Authorities' waste management responsibilities*. Paper presented at the International Waste Management. Biennial Congress and Exhibition, Melbourne, Australia. <https://www.iswa.org/iswa-world-congress/?v=68caa8201064> Date of access: 5 Mar. 2021.

Brockett, L. 1996. The history of planning South African new towns: political influences and social principles adopted. *New Contree*, 1(1):160-179.

Brunekreef, B., Harrison, R.M., Künzli, N., Querol, X., Sutton, M.A., Heederik, D.J., . . . Sigsgaard, T. 2015. Reducing the health effect of particles from agriculture. *The Lancet Respiratory Medicine*, 3(11):831-832.

Bugarski, A.D. & Hummer, J.A. 2020. Contribution of various types and categories of diesel-powered vehicles to aerosols in an underground mine. *Journal of occupational and environmental hygiene*, 17(4):121-134.

Bulkeley, H. & Betsill, M.M. 2003. Introduction. In Bulkeley, H. & Betsill, M.M., eds. *Cities and Climate Change Urban sustainability and global environmental governance*. New York, United State of America: Routledge. pp. 1-5.

Burchell, R.W., Listokin, D. & Galley, C.C. 2000. Smart growth: More than a ghost of urban policy past, less than a bold new horizon. *Housing policy debate*, 11(4):821-879.

Burger, L.W., Held, G. & Snow, N.H. 1997. *Revised User's Manual for the Airborne Dust Dispersion Model from Area Sources (ADDAS) - Eskom TSI Report No. TRR/T97?066*.

Burgess, R. 2000. The Compact City Debate: A Global Perspective. In Jenks, M. & Burgess, R., eds. *Compact Cities: Sustainable Urban Forms for Developing Countries*. New York: Spon

Press. pp. 9-24.

Burnett, R.T., Pope, C.A., 3rd, Ezzati, M., Olives, C., Lim, S.S., Mehta, S., . . . Cohen, A. 2014. An integrated risk function for estimating the global burden of disease attributable to ambient fine particulate matter exposure. *Environmental Health Perspectives*, 122(4):397-403.

Burton, E. 2000. The compact city: Just or just compact? A preliminary analysis. *Urban studies*, 37(11):1969-2006.

Burton, E. 2002. Measuring urban compactness in UK towns and cities. *Environment and Planning B: Planning and Design*, 29(1):219-250.

Busayo, E.T., Kalumba, A.M. & Orimoloye, I.R. 2019. Spatial planning and climate change adaptation assessment: Perspectives from Mdantsane Township dwellers in South Africa. *Habitat International*, 90(1), art101978. doi:10.1016/j.habitatint.2019.04.005.

Byrne, A. 2015. The 1979 convention on long-range transboundary air pollution: Assessing its effectiveness as a multilateral environmental regime after 35 years. *Transnational Environmental Law*, 4(1):37-67.

Cairncross, E. 2016. *The State of South Africa's Air Quality Monitoring Network and Its Air Quality*. Paper presented at the National Association for Clean Air, Nelspruit, 5-7 October.

Cairncross, E., Dalvie, A., Euripidou, R., Irlam, J. & Naidoo, R.N. 2018. Climate Change and Air Pollution The Impact on Human Health in Developed and Developing Countries. In: Akhtar, R. & Palagiano, C., eds. *Climate Change, Air Pollution and Health in South Africa*. Cham, Switzerland: Springer. pp. 327-348. <https://link.springer.com/book/10.1007/978-3-319-61346-8> Date of access: 18 Oct. 2019.

Calthorpe, P. 1993. *The Next American Metropolis: Ecology, Community, and the American Dream*. New York: Princeton Architectural Press.

Calthorpe, P. 2011. *Urbanism in the age of climate change*. New York: Island Press.

Campbell, S. 2018. Green cities, growing cities, just cities? Urban planning and the contradictions of sustainable development. *Classic Readings in Urban Planning*. Routledge. pp. 308-326.

Cariolet, J.-M., Colombert, M. & Vuillet, M. 2015. *Assessing urban planning resilience to outdoor air pollution in Greater Paris*. Paper presented at the PLEA Conference, Bologna, Italy.

Cepeda, M., Schoufour, J., Freak-Poli, R., Koolhaas, C.M., Dhana, K., Bramer, W.M., . . .

Franco, O.H. 2017. Levels of ambient air pollution according to mode of transport: a systematic review. *Lancet Public Health*, 2(1): art23-34. doi:10.1016/s2468-2667(16)30021-4.

Cervero, R. 2009. Public Transport and Sustainable Urbanism: Global Lessons. In Curtis, C., Renne, J.L. & Bertolini, L., eds. *Transit Oriented Development: Making it Happen*. Farnham: Ashgate Publishing Company. pp. 23-35.

Cervero, R. & Arrington, G.B. 2008. Vehicle Trip Reduction Impacts of Transit-Oriented Housing. *Journal of Public Transportation*, 11(3):1-17.

Chakwizira, J., Thompson, A. & Dayomi, M. 2011. Some Missing Dimensions of Urban Public Transport in Africa: Insights and Perspectives from South Africa. *The Built & Human Environment Review*, 4(1):56-84.

Chang, C.T. 2006. Characteristics and Emission Factors of Fugitive Dust at Gravel Processing Sites. *Aerosol and Air Quality Research*, 6(1):15-29.

Charman, A., Tonkin, C., Denoon-Stevens, S. & Demeestère, R. 2017. *Post-Apartheid Spatial Inequality: Obstacles of Land Use Management on Township Micro-Enterprise Formalisation*. Cape Town, South Africa.

Chen, D.M.-C., Bodirsky, B.L., Krueger, T., Mishra, A. & Popp, A. 2020. The world's growing municipal solid waste: trends and impacts. *Environmental Research Letters*, 15(1), art074021. doi:10.1088/1748-9326/ab8659.

Chen, L., Li, L., Yang, X., Zhang, Y., Chen, L. & Ma, X. 2019. Assessing the Impact of Land-Use Planning on the Atmospheric Environment through Predicting the Spatial Variability of Airborne Pollutants. *International Journal of Environmental Research and Public Health*, 16(1), art172. doi:10.3390/ijerph16020172.

Chen, Z., Chen, D., Zhao, C., Kwan, M.-p., Cai, J., Zhuang, Y., . . . Xu, B. 2020. Influence of meteorological conditions on PM_{2.5} concentrations across China: A review of methodology and mechanism. *Environment International*, 139(1), art105558. doi:10.1016/j.envint.2020.105558.

Cherry, T.L., Hovi, J. & Mcevoy, D.M. 2014. Introduction. In Cherry, T.L., Hovi, J. & Mcevoy, D.M., eds. *Toward a New Climate Agreement: Conflict, resolution and governance*. New York, United States of America: Routledge. pp. xii-xvii.

Chidhindi, P. 2022. *Using dispersion models as a regulatory tool in South Africa*. Potchefstroom: North-West University. (Thesis - MA)

Cho, B.H., Nam, B.H., An, J. & Youn, H. 2020. Municipal solid waste incineration (MSWI)

ashes as construction materials—A review. *Materials*, 13(1), art3143.
doi:10.3390/ma13143143.

Cho, H.S. & Choi, M.J. 2014. Effects of compact urban development on air pollution: Empirical evidence from Korea. *Sustainability*, 6(9):5968-5982.

Choudhary, D.M. & Garg, V. 2013. *Causes, Consequences and Control of Air Pollution*. Paper presented at the All India Seminar by :Malaviya National Institute of Technology, Jaipur, India.
<https://mnit.ac.in/research/cpublications> Date of access: 19 Aug. 2019.

Cichowicz, R. & Stelegowski, A. 2018. Selected air pollutants in urban and rural areas, under the influence of power plants. *Acta Innovations*, 29(1):41-52.

City Health Department & Air Pollution Control Section (Cape Town). 2005. *Air Quality Management Plan for the City of Cape Town*. Cape Town, South Africa.

Clark, L.P., Millet, D.B. & Marshall, J.D. 2011. Air Quality and Urban Form in U.S. Urban Areas: Evidence from Regulatory Monitors. *Environment Science & Technology*, 45(16):7028-7035.

Coetzee, J. 2010. Not another 'night at the museum': 'Moving on' from 'developmental' - local government to 'developmental local state. *Town and Regional Planning*, 56(1):18-27.

Coetzee, M., Feldman, M., Huebner, K., Majozi, M., Patel, P. & Rauch, T. 2000. *IDP Guide Book: a general overview*. Polokwane, South Africa.

Cogut, A. 2016. *Open burning of waste: a global health disaster*. Geneva, Switzerland.

Cohen, A.J., Brauer, M., Burnett, R., Anderson, H.R., Frostad, J., Estep, K., . . . Forouzanfar, M.H. 2017. Estimates and 25-year trends of the global burden of disease attributable to ambient air pollution: an analysis of data from the Global Burden of Diseases Study 2015. *Lancet*, 389(10082):1907-1918.

Cohen, L., Manion, L. & Morrison, K. 2007. *Research Methods in Education*. 6th ed. London: Routledge.

Cohen, L., Manion, L. & Morrison, K. 2018. *Research methods in education*. 8th ed. London: Routledge.

Collective Impact Forum. 2014. *What Is Collective Impact: Collective impact brings people together in a structured way to achieve social change*. <https://collectiveimpactforum.org/what-is-collective-impact/> Date of access: 20 Apr. 2023.

- Colville, R.N., Hutchinson, E.J., Mindell, J.S. & Warren, R.F. 2001. The transport sector as a source of air pollution. *Atmospheric environment*, 35(9):1537-1565.
- Committee of Transport Officials. 2013. *South African Trip Data Manual - TMH 17*. Pretoria: South African National Roads Agency Limited.
- Condon, P.M., Cavens, D. & Miller, N. 2013. *Urban Planning Tools for Climate Change Mitigation*. Cambridge, United States of America: Lincoln Institute of Land Policy.
- Congress for the New Urbanism. 1996. *Region, Neighborhood, District, Corridor, Block, Street and Building*. New York: McGraw-Hill.
- Congress for the New Urbanism. 2000. *Principles for Inner City Neighborhood Design*. New York: McGraw-Hill.
- Coscolla, C. & Yusa, V. Pesticides and Agricultural Air Quality. In Guardia, M.D.L. & Armenta, S., eds. *Comprehensive Analytical Chemistry*. Amsterdam, Netherlands: Elsevier. pp. 423-485.
- Council of Scientific & Industrial Science (South Africa). 2000. *Guidelines for Human Settlement Planning and Design Volume 1*. Pretoria, South Africa.
- Cozens, P. & Hillier, D. 2008. The shape of things to come: New urbanism, the grid and the cul-de-sac. *International Planning Studies*, 13(1):51-73.
- Creswell, J.W. 2009. *Research design: Qualitative, quantitative, and mixed methods approaches*. 3rd ed. Thousand Oaks: SAGE Publications.
- Creswell, J.W. & Creswell, J.D. 2018. *Qualitative, Quantitative, and Mixed Methods Approaches*. 5th ed. Thousand Oaks: SAGE Publications.
- Creswell, J.W. & Plano-Clark, V.L. 2018. *Designing and Conducting - Mixed Methods Research*. 3rd ed. Thousand Oaks: SAGE Publications.
- CS Consulting. 2013. *Spatial Development Frameworks*. Pretoria, South Africa.
- Curtis, C. 2008. Evolution of the transit-oriented development model for low-density cities: a case study of Perth's new railway corridor. *Planning, Practice & Research*, 23(3):285-302.
- Dadashpoor, H. & Shahhossein, G. 2024. Defining urban sprawl: A systematic review of 130 definitions. *Habitat international*, 146(1), doi:10.1016/j.habitatint.2024.103039.
- Dahiya, B. 2012. Cities in Asia, 2012: Demographics, economics, poverty, environment and

governance. *Cities*, 29(1):44-61.

Danielsen, K.A., Lang, R.E. & Fulton, W. 1999. Retracting suburbia: Smart growth and the future of housing. *Housing policy debate*, 10(3):513-540.

Dantzig, G.B. & Saaty, T.L. 1973. *Compact City: A Plan for a Liveable Urban Environment*. San Francisco: W. H. Freeman.

Das, D.K. 2022. Factors and strategies for environmental justice in organized urban green space development. *Urban Planning*, 7(2):160-173.

Davidson, A. & Naidoo, D. 2018. *State of Environment Outlook Report for the Western Cape Province 2014 - 2017*. Cape Town: Western Cape Government.

Dawadi, S., Shrestha, S. & Giri, R.A. 2021. Mixed-methods research: A discussion on its types, challenges, and criticisms. *Journal of Practical Studies in Education*, 2(2):25-36.

De Oliveira, G., Chen, J.M., Mataveli, G.A., Chaves, M.E., Seixas, H.T., Cardozo, F.d.S., . . . dos Santos, C.A. 2020. Rapid recent deforestation incursion in a vulnerable indigenous land in the Brazilian Amazon and fire-driven emissions of fine particulate aerosol pollutants. *Forests*, 11(8), art829. doi:10.3390/f11080829.

De Schiller, S. & Evans, J.M. 2000. Urban Climate and Compact Cities in Developing Countries. In Jenks, M. & Burgess, R., eds. *Compact Cities: Sustainable Urban Forms for Developing Countries*. New York: Spon Press. pp. 117-124.

De Visser, J. 2009. Developmental local government in South Africa: Institutional fault lines. *Commonwealth Journal of Local Governance*, 2(1):7-25.

Dekker, T., Vollebergh, H.R., de Vries, F.P. & Withagen, C.A. 2012. Inciting protocols. *Journal of Environmental Economics and Management*, 64(1):45-67.

Department of Agriculture Land Reform and Rural Development (South Africa). 2023. *Economic Review of the South African Agriculture, 2022*. Pretoria, South Africa.

Department of Cooperative Governance and Traditional Affairs (South Africa). 2016. *The Integrated Urban Development Framework: A New Deal for South African Cities and Towns*. Johannesburg, South Africa.

Department of Environment Forestry and Fisheries. 2020. *The draft second generation air quality management plan for Vaal triangle airshed priority area*. Pretoria, South Africa.

Department of Environmental Affairs. 2009. *Guideline for development of integrated waste management plan*. Pretoria, South Africa.

Department of Environmental Affairs. 2018. *The 2017 National Framework for Air Quality Management in the Republic of South Africa*. Pretoria, South Africa.

Department of Environmental Affairs (South Africa). 2007. *South Africa Environment Outlook: A report on the state of the environment*. Pretoria, South Africa.

Department of Environmental Affairs (South Africa). 2014. *South Africa's Greenhouse Gas (GHG) Mitigation Potential Analysis*. Pretoria, South Africa.

Department of Environmental Affairs (South Africa). 2016. *South Africa Environmental Outlook: a report on the state of the environment*. Pretoria, South Africa.

Department of Environmental Affairs (South Africa). 2019. *Strategy to Address Air Pollution in Dense Low-Income Settlements: A "Burning" Issue*. Pretoria, South Africa.

Department of Environmental Affairs and Tourism (South Africa). 2005. *South Africa Country Report: Fourteenth Session of the United Nations Commission on Sustainable Development*. Pretoria, South Africa.

Department of Environmental Affairs and Tourism (South Africa). 2007. *The 2007 National Framework for Air Quality Management in the Republic Of South Africa*. Pretoria, South Africa.

Department of Environmental Affairs and Tourism (South Africa). 2008. *Manual for Air Quality Management Planning*. Pretoria, South Africa.

Department of Health (South Africa). 2019. *Guideline for the Management of Domestic Indoor Air Quality: A Guide for Environmental Health Practitioners in South Africa*. Pretoria, South Africa.

Department of Planning Monitoring and Evaluation (South Africa). 2005. *State of Air Report 2005: A report on the state of the air in South Africa*. Pretoria, South Africa.

Department of Planning Monitoring and Evaluation (South Africa). 2014. *Medium-Term Strategic Framework*. Pretoria, South Africa.

Department of Planning Monitoring and Evaluation (South Africa). 2019. *Medium-Term Strategic Framework*. Pretoria, South Africa.

Department of Provincial and Local Government (South Africa). 2000. *IDP Guide Book*.

Pretoria, South Africa.

Department of Rural Development and Land Reform (South Africa). 2011. *Guidelines for the Development of Spatial Development Frameworks*. Pretoria, South Africa.

Department of Rural Development and Land Reform (South Africa). 2012. *Integrated Planning Development Template*. Pretoria, South Africa.

Department of Rural Development and Land Reform (South Africa). 2014. *SDF Guidelines and Evaluation Framework*. Pretoria, South Africa.

Department of Rural Development and Land Reform (South Africa). 2022. *National Spatial Development Framework*. Pretoria, South Africa.

Department of Transport (South Africa). 2015. *National Land Transport Strategic Framework*. Pretoria, South Africa.

Department of Transport (South Africa). 2016. *National Transport Master Plan 2050*. Pretoria, South Africa.

Department of Transport (South Africa). 2018. *Green Transport Strategy for South Africa: 2018-2050*. Pretoria, South Africa.

Department of Water and Environmental Affairs (South Africa). 2012. *The 2012 National Framework for Air Quality Management in the Republic Of South Africa*. Pretoria, South Africa.

Depledge, J. 2017. Foundations for the Paris Agreement. In Klein, D., Carazo, M.P., Doelle, M., Bulmer, J. & Higham, A., eds. *The Paris Agreement on Climate Change: Analysis and Commentary*. Oxford, United Kingdom: Oxford University Press. pp. 27-42.

Dewar, D. 1995. The urban question in South Africa: the need for a planning paradigm shift. *Third World Planning Review*, 17(4):407-420.

Dewar, D. & Kiepiel, J. 2012. Spatial development frameworks on a broader scale: An integrative approach. *Town and Regional Planning*, 61(1):30-35.

Di Nicola, F., Brattich, E. & Di Sabatino, S. 2022. A new approach for roughness representation within urban dispersion models. *Atmospheric Environment*, 283(1), art119181. doi:10.1016/j.atmosenv.2022.119181.

Dieleman, F. & Wegener, M. 2004. Compact city and urban sprawl. *Built environment*, 30(4):308-323.

- Dierwechter, Y. 2017. *Urban Sustainability through Smart Growth: Intercurrence, Planning, and Geographies of Regional Development across Greater Seattle*. Cham: Springer.
- Dlamini, B. & Reddy, P.S. 2018. Theory and Practice of Integrated Development Planning: A case study of Umtshezi Local Municipality in the KwaZuluNatal Province of South Africa. *African Journal of Public Affairs*, 10(1):1-24.
- Drewes, E. & Van Aswegen, M. 2013. National Planning in South Africa: a critical review. *WIT Transactions on Ecology and The Environment*, 173(1), art1301. doi:10.2495/SDP1301.
- Du Plessis, C. & Landman, K. 2002. *Sustainability Analysis of Human Settlements in South Africa*. Pretoria, South Africa.
- Du Plessis, D.J. 2014. A Critical Reflection on Urban Spatial Planning Practices and Outcomes in Post-Apartheid South Africa. *Urban Forum*, 25(1), art5. doi:10.1007/s12132-013-9201-5.
- Du Plessis, D.J. 2015. Land-use mix in South African cities and the influence of spatial planning: Innovation or following the trend. *South African Geographical Journal*, 9(3):217-242.
- Duany, A. & Plater-Zyberk, E. 1994. The neighborhood, the district and the corridor. In Katz, P., ed. *The new urbanism: Toward an architecture of community*. New York: McGraw-Hill. pp. 17-20.
- Duany, A. & Plater-Zyberk, E. 2003. *Smart Code & Manual Version*. Michigan: New Urban Publications.
- Duminy, J. & Parnell, S. 2020. *Supporting City Futures: The Cities Support Programme and the Urban Challenge in South Africa*. Cape Town: African Centre for Cities.
- El Aziz, N.A.A. 2016. Air Quality and Urban Planning Policies: The Case of Cairo City CBD. *Environmental Science, Engineering*. <https://www.semanticscholar.org/paper/Air-Quality-and-Urban-Planning-Policies-The-Case-of-Aziz/21ab0ca79f10c5f23dfe0a7890b7876de6d7faa2>
Date of access: 20 May 2021.
- Ellis, C. 2002. The new urbanism: Critiques and rebuttals. *Journal of Urban Design*, 7(3):261-291.
- Emberson, L.D., Ashmore, M.R., Murray, F., Kuylenstierna, J.C.I., Percy, K.E., Izuta, T., . . . Domingos, M. 2001. Impacts of air pollutants on vegetation in developing countries. *Water, Air, and Soil Pollution*, 130(1):107-118.
- Engelbrecht, J.C. & I.J. van der Walt. 2007. A generic air quality management plan for

Municipalities. *Clean Air Journal*, 26(1):5-15.

Engelbrecht, J.C. & I.J. van der Walt. 2012. Development of an air quality management framework for municipal government. *African Journal of Environmental Science and Technology*, 6(10):407-418.

Engelbrecht, J.P., Swanepoel, L., Chow, J.C., Watson, J.G. & Egami, R.T. 2001. PM_{2.5} and PM₁₀ concentrations from the Qalabotjha low-smoke fuels macro-scale experiment in South Africa. *Environmental monitoring and assessment*, 69(1):1-15.

Ennis, G. & Tofa, M. 2020. Collective impact: A review of the peer-reviewed research. *Australian social work*, 73(1):32-47.

Ericsson, E. 2000. Variability in urban driving patterns. *Transportation Research Part D: Transport and Environment*, 5(5):337-354.

Eriksson, O. & Finnveden, G. 2017. Energy recovery from waste incineration—the importance of technology data and system boundaries on CO₂ emissions. *Energies*, 10(1), art539. doi:10.3390/en10040539.

Ete, T., Girma, E. & Mamo, K. 2021. Risk perceptions and experiences of residents living nearby municipal solid waste open dumpsite in ginchu town, Ethiopia: a qualitative study. *Risk Management and Healthcare Policy*, 14(1):2035-2044.

Etyemezian, V., Tesfaye, M., Yimer, A., Chow, J., Mesfin, D., Nega, T., . . . Wondmagegn, M. 2005. Results from a pilot-scale air quality study in Addis Ababa, Ethiopia. *Atmospheric environment*, 39(40):7849-7860.

European Agricultural Machinery Industry Association. 2022. *The role of agricultural machinery in decarbonising agriculture*. Brussels, Belgium.

European Environment Agency. 2019. *EMEP/EEA Air Pollutant Emission Inventory Guidebook 2019*. Copenhagen, Denmark.

Fakoya, M.B. 2014. Institutional challenges to municipal waste management service delivery in South Africa. *Journal of human ecology*, 45(2):119-125.

Fan, T. & Chapman, A. 2022. Policy driven compact cities: Toward clarifying the effect of compact cities on carbon emissions. *Sustainability*, 14(19), art12634. doi:10.3390/su141912634.

Feig, G., Garland, R.M., Naidoo, S., Maluleke, A. & Van der Merwe, M. 2019. Assessment of

changes in concentrations of selected criteria pollutants in the Vaal and Highveld priority areas. *Clean Air Journal*, 29(2):1-13.

Fenger, J. 2009. Air pollution in the last 50 years – From local to global. *Atmospheric Environment*, 43(1):13-22.

Ferguson, L., Taylor, J., Davies, M., Shrubsole, C., Symonds, P. & Dimitroulopoulou, S. 2020. Exposure to indoor air pollution across socio-economic groups in high-income countries: A scoping review of the literature and a modelling methodology. *Environment international*, 143(1), art105748. doi:10.1016/j.envint.2020.105748.

Ferm, M. & Sjöberg, K. 2015. Concentrations and emission factors for PM_{2.5} and PM₁₀ from road traffic in Sweden. *Atmospheric Environment*, 119(1), art37. doi:10.1016/j.atmosenv.2015.08.037.

Ferronato, N. & Torretta, V. 2019. Waste mismanagement in developing countries: A review of global issues. *International journal of environmental research and public health*, 16(1), art1060. doi:10.3390/ijerph16061060.

Field, B.C. & Olewiler, N.D. 2015. *Environmental Economics*. New York: McGraw-Hill.

Financial and Fiscal Commission (South Africa). 2012. *Submission for the Division of Revenue - Technical Report*. Midrand, South Africa.

Finus, M. 2003. Stability and design of international environmental agreements: the case of transboundary pollution. *International yearbook of environmental and resource economics*, 4(4):1-55.

Fowler, D., Brimblecombe, P., Burrows, J., Heal, M.R., Grennfelt, P., Stevenson, D.S., . . . Viena, M. 2020. A chronology of global air quality. *Philosophical Transactions A*, 378(1), art0314. doi:10.1098/rsta.2019.0314.

Frank, L., Kavage, S. & Litman, T. 2006. *Promoting public health through Smart Growth: Building healthier communities through transportation and land use policies and practices*. Vancouver, Canada.

Frazenburg, C., Sepadi, M.M. & Chitakira, M. 2025. Investigating the Disproportionate Impacts of Air Pollution on Vulnerable Populations in South Africa: A Systematic Review. *Atmosphere*, 16(1), art49. doi:10.3390/atmos16010049.

Freilich, R.H. & Popowitz, N.M. 2010. The umbrella of sustainability: smart growth, new urbanism, renewable energy and green development in the 21st century. *The Urban Lawyer*,

42(1):1-39.

Fugiel, A., Burchart-Korol, D., Czaplicka-Kolarz, K. & Smoliński, A. 2017. Environmental impact and damage categories caused by air pollution emissions from mining and quarrying sectors of European countries. *Journal of Cleaner Production*, 143(1):159-168.

Gallegos, C.Á.E. 2017. The city from complex system theories. An approach to the study of Malaga Urban Area. *European Journal of Geography*, 7(5):162-174.

Galychyn, O. & Üstundağ, K. 2017. Organic urbanism: Human-oriented design for metropolises. *Procedia Environmental Sciences*, 37(1):396-407.

Gao, M., Beig, G., Song, S., Zhang, H., Hu, J., Ying, Q., . . . Lu, X. 2018. The impact of power generation emissions on ambient PM_{2.5} pollution and human health in China and India. *Environment international*, 121(1):250-259.

García-Olivares, A., Solé, J. & Osychenko, O. 2018. Transportation in a 100% renewable energy system. *Energy Conversion and Management*, 158(1):266-285.

Garde, A. 2020. New urbanism: Past, present, and future. *Urban Planning*, 5(4):453-463.

Garland, R.M., Naidoo, M., Sibiyi, B.A. & Oosthuizen, R. 2017. Air quality indicators from the Environmental Performance Index: potential use and limitations in South Africa. *Clean Air Journal*, 27(1):33-41.

Gaya, H. & Smith, E.E. 2016. Developing a qualitative single case study in the strategic management realm: An appropriate research design. *International Journal of Business Management and Economic Research*, 7(2):529-538.

Geller, A.L. 2003. Smart growth: a prescription for livable cities. *American journal of public health*, 93(9):1410-1415.

Gesley, J. 2018. Switzerland. *Regulation of Air Pollution*. Washington: The Law Library of Congress. pp. 122-134.

Ghosh, M., Banerjee, P. & Ray, H. 2014. Environmental pollution due to gaseous emissions during non-ferrous extraction processes. *Russian Journal of Non-Ferrous Metals*, 55(1):263-269.

Gibberd, J. 2010. Sustainable Development Criteria for Built Environment Projects in South Africa (CSIR). *Human Settlements Review*, 1(1):34-58.

- Giljum, S., Maus, V., Kuschnig, N., Luckeneder, S., Tost, M., Sonter, L.J., . . . Bebbington, A.J. 2022. A pantropical assessment of deforestation caused by industrial mining. *Sustainability Science*, 119(38), art2118273119. doi:10.1073/pnas.2118273119.
- Godfrey, L. & Oelofse, S. 2017. Historical review of waste management and recycling in South Africa. *Resources*, 6(1), art57. doi:10.3390/resources6040057.
- Goitom, H. 2018. South Africa. *Regulation of Air Pollution*. Washington: The Law Library of Congress. pp. 111-121.
- Gómez-Baggethun, E. & Barton, D.N. 2013. Classifying and valuing ecosystem services for urban planning. *Ecological economics*, 86(1):235-245.
- González, R.R. & Medina, J.S. 2004. Theories, models and urban realities. From New York to Kathmandu. *Dela*, 21(1):69-81.
- Grainger, E., Rishton, L., Godslan, J. & Stanley, D. 2014. Breaking new ground to promote change. *The Lancet Respiratory Medicine*, 2(10), art781. doi:10.1016/S2213-2600(14)70178-X.
- Guan, W.-J., Zheng, X.-Y. & Zhong, N.-S. 2017. Industrial pollutant emission and the major smog in China: from debates to action. *The Lancet Planetary Health*, 1(1), art57. doi:10.1016/S2542-5196(17)30024-4.
- Guendehou, G.S., Koch, M., Hockstad, L., Pipatti, R. & Yamada, M. 2006. *Incineration and open burning of waste*. Geneva, Switzerland.
- Gugger, H. & Kerschbaumer, G. 2013. The Compact City: Sustainable, or Just Sustaining the Economy. *The economic performance of sustainable construction*, 1(1):55-70.
- Gulia, S., Nagendra, S.S., Khare, M. & Khanna, I. 2015. Urban air quality management: A review. *Atmospheric Pollution Research*, 6(2):286-304.
- Gwaze, P. & Mashele, S.H. 2018. South African Air Quality Information System (SAAQIS) mobile application tool: bringing real-time state of air quality to South Africans. *Clean Air Journal*, 28(1):3-4.
- Gwilliam, K., Kojima, M. & Johnson, T. 2004. *Reducing Air Pollution from Urban Transport*. Washington.
- Haase, D., Güneralp, B., Dahiya, B., Bai, X. & Elmqvist, T. 2018. Global Urbanization: Perspectives and Trends. In Elmqvist, T., Bai, X., Frantzeskaki, N., Griffith, C., Maddox, D., Mcphearson, T., Parnell, S., Romero-Lankao, P., Simon, D. & Watkins, M., eds. *The Urban*

Planet Knowledge Towards Sustainable Cities. Cambridge, United Kingdom: Cambridge University Press. pp. 19-44.

Hall, K.B. & Porterfield, G.A. 2001. *Community By Design: New Urbanism for Suburbs and Small Communities*. New York: McCraw Hill.

Hamad, J. & Jasim, S. 2024. Role of green belt in reducing city pollutants. *Journal of Kirkuk University for Agricultural Sciences*, 15(3):221-231.

Hancock, B., Ockleford, E. & Windridge, K. 2001. *An introduction to qualitative research*.: Yorksire: Nihir Research Design Service.

Handy, S. 2005. Smart growth and the transportation-land use connection: What does the research tell us? *International regional science review*, 28(2):146-167.

Handy, S. 2015. *Increasing Highway Capacity Unlikely to Relieve Traffic Congestion*. California, United States of America.

Hankey, S. & Marshall, J.D. 2017. Urban form, air pollution, and health. *Current environmental health reports*, 4(1):491-503.

Haq, G. & Schwela, D. 2012. *Transport and Environment in Sub-Saharan Africa*. Stockholm.

Harizanova-Bartos, H. & Stoyanova, Z. 2018. *Impact of Agriculture on Air Pollution*. Paper presented at the International Conference on Innovations in Science and Education, Prague, Czech Republic. <https://ojs.journals.cz/index.php/CBUIC/issue/view/85> Date of access: 19 Aug. 2019.

Harrison, P. 2001. The genealogy of South Africa's integrated development plan. *Third World Planning Review*, 23(2):175-193.

Harrison, P. 2006. Integrated Development Plans and Third Way Politics. In Pillay, U., Tomlinson, R. & Du Toit, J., eds. *Democracy and Delivery: Urban Policy in South Africa*. Cape Town: HSRC Press. pp. 186-207.

Harrison, P. & Todes, A. 2014. Spatial Considerations in the Development of Urban Policy in South Africa: A Research Paper as Input into the Preparation of the Integrated Urban Development Framework. http://www.cogta.gov.za/cgta_2016/wp.

Haughton, G. 1997. Developing sustainable urban development models. *Cities*, 14(4):189-195.

- Heller, T.C. 1999. Additionality, Transactional Barriers and the Political Economy of Climate Change. In Carraro, C., ed. *International Environmental Agreements on Climate Change*. Berlin, Germany: Springer. pp. 203-224.
- Hersey, S.P., Garland, R.M., Crosbie, E., Shingler, T., Sorooshian, A., Piketh, S., . . . Burger, R. 2015. An overview of regional and local characteristics of aerosols in South Africa using satellite, ground, and modeling data. *Atmospheric Chemistry and Physics*, 15(8):4259-4278.
- Hess, D.B. & Lombardi, P.A. 2004. Policy support for and barriers to transit-oriented development in the inner city: Literature review. *Transportation research record*, 1887(1):26-33.
- Hikichi, L. 2003. *New urbanism and transportation*. University of Wisconsin: Milwaukee. pp. 1-28.
- Ho, Q.B., Vu, H.N.K., Nguyen, T.T., Nguyen, T.T.H. & Nguyen, T.T.T. 2019. A combination of bottom-up and top-down approaches for calculating of air emission for developing countries: A case of ho Chi Minh City, Vietnam. *Air Quality, Atmosphere & Health*, 12(9):1059-1072.
- Holden, E. & Norland, I.T. 2005. Three challenges for the compact city as a sustainable urban form: household consumption of energy and transport in eight residential areas in the greater Oslo region. *Urban studies*, 42(12):2145-2166.
- Hoornweg, D. & Bhada-Tata, P. 2015. *What a Waste: A Global Review of Solid Waste Management*. Washington, United States.
- Horwitz, A. 2017. *Let's Clear the Air: Keys to Successful International Environmental Agreements*. Bryn Mawr: Bryn Mawr College. (Thesis - MA).
- Hudedmani, M., Soppimath, V. & Mathad, S. 2016. *Impacts Of Energy Generation On Environment*. Paper presented at the 3rd International Conference on Science, Technology and Management, New Delhi. <https://conferenceworld.in/Conference.php?cID=20> Date of access: 10 Feb. 2019.
- Hystad, P., Larkin, A., Rangarajan, S., AlHabib, K.F., Avezum, Á., Calik, K.B.T., . . . Du Plessis, J.L. 2020. Associations of outdoor fine particulate air pollution and cardiovascular disease in 157 436 individuals from 21 high-income, middle-income, and low-income countries (PURE): a prospective cohort study. *The Lancet Planetary Health*, 4(6):235-245.
- Idris, M., Darma, T., Koki, F., Suleiman, A., Ali, M., Yarima, S., . . . Aliyu, A. 2019. An analysis of air pollution at some industrial areas of Kano using the AERMOD Model. *Bayero Journal of Pure and Applied Sciences*, 12(1):117-127.

Institute of Air Quality Management (United Kingdom). 2017. *Land-Use Planning & Development Control: Planning for Air Quality*. London, England.

Inturri, G. & Ignaccolo, M. 2013. *Making the connection – energy, transport and urban planning: An integrated approach to improving the energy efficiency of transport systems*. Dublin, Ireland.

Isaksen, E.T. 2020. Have international pollution protocols made a difference? *Journal of Environmental Economics and Management*, 103(1), art102358.
doi:10.1016/j.jeem.2020.102358.

Ito, H. 2019. Strategies in promoting eco-policies: The case of Toyama city, Japan. *Asian Social Science*, 15(5):34-43.

Ivanova, V.R. 2020. The anthropogenic air pollution and human health. *Journal of IMAB–Annual Proceeding Scientific Papers*, 26(2):3057-3062.

Jabareen, Y.R. 2006. Sustainable urban forms: Their typologies, models, and concepts. *Journal of planning education and research*, 26(1):38-52.

Jadhav, R.S., Kiran, P.P. & Motwani, R.H. 2013. *Compact city: Sustainable Concepts* [PowerPoint]. <https://www.slideshare.net/slideshow/compact-city/27281071> Date of access: 25 Jul. 2024.

Jakeni, Y., Maphanga, T., Madonsela, B.S. & Malakane, K.C. 2024. Identification of Illegal Dumping and Community Views in Informal Settlements, Cape Town: South Africa. *Sustainability*, 16(1), art1429. doi:10.3390/su16041429.

Jaoude, G.A., Mumm, O. & Carlow, V.M. 2022. An Overview of Scenario Approaches: A Guide for Urban Design and Planning. *Journal of Planning Literature*, 37(3):467-487.

Jayarathne, T., Stockwell, C.E., Bhawe, P.V., Praveen, P.S., Rathnayake, C.M., Islam, M.R., . . . Goetz, J.D. 2018. Nepal Ambient Monitoring and Source Testing Experiment (NAMaSTE): emissions of particulate matter from wood-and dung-fueled cooking fires, garbage and crop residue burning, brick kilns, and other sources. *Atmospheric Chemistry and Physics*, 18(3):2259-2286.

Jenks, M. & Jones, C. 2010. Issues and Concepts. In Jenks, M. & Jones, C., eds. *Dimensions of the Sustainable City*. New York: Springer. pp. 1-20.

Jia, L., Zhou, X. & Wang, Q. 2023. Effects of agricultural machinery operations on PM_{2.5}, PM₁₀ and TSP in farmland under different tillage patterns. *Agriculture*, 13(5), art930.

doi:10.3390/agriculture13050930.

Jin, M.-Y., Zhang, L.-Y., Peng, Z.-R., He, H.-D., Kumar, P. & Gallagher, J. 2024. The impact of dynamic traffic and wind conditions on green infrastructure performance to improve local air quality. *Science of The Total Environment*, 917(1), art170211.

doi:10.1016/j.scitotenv.2024.170211.

Johnson, T., Guttikunda, S., Wells, G.J., Artaxo, P., Bond, T.C., Russell, A.G., . . . West, J. 2011. *Tools for Improving Air Quality Management: A Review of Top-Down Source Apportionment Techniques and Their Application in Developing Countries*. Washington.

Jones, S. 2012. A tale of two cities: Climate change policies in Vancouver and Melbourne—Barometers of cooperative federalism? *International Journal of Urban and Regional Research*, 36(6):1242-1267.

Joscelyne, K. 2015. *The nature, scope and purpose of spatial planning in South Africa: towards a more coherent legal framework under SPLUMA*. Cape Town: University of Cape Town. (Thesis - MA).

Kahraman, M.M. & Erkayaoglu, M. 2021. A data-driven approach to control fugitive dust in mine operations. *Mining, Metallurgy & Exploration*, 38(1):549-558.

Kania, J. & Kramer, M. 2011. Collective Impact. *Stanford Social Innovation Review*, 9(1):36-41.

Kapwata, T., Language, B., Piketh, S. & Wright, C.Y. 2018. Variation of indoor particulate matter concentrations and association with indoor/outdoor temperature: a case study in rural Limpopo, South Africa. *Atmosphere*, 9(4), art124. doi:10.3390/atmos9040124.

Karagulian, F., Belis, C.A., Dora, C.F.C., Prüss-Ustün, A.M., Bonjour, S., Adair-Rohani, H., . . . Amann, M. 2015. Contributions to cities' ambient particulate matter (PM): A systematic review of local source contributions at global level. *Atmospheric Environment*, 120(1):475-483.

Keen, S. 2016. The health benefits of attaining and strengthening air quality standards in Cape Town. *Clean Air Journal*, 26(1):22-27

Keita, S., Liousse, C., Assamoi, E.-M., Doumbia, T., N'Datchoh, E.T., Gnamien, S., . . . Yoboué, V. 2021. African anthropogenic emissions inventory for gases and particles from 1990 to 2015. *Earth System Science Data*, 13(1):3691-3705.

Kekana, H., Ruhiiga, T., Ndou, N. & Palamuleni, L. 2023. Environmental justice in South Africa: the dilemma of informal settlement residents. *GeoJournal*, 88(4):3709-3725.

- Kerr, A. 2017. Tax (i) ing the poor? Commuting costs in South African cities. *South African Journal of Economics*, 85(3):321-340.
- Kgabi, N. 2012. Air quality policy and scientific research in Southern Africa. *WIT Transactions on Ecology and the Environment*, 157(1):151-163.
- Khalaf, I. & Altmimi, A. 2021. Testing the Relationship Between Air Temperature and Relative Humidity by Using T-Test for Some Selected Stations in Iraq. *Al-Mustansiriyah Journal of Science*, 32(2):1-10.
- Khumalo, N.N.Y. 2015. *A Review of the Alignment Between the Integrated Development Plan and the Performance Management System of the Capricorn District Municipality*. Stellenbosch: Stellenbosch University. (Thesis - MA).
- Kihato, M. 2012. *Integrating planning and environmental issues through the law in South Africa: learning from international experience*. Pretoria: University of South Africa. (Thesis - MA).
- Kim, Y.P., Lee, G., Emmons, L. & Park, R. 2018. Megacity Air Pollution Studies. *Aerosol and Air Quality Research*, 18(1), art9. doi:10.4209/aaqr.2018.09.MAPS.
- Kirchhofer, M. 1982. The planning of Sasolburg and Secunda-achievements and prospects. *Town and Regional Planning*, 1(1):1-28.
- Kjellstrom, T., Lodh, M., McMichael, T., Ranmuthugala, G., Shrestha, R. & Kingsland, S. 2006. Air and Water Pollution: Burden and Strategies for Control. In Jamison, D.T., Breman, J.G., Measham, A.R., Alleyne, G., Claeson, M., Evans, D.B., Jha, P., Mills, A. & Musgrove, P., eds. *Disease Control Priorities in Developing Countries*. 2nd ed. New York: Oxford University Press. pp. 817-832.
- Klausbruckner, C., Annegarn, H., Henneman, L.R. & Rafaj, P. 2016. A policy review of synergies and trade-offs in South African climate change mitigation and air pollution control strategies. *Environmental Science & Policy*, 57(1):70-78.
- Knaap, G. & Talen, E. 2005. New urbanism and smart growth: A few words from the academy. *International Regional Science Review*, 28(2):107-118.
- Koning, J. & van Dijk, T. 2024. Rehabilitating utopias: the importance of imagination to confronting our spatial challenges. *Planning Practice & Research*, 39(1):136-155.
- Kopplitz, S.N., Jacob, D.J., Sulprizio, M.P., Myllyvirta, L. & Reid, C. 2017. Burden of Disease from Rising Coal-Fired Power Plant Emissions in Southeast Asia. *Environment Science &*

Technology, 51(3):1467-1476.

Kota, Z. 2016. *Realising the right to a healthy environment - An analysis of the policy efforts, budgeting and enjoyment of the right to a healthy environment in South Africa*. Johannesburg, South Africa.

Krause, M. & Smith, S. 2006. *Final–Methodology to Calculate Particulate Matter (PM) 2.5 and PM 2.5 Significance Thresholds*. California, United State of America.

Kumar, D. & Rajput, N.S. 2022. Air Pollution in mining Industries has very adverse effects on Human Health, Flora, and Fauna, and proper assessment is needed around the mining areas. *International Journal of Engineering Technology and Management Sciences*, 6(5):734-741.

Kura, B., Verma, S., Ajdari, E. & Iyer, A. 2013. Growing public health concerns from poor urban air quality: strategies for sustainable urban living. *Computational Water, Energy, and Environmental Engineering*, 1(2):1-9.

Kuşkapan, E. & Çodur, M.Y. 2022. Promoting Pedestrian Transportation to Reducing Air Pollution from Urban Transport. *Journal of Environmental & Earth Sciences*, 4(1):47-503.

L'Etang, J. 2013. *Spatial design for the Lansdowne road corridor*. Cape Town: University of Cape Town. (Thesis - MA).

Lake, E. 2020. Influence of Temperature and Relative Humidity on Air Pollution in Addis Ababa, Ethiopia. *Journal of Environmental & Earth Sciences*, 2(2):19-25.

Landrigan, P.J., Sly, J.L., Ruchirawat, M., Silva, E.R., Huo, X., Diaz-Barriga, F., . . . Asante, K.A. 2016. Health consequences of environmental exposures: changing global patterns of exposure and disease. *Annals of global health*, 82(1):10-19.

Langerman, K.E., Garland, R.M., Feig, G., Mpanza, M. & Wernecke, B. 2023. South Africa's electricity disaster is an air quality disaster, too. *Clean Air Journal*, 33(1):1-2.

Langner, C. & Klemm, O. 2011. A comparison of model performance between AERMOD and AUSTAL2000. *Journal of the Air & Waste Management Association*, 61(6):640-646.

Language, B. 2020. *Characterisation of respirable indoor particulate matter in South African low-income settlements*. Potchefstroom: North-West University. (Thesis - PhD).

Laubscher, N., Hoffman, L., Drewes, E. & Nysschen, J. 2016. *SPLUMA: A Practical Guide*. Johannesburg: Lexis Nexis.

Lavhelani, F.G. 2021. *Quantifying the use of firewood as a source of energy in North West Province: A case study for Matlwang Potchefstroom*: North-West University. (Thesis - MA).

Lehmann, S. 2008. Sustainability on the urban scale: Green urbanism—New models for urban growth and neighbourhoods. In Droege, P., ed. *Urban energy transition*. Cambridge: Elsevier. pp. 409-430.

Lehmann, S. 2011. What is Green Urbanism? Holistic Principles to Transform Cities for Sustainability. In Blanco, J. & Kheradmand, H., eds. *Climate Change - Research and Technology for Adaptation and Mitigation*. London: IntechOpen. pp. 243-266.

Leigh, N.G. & Hoelzel, N.Z. 2012. Smart growth's blind side: Sustainable cities need productive urban industrial land. *Journal of the American Planning Association*, 78(1):87-103.

Lekunze, J.N. & Lekunze, A.R. 2017. Linking energy efficiency legislation and the agricultural sector in South Africa. *TD: The Journal for Transdisciplinary Research in Southern Africa*, 13(1):1-10.

Lelieveld, J., Evans, J.S., Fnais, M., Giannadaki, D. & Pozzer, A. 2015. The contribution of outdoor air pollution sources to premature mortality on a global scale. *Nature*, 525(7569):367-371.

Lenka, S., Rajendiran, S., Coumar, M.V., Dotaniya, M. & Saha, J. 2016. *Impacts of fertilizers use on environmental quality*. Paper presented at the National seminar on environmental concern for fertilizer use in future, Bidhan Chandra KrishiViswavidyalaya, Kalyani.

Lewis, R. & Knaap, G.J. 2012. Targeting Spending for Land Conservation: An Evaluation of Maryland's Rural Legacy Program. *Journal of the American Planning Association*, 78(1):34-52.

Li, B., Wang, J., Wu, S., Jia, Z., Li, Y., Wang, T., . . . Zhou, S. 2019. New method for improving spatial allocation accuracy of industrial energy consumption and implications for polycyclic aromatic hydrocarbon emissions in China. *Environmental science & technology*, 53(8):4326-4334.

Liebenberg-Enslin, H. 2014. *Wind erosion modelling system parameters to determine a practical approach for wind erosion assessments*. City of Johannesburg: University of Johannesburg. (Thesis - PhD).

Liebenberg-Enslin, H. 2024. Air quality evolution in South Africa over the past 20 years: A journey from a consultant's viewpoint. *Clean Air Journal*, 34(2):1-3.

Lim, S.S., Vos, T., Flaxman, A.D., Danaei, G., Shibuya, K., Adair-Rohani, H., . . . Andrews, K.G.

2012. A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. *The lancet*, 380(9859):2224-2260.

Lincoln, Y.S. & Guba, E.G. 1985. *Naturalistic inquiry*. Newbury Park: SAGE Publications Inc.

Lindau, L.A., Hidalgo, D. & Facchini, D. 2010. Bus Rapid Transit in Curitiba, Brazil: A Look at the Outcome after 35 Years of Bus-Oriented Development. *Transportation Research Record*, 21(93):17-27.

Lindeque, L.F., Burger, R.P. & Piketh, S.J. 2021. The health and economic benefits of reduced residential solid fuel burning on the south African Highveld. *Atmosphere*, 12(11), art1405. doi:10.3390/atmos12111405.

Liu, Y., Lee, K., Perez-Padilla, R., Hudson, N. & Mannino, D. 2008. Outdoor and indoor air pollution and COPD-related diseases in high-and low-income countries. *The international journal of tuberculosis and lung disease*, 12(2):115-127.

Liu, Y., Wu, J., Yu, D. & Ma, Q. 2018. The relationship between urban form and air pollution depends on seasonality and city size. *Environmental Science and Pollution Research*, 25(1):15554-15567.

Liu, Z., Shen, L., Yan, C., Du, J., Li, Y. & Zhao, H. 2020. Analysis of the Influence of Precipitation and Wind on PM_{2.5} and PM₁₀ in the Atmosphere. *Advances in Meteorology*, 2020(1), art5039613. doi:10.1155/2020/5039613.

Lobejko, S., Stankowska, A. & Zabielski, M. 2015. *Planning and Management in Eco-cities*. CeDeWu, Poland.

Local Government Transition Act 61 of 1995.

Locke, K., Feldman, M. & Golden-Biddle, K. 2022. Coding practices and iterativity: Beyond templates for analyzing qualitative data. *Organizational research methods*, 25(2):262-284.

Løkke, A. & Dissing-Sørensen, P. 2014. Theory Testing Using Case Studies. *Journal of Business Research Methods*, 12(1):66-74.

López-Aparicio, S., Guerreiro, C., Viana, M., Reche, C. & Querol, X. 2013. *Contribution of agriculture to Air Quality problems in cities and in rural areas in Europe*. Copenhagen, Denmark.

Lourens, A.S.M. 2012. *Air quality in the Johannesburg-Pretoria megacity, its regional influence*

and identification of parameters that could mitigate pollution. Potchefstroom: North-West University. (Thesis - MA).

Lucas, K. 2011. Making the connections between transport disadvantage and the social exclusion of low income populations in the Tshwane Region of South Africa. *Journal of transport geography*, 19(6):1320-1334.

Maamoun, N. 2017. *International Environmental Agreements: Empirical Evidence of a Hidden Success*. Paper presented at the 10th Annual Conference of the Political Economy of International Organizations, University of Bern, Switzerland. https://www.peio.me/wp-content/uploads/2018/01/PEIO11_paper_33.pdf Date of access: 4 Apr. 2021.

Mabin, A. 2002. Local government in the emerging national planning context. In Parnell, S., Pieterse, E., Swilling, M. & Wooldridge, D., eds. *Democratising local government: The South African experience*. Cape Town: UCT Press. pp. 40-56.

Madonsela, B.S., Maphanga, T., Malakane, K.C., Phungela, T.T., Gqomfa, B., Grangxabe, S., . . . Karmaoui, A. 2024. The Influence of Outdoor Exposure Concentrations on Indoor Air Quality in Rudimentary Designed Household Structures: Mpumalanga Province, South Africa. *Pollution*, 10(1):466-480.

Madumo, O. 2015. Developmental local government challenges and progress in South Africa. *Administratio Publica*, 23(2):153-166.

Maennel, A. & Kim, H.-G. 2018. Comparison of greenhouse gas reduction potential through renewable energy transition in South Korea and Germany. *Energies*, 11(1), art206. doi:10.3390/en11010206.

Makonese, T., Masekameni, D.M., Annegarn, H.J. & Forbes, P.B. 2015. Influence of fire-ignition methods and stove ventilation rates on gaseous and particle emissions from residential coal braziers. *Journal of Energy in Southern Africa*, 25(4):16-28.

Manisalidis, I., Stavropoulou, E., Stavropoulos, A. & Bezirtzoglou, E. 2020. Environmental and health impacts of air pollution: a review. *Frontiers in public health*, 8(1), art14. doi:10.3389/fpubh.2020.00014.

Mansfield, T.J., Rodriguez, D.A., Huegy, J. & MacDonald Gibson, J. 2015. The effects of urban form on ambient air pollution and public health risk: A case study in Raleigh, North Carolina. *Risk Analysis*, 35(5):901-918.

Manyatsha, K., Piketh, S. & Edokpayi, J. 2022. *The Determinants of Households Energy Fuel*

Choice in Limpopo Province the Case Study of Boshega Village. Paper presented at the National Association for Clean Air, Kempton Park, South Africa.

Manzueta, R., Kumar, P., Ariño, A.H. & Martín-Gómez, C. 2024. Strategies to reduce air pollution emissions from urban residential buildings. *Science of The Total Environment*, 951(1), art175809. doi:10.1016/j.scitotenv.2024.175809.

Marquez, L.O. & Smith, N.C. 1999. A framework for linking urban form and air quality. *Environmental Modelling & Software*, 14(6):541-548.

Marshall, J.D. 2008. Reducing urban sprawl could play an important role on addressing climate change. *Environmental Science & Technology*, 1(1):3133-3137.

Marshall, J.D., Brauer, M. & Frank, L.D. 2009. Healthy neighborhoods: walkability and air pollution. *Environmental health perspectives*, 117(11):1752-1759.

Martín, F., Janssen, S., Rodrigues, V., Sousa, J., Santiago, J.L., Rivas, E., . . . Villani, M. 2024. Using dispersion models at microscale to assess long-term air pollution in urban hot spots: A FAIRMODE joint intercomparison exercise for a case study in Antwerp. *Science of the Total Environment*, 925(1), art171761. doi:10.1016/j.scitotenv.2024.171761.

Marutlulle, N.K. 2022. Critical analysis of the role played by apartheid in the present housing delivery challenges encountered in South Africa. *Africa's Public Service Delivery and Performance Review*, 10(1), art373.

Mashiri, M., Njenga, P., Njenga, C., Chakwizira, J. & Friedrich, M. 2017. Towards a Framework for Measuring Spatial Planning Outcomes in South Africa. *Sociology and Anthropology*, 5(2):146-168.

Matooane, M., John, J., Oosthuizen, R. & Binedell, M. 2004. *Vulnerability of South African Communities to Air Pollution*. Paper presented at the 8th World Congress on Environmental Health, Durban, South Africa, 22-27 February.

Matsumoto, T. 2011. *Compact City Policies: Comparative Assessment*. Paper presented at the 47th ISOCARP Congress, Wuhan, China, 24-28 Oct.

McCarty, J. & Kaza, N. 2015. Urban form and air quality in the United States. *Landscape and Urban Planning*, 139(1):168-179.

Medearis, D. & Daseking, W. 2012. Freiburg, Germany: Germany's Eco-Capital. In Beatley, T., ed. *Green Cities of Europe: Global Lessons on Green Urbanism*. Washington: Island Press. pp. 65-82.

Menikpura, N. & Sang-Arun, J. 2013. *Estimation Tool for Greenhouse Gas (GHG) Emissions from Municipal Solid Waste (MSW) Management in a Life Cycle Perspective*. Kamiyamaguchi, Japan.

Metsimaholo Local Municipality. 2016. *Metsimaholo Local Municipality Spatial Development Framework: Sasolburg*.

Michigan Public (United States of America). 2017. Troy project aims to create walkable downtown amidst urban sprawl. <https://www.interlochenpublicradio.org/michigan-business-economy/2017-08-10/troy-project-aims-to-create-walkable-downtown-amidst-urban-sprawl>
Date of access: 26 June 2024.

Mishra, N. & Das, N. 2017. Coal Mining and Local Environment: A Study in Talcher Coalfield of India. *Air, Soil and Water Research*, 10(1), art8913. doi:10.1177/1178622117728913.

Mkhonto, P.D.M. 2013. *Atmospheric dispersion modelling study of a township within a declared national priority area*. City of Johannesburg: University of Johannesburg. (Thesis - MA).

Mngoma, W., Pillay, P. & Reddy, P.S. 2011. Environmental Governance at the Local Government Sphere in South Africa. *African Journal of Public Affairs*, 4(2):105-118.

Mohlala, K. 2020. *A critical evaluation of local government air quality management: The Gauteng experience*. Potchefstroom: North-West University. (Thesis - MA).

Mokoele, J. & Sebola, M. 2018. Unplanned urbanisation in South African cities: The emergence of urban environmental problems. *The Business & Management Review*, 9(3):574-584.

Moletsane, S.D. 2023. *Ambient and household exposure to particulate matter in a low-income settlement*. Potchefstroom: North-West University. (Thesis - MA).

Moletsane, S.D., Lindeque, F., Nkosi, N.C., Adesina, J.A., Burger, R.P., Mkhathshwa, G., . . . Piketh, S.J. 2021. Intra-urban variability of PM_{2.5} in a dense, low-income settlement on the South African Highveld. *Clean Air Journal*, 31(1):1-9.

Moorcroft, S. & Barrowcliffe, R. 2015. *Land-Use Planning & Development Control: Planning For Air Quality*. London, England.

Morakinyo, O.M. & Mokgobu, M.I. 2022. Indoor household exposures and associated morbidity and mortality outcomes in children and adults in South Africa. *International journal of environmental research and public health*, 19(1), art9471. doi:10.3390/ijerph19159471.

- Morakinyo, O.M., Mukhola, M.S. & Mokgobu, M.I. 2020. Ambient gaseous pollutants in an urban area in South Africa: Levels and potential human health risk. *Atmosphere*, 11(1), art751. doi:10.3390/atmos11070751.
- Morapedi, K. & Makhari, M. 2017. *National transport master plan (NATMAP) 2050*. Paper presented at the 36th Southern African Transport Conference, Pretoria, South Africa.
- Moreoane, L. 2021. *Evaluating the quality of Air Quality Management Plans (AQMP) in South Africa – the case of the Vaal Triangle*. Potchefstroom: North-West University. (Thesis - MA).
- Morosele, I.P. & Langerman, K.E. 2020. The impacts of commissioning coal-fired power stations on air quality in South Africa: insights from ambient monitoring stations. *Clean Air Journal*, 30(2):1-11.
- Mpanza, M., Adam, E. & Moolla, R. 2020. Dust deposition impacts at a liquidated gold mine village: Gauteng province in South Africa. *International Journal of Environmental Research and Public Health*, 17(1), art4929. doi:10.3390/ijerph17144929.
- Mukwevho, P., Retief, F. & Burger, R. 2022. Conceptualising air quality management instruments in South Africa. *Clean Air Journal*, 32(2):1-15.
- Mukwevho, P., Retief, F., Burger, R. & Moolna, A. 2024. Identifying critical assumptions and risks in air quality management planning using Theory of Change approach. *Clean Air Journal*, 34(1):1-19.
- Municipal Systems Act 32 of 2000.*
- Murzin, M. & Gorlenko, N. 2021. *Analyzing effects of dust from mining enterprises on the environment*. Paper presented at the V International Scientific Conference: AGRITECH-IV-2020: Agribusiness, Environmental Engineering and Biotechnologies, Krasnoyarsk. <https://iopscience.iop.org/year/1755-1315/Y2021> Date of access: 22 Aug. 2019.
- Musakwa, W. & Van Niekerk, A. 2018. Monitoring urban sprawl and sustainable urban development using the Moran Index: A case study of Stellenbosch, South Africa. *International Journal of Applied Geospatial Research*, 5(3):561-581.
- Musvoto, G., Lincoln, G. & Hansmann, R. 2016. The Role of Spatial Development Frameworks in Transformation of the eThekweni Municipality, KwaZulu-Natal, South Africa: Reflecting on 20 Years of Planning. *Urban Forum*, 27(1), art210. doi:10.1007/s12132-015-9272-6.
- Muyemeki, L. 2021. *An integrated systems approach towards air quality management in the Vaal Triangle Priority Area*. Potchefstroom: North-West University. (Thesis - PhD).

- Muyemeki, L., Burger, R., Piketh, S.J., Beukes, J.P. & Van Zyl, P.G. 2021. Source apportionment of ambient PM₁₀₋₂₅ and PM_{2.5} for the Vaal Triangle, South Africa. *South African Journal of Science*, 117(5/6), art8617. doi:10.17159/sajs.2021/8617.
- Naidoo, S., Piketh, S.J. & Curtis, C. 2014. Quantification of emissions generated from domestic burning activities from townships in Johannesburg. *Clean Air Journal*, 24(1):34-41.
- Naiker, Y. 2007. *An assessment of Local Government Capacity in KwaZulu-Natal to implement the National Environment Management: Air Quality Act*. Durban: University of KwaZulu-Natal. (Thesis - MA).
- Naiker, Y., Diab, R.D., Zunckel, M. & Hayes, E.T. 2012. Introduction of local Air Quality Management in South Africa: overview and challenges. *Environmental Science & Policy*, 17(1):62-71.
- Napier, M. 2007. *Informal settlement integration, the environment and sustainable livelihoods in sub-Saharan Africa*. Pretoria, South Africa.
- Nassar, U. 2013. Principles of green urbanism: The absent value in Cairo, Egypt. *International Journal of Social Science and Humanity*, 3(4):339-343.
- National Academies of Sciences Engineering and Medicine (United States of America). 2003. *Bus Rapid Transit: Case Studies in Bus Rapid Transit*. Washington, United States of America.
- National Academies of Sciences Engineering and Medicine (United States of America). 2004. *Transit-Oriented Development in the United States: Experiences, Challenges, and Prospects*. Washington, United States of America.
- National Environment Management Act 107 of 1998*.
- National Environment Management: Air Quality Act 39 of 2004*.
- National Planning Commission (South Africa). 2011. *National Development Plan*. Pretoria, South Africa.
- Ndlovu, N. 2006. *Challenges and Problems Encountered in the Implementation of Integrated Development Plans in KwaZulu-Natal: A Case Study of Kwaximba Local Municipality*. Westville: University of KwaZulu-Natal. (Thesis - MA).
- Ndlovu, N., Little, K., Titshall, L. & Rolando, C. 2019. Site preparation and vegetation management impacts on *Pinus patula* growth and rotation end productivity in South Africa. *Australian Forestry*, 82(2):107-115.

- Nel, V. 2016. SPLUMA, Zoning and Effective Land Use Management in South Africa. *Urban Forum*, 27(1), art5. doi:10.1007/s12132-015-9265-5.
- Neuman, M. 2005. The compact city fallacy. *Journal of planning education and research*, 25(1):11-26.
- Newman, P. & Kenworthy, J. 2015. *The End of Automobile Dependence: How Cities are Moving Beyond Car-Based Planning*. New York: Island Press.
- Nguyen, G.T.H., La, L.T., Hoang-Cong, H. & Le, A.H. 2024. An exploration of meteorological effects on PM_{2.5} air quality in several provinces and cities in Vietnam. *Journal of Environmental Sciences*, 145(1):139-151.
- Nkosi, N.C. 2018. *Quantifying particulate emissions from domestic burning in kwaDela Township, Mpumalanga*. Potchefstroom: North-West University (Thesis - MA).
- Nkosi, N.C., Burger, R.P., Pauw, C. & Piketh, S.J. 2023. The impact of vehicle parameters on non-exhaust traffic road PM₁₀ emissions: A case in South African low-income settlement. *Clean Air Journal*, 33(2):114-118.
- Nkosi, V., Wichmann, J. & Voyi, K. 2017. Indoor and outdoor PM₁₀ levels at schools located near mine dumps in Gauteng and North West Provinces, South Africa. *BMC public health*, 17(1), art42. doi:10.1186/s12889-016-3950-8.
- Noah, M. 2002. *An investigation into the environmental impact of the taxi industry in Butterworth*. Paper presented at the 21st Annual South African Transport Conference: 'Towards Building Capacity and Accelerating Delivery', Pretoria.
<https://repository.up.ac.za/handle/2263/6015> Date of access: 20 Jul. 2019.
- Ntiwane, B. & Coetzee, J. 2018. Environmental justice in the context of planning. *Town and Regional Planning*, 72(1):84-98.
- Ntiwane, B.C. 2019. *Reshaping spatial planning paradigm in an attempt to achieve environmental justice in South Africa*. Pretoria: University of South Africa. (Thesis - PhD).
- Ntlabezo, E.M. 2013. *Integration of the integrated development plan and performance management processes considered*. Potchefstroom: North-West University. (Thesis - MA).
- O'Brien, E. & Gowan, R. 2012. *What Makes International Agreements Work: Defining Factors for Success*. New York, United States of America.
- O'Reilly, D., White, M., Langenheim, N. & Alambeigi, P. 2024. The Governance of Traffic

Noise Impacting Pedestrian Amenities in Melbourne Australia: A Critical Policy Review. *International Journal of Environmental Research and Public Health*, 21(8), art1080. doi:10.3390/ijerph21081080.

Oguntoke, O., Ojelede, M.E. & Annegarn, H.J. 2013. Frequency of mine dust episodes and the influence of meteorological parameters on the Witwatersrand area, South Africa. *International Journal of Atmospheric Sciences*, 2013(1), art128463. doi:10.1155/2013/128463.

Omotoso, A.B. & Omotayo, A.O. 2024. The interplay between agriculture, greenhouse gases, and climate change in Sub-Saharan Africa. *Regional Environmental Change*, 24(1), art1. doi:10.1007/s10113-023-02159-3.

Onghena, P. 2005. Single-Case Designs. In Everitt, B.S. & Howell, D.C., eds. *Encyclopedia of Statistics in Behavioral Science*. Chichester: John Wiley & Sons. pp. 1850-1854.

Organisation for Economic Co-operation and Development. 2018. *Metropolitan areas*. Château de la Muette, Paris.

Ozcan, N.S. & Cubukcu, K.M. 2016. Examination of the Relationship between Urban Air Pollution and Urban Planning Decisions in Cigli Case, Izmir (Turkey). *Environment-Behaviour Proceedings Journal*, 1(2):178-187.

Padma, S., Velmurugan, S., Kalsi, N., Ravinder, K., Erramapalli, M. & Kannan, S. 2020. Traffic impact assessment for sustainable development in urban areas. *Transportation Research Procedia*, 48(1):3173-3187.

Palamuleni, L.G. & Tshabalala, F.E. 2023. A residential class-based comparative analysis of the intensity of illegal waste dumping in Gauteng, South Africa. *Present Environment & Sustainable Development*, 17(1):203-222.

Paracchini, M.L., Pacini, C., Jones, M.L.M. & Pérez-Soba, M. 2011. An aggregation framework to link indicators associated with multifunctional land use to the stakeholder evaluation of policy options. *Ecological indicators*, 11(1):71-80.

Park, R.E. 1915. The City: Suggestions for the Investigation of Human Behavior in the City Environment. *American Journal of Sociology*, 20(5):577-612.

Patel, H., Talbot, N., Salmond, J., Dirks, K., Xie, S. & Davy, P. 2020. Implications for air quality management of changes in air quality during lockdown in Auckland (New Zealand) in response to the 2020 SARS-CoV-2 epidemic. *Science of the Total Environment*, 746(1), art141129. doi:10.1016/j.scitotenv.2020.141129.

- Patiño, W.R., Vlček, O., Bauerová, P., Belda, M., Bureš, M., Eben, K., . . . Karel, J. 2024. On the suitability of dispersion models of varying degree of complexity for air quality assessment and urban planning. *Building and Environment*, 264(1), art111892. doi:10.1016/j.buildenv.2024.111892.
- Pauw, C. 2020. Some observations about air quality in dense, low-income settlements. *Clean Air Journal*, 30(1):1-2.
- Petrie, B., Wolpe, P., Reddy, Y., Adriázola, P., Gerhard, M., Landesman, T., . . . Marie, A. 2018. *Multi-Level Climate Governance in South Africa: Catalysing Finance for Local Climate Action*. Cape Town, South Africa.
- Pieterse, E. 2002. From divided to integrated city? *Urban Forum*, 13(1):3-37.
- Pieterse, E. 2004. Recasting urban integration and fragmentation in post-apartheid South Africa. *Development Update*, 5(1):81-104.
- Pont, M.B., Haupt, P., Berg, P., Alstäde, V. & Heyman, A. 2021. Systematic review and comparison of densification effects and planning motivations. *Buildings and Cities*, 2(1):378-401.
- Pretorius, I., Piketh, S., Burger, R. & Neomagus, H. 2015. A perspective on South African coal fired power station emissions. *Journal of Energy in Southern Africa*, 26(3):27-40.
- Prieto-Rodriguez, J., Perez-Villadoniga, M.J., Salas, R. & Russo, A. 2022. Impact of London toxicity charge and ultra low emission zone on NO₂. *Transport Policy*, 129(1):237-247.
- Public Affairs Research Institute. 2018. *The Challenge of Prioritisation and Alignment in Public Sector Planning and Implementation*. Witwatersrand, South Africa.
- Pulumo, N. 2015. *Investigating the Level of Alignment Between the Municipal Capital Budgets and The Spatial Development Frameworks in the Ehlanzeni District Municipality*. Stellenbosch: Stellenbosch University. (Thesis - MA).
- Rabaji, O. 2019. *Waste dumping in Sharpeville (Emfuleni Municipality): An investigation of the characteristics and the potential impacts on air quality*. Potchefstroom: North West University. (Thesis - MA).
- Rega, C. & Bonifazi, A. 2014. Strategic Environmental Assessment and spatial planning in Italy: sustainability, integration and democracy. *Journal of Environmental Planning and Management*, 57(9):1333-1358.

Retief, F., Bond, A., Pope, J., Morrison-Saunders, A. & King, N. 2016. Global megatrends and their implications for environmental assessment practice. *Environmental Impact Assessment Review*, 61(1):52-60.

Retief, F. & Cilliers, D. 2015. Land use management and planning. In Du Plessis, A., ed. *South African Environmental Law: The Governing Function of Local Government*. Cape Town: Juta. pp. 563-586.

Retief, F.P., Steenkamp, C. & Alberts, R.C. 2021. Strategic environmental assessment in South Africa: the road not taken. In González, A. & Fische, T.B., eds. *Handbook on strategic environmental assessment*. Cheltenham, United Kingdom: Edward Elgar Publishing. pp. 349-362.

Rezasoltani, S., Champagne, P. & Mann, V. 2024? Biostabilization of gold mine tailings for mitigating fugitive dust emission using cyanobacteria. *Social Science Research Network (Provisionally accepted)*. doi:10.2139/ssrn.3982879.

Ridzuan, N., Ujang, U., Azri, S. & Choon, T.L. 2020. *Visualising urban air quality using AERMOD, CALPUFF and CFD models: A critical review*. Paper presented at the 5th International Conference on Smart City Applications, Virtual Safranbolu, Turkey 7-8 October.

Ringquist, E.J. & Kostadinova, T. 2005. Assessing the effectiveness of international environmental agreements: The case of the 1985 Helsinki Protocol. *American Journal of Political Science*, 49(1):86-102.

Roberts, D. 2016. A global roadmap for climate change action: From COP17 in Durban to COP21 in Paris. *South African Journal of Science*, 112(5/6), art0158. doi:10.17159/sajs.2016/a0158.

Roberts, G., Wooster, M. & Lagoudakis, E. 2009. Annual and diurnal african biomass burning temporal dynamics. *Biogeosciences*, 6(5):849-866.

Robinson, S. A., Douma, A., Poore, T. & Singh, K. 2023. The role of colonial pasts in shaping climate futures: Adaptive capacity in Georgetown, Guyana. *Habitat International*, 139(1), art102902. doi:10.1016/j.habitatint.2023.102902.

Rocha, M. & Falduto, C. 2019. *Key questions guiding the process of setting up long-term low-emissions development strategies*. Paris, France.

Rodseth, C., Notten, P. & Von Blottnitz, H. 2020. A revised approach for estimating informally disposed domestic waste in rural versus urban South Africa and implications for waste

management. *South African Journal of Science*, 116(1-2), doi:10.17159/sajs.2020/5635.

Rogalsky, D.K., Mendola, P., Metts, T.A. & Martin, W.J. 2014. Estimating the number of low-income americans exposed to household air pollution from burning solid fuels. *Environmental health perspectives*, 122(8):806-810.

Rogelj, J., Chen, C., Nabel, J., Macey, K., Hare, W., Schaeffer, M., . . . Meinshausen, M. 2010. Analysis of the Copenhagen Accord pledges and its global climatic impacts—a snapshot of dissonant ambitions. *Environmental research letters*, 5(1), art034013. doi:10.1088/1748-9326/5/3/034013.

Romanova, E. 2018. *Increase in Population Density and Aggravation of Social and Psychological Problems in Areas with High-Rise Construction*. Paper presented at the E3S Web of Conferences. https://www.e3s-conferences.org/articles/e3sconf/pdf/2018/08/e3sconf_hrc2018_03061.pdf Date of access: 2 Mar. 2025.

Romero-Ania, A., De Vicente Oliva, M.A. & Rivero Gutiérrez, L. 2021. Economic evaluation of the urban road public transport system efficiency based on data envelopment analysis. *Applied Sciences*, 12(1), art57. Doi:10.3390/app12010057.

Romieu, I. & Hernandez-Avila, M. 2003. Air Pollution and Health in Developing Countries:A Review of Epidemiological Evidence. In Mcgranahan, G. & Murray, F., eds. *Air Pollution and Health in Rapidly Developing Countries*. London, England: Earthscan Publications Ltd. pp. 49-62.

Rosenzweig, C. & Neofotis, P. 2013. Detection and attribution of anthropogenic climate change impacts. *Wiley interdisciplinary reviews: climate change*, 4(2):121-150.

Ruhiiga, T. 2014. Urbanisation in South Africa: a critical review of policy, planning and practice. *African population studies*, 28(1):610-622.

Rukema, J. 2022. Public Infrastructure and Its Impacts on Social Inclusion and Foster Economic Growth in South Africa. *Anthropology and Ethnology Open Access Journal*, 5(1), art166. doi: 10.23880/aeoaj-16000166.

Salat, S. & Ollivier, G. 2017. *Transforming the Urban Space through Transit-Oriented Development: The 3V Approach*. Washington, United States of America.

Salmond, J., Sabel, C.E. & Vardoulakis, S. 2018. Towards the Integrated Study of Urban Climate, Air Pollution, and Public Health. *Climate*, 6(1), art14. doi:10.3390/cli6010014.

Salo, I. 2014. *More than an apartheid loss: recovering and remembering Fairview, a 'lost' Group Areas history*. Cape Town: University of Cape Town. (Thesis - MA).

Samskara Studio. 2024. *Green Urban Planning: How Sustainable Design is Shaping Modern Cities*. <https://www.linkedin.com/pulse/green-urban-planning-how-sustainable-design-shaping-modern-0owze/?trackingId=nObyHcmbS2CCav6dU1IAmg%3D%3D> Date of access: 3 May 2024.

Sandler, T. 2017. Environmental cooperation: contrasting international environmental agreements. *Oxford Economic Papers*, 69(2):345-364.

Säynäjoki, E.S., Heinonen, J. & Junnila, S. 2014. The Power of Urban Planning on Environmental Sustainability: a focus group study in Finland. *Sustainability*, 6(1):6622-6643.

Schensul, D. & Heller, P. 2011. Legacies, change and transformation in the post-apartheid city: towards an urban sociological cartography. *International Journal of Urban and Regional Research*, 35(1):78-109.

Schlotfeldt, C.J. 1995. *The "Red Book": Background, purpose and way forward. Paper presented at Red Book Workshops*. Pretoria, South Africa.

Schoeman, C. 2004. The alignment between integrated transport plans and the preparation of integrated development plans in South Africa. *WIT Press*, 16(1):93-102.

Schoeman, I. 2017. The National Land Transport Strategic Framework for South Africa (2015) and related transportation instruments: The application of transportation modelling for improved decision making? *International Journal of Transport Development and Integration*, 1(2):277-289.

Schweitzer, L. & Zhou, J. 2010. Neighborhood air quality, respiratory health, and vulnerable populations in compact and sprawled regions. *Journal of the American Planning Association*, 76(3):363-371.

Scorgie, Y. 2012. *Urban Air Quality Management and Planning in South Africa*. Johannesburg: University of Johannesburg. (Thesis - PhD).

Scott, G.M. 2010. *Development of a Methodology for the Delineation of Air Quality Management Areas in South Africa*. Durban: University of KwaZulu-Natal. (Thesis - PhD).

Seangkiatiyuth, K., Surapipith, V., Tantrakarnapa, K. & Lothongkum, A. 2011. Application of the AERMOD modeling system for environmental impact assessment of NO₂ emissions from a cement complex. *Journal of environmental sciences*, 23(6):931-940.

- Sharma, S., Malik, J., Wilson, S., Sehgal, M., Kumar, S., Dhingra, S., . . . Ghate, A.T. 2018. *Measures to Control Air Pollution in Urban Centres of India: Policy and Institutional framework*. New Delhi, India.
- Shikwambana, L. & Tsoeleng, L.T. 2020. Impacts of population growth and land use on air quality. A case study of Tshwane, Rustenburg and Emalahleni, South Africa. *South African Geographical Journal*, 102(2):209-222.
- Shilpi, F., Xu, L., Behal, R. & Blankespoor, B. 2018. *People on the move: Spatial mismatch and migration in post-apartheid South Africa*. Washington.
- Simphiwe, M. 2014. Urban Transformation in Peripheries: Transformation of South African Cities for Sustainability and Social Justice. (Unpublished).
- Sithenkosi, L. & Nzewi, O.I. 2024. A Blueprint to Dismantle Apartheid Spatial Differentiation? A Reflection on 25 Years of the White Paper on Local Government. *Commonwealth Youth & Development*, 21(2), art16538. doi:10.25159/1727-7140/16538.
- Sivaramanan, S. 2015. Air Pollution sources, pollutants and mitigation measures. *Research Gate*, 10(2), art8485. doi:10.13140/2.1.5106.8485.
- Sivertsen, B. & Bartonova, A. 2012. Air quality management planning (AQMP). *Chemical Industry and Chemical Engineering Quarterly*, 18(4-2):667-674.
- Smit, R., Kingston, P., Wainwright, D.H. & Tooker, R. 2017. A tunnel study to validate motor vehicle emission prediction software in Australia. *Atmospheric Environment*, 151(1):188-199.
- Snoun, H., Krichen, M. & Chérif, H. 2023. A comprehensive review of Gaussian atmospheric dispersion models: current usage and future perspectives. *Euro-Mediterranean Journal for Environmental Integration*, 8(1):219-242.
- Sohoni, A.V., Thomas, M. & Rao, K.K. 2017. Application of the concept of transit oriented development to a suburban neighborhood. *Transportation research procedia*, 25(1):3220-3232.
- Sonter, L., Herrera, D., Barrett, D., Galford, G., Moran, C. & Filho, B. 2017. Mining drives extensive deforestation in the Brazilian Amazon. *Nature Communications*, 8(1013), art557. doi:10.1038/s41467-017-00557-w.
- South Africa Air Quality Information System. 2020. South African Air Quality Management Plans. <https://saaqis.environment.gov.za/home/text/358> Date of access: 15 Jul. 2020.
- South African Cities Network. 2015. *SPLUMA as a Tool for Spatial Transformation*.

Johannesburg, South Africa.

South African Cities Network. 2016. *The State of South African Cities Report*. Johannesburg, South Africa.

South African Cities Network. 2020. *Beyond 2021: A Local Government Outlook*. Johannesburg, South Africa.

South African Cities Network. 2022. *The State of South African Cities Report*. Johannesburg, South Africa.

South African Cities Network. 2023. *Spatial Transformation: Measuring success in South African Cities*. Johannesburg, South Africa.

South African Local Government Association (South Africa). 2012. *Guidelines to assist municipalities with the formulation of Spatial Development Framework*. Pretoria, South Africa.

Spatial Planning and Land use Management Act 16 of 2013.

Spiekermann, K. & Wegener, M. 2018. Multi-level urban models. *Journal of Transport and Land Use*, 11(1):67-81.

State of Maryland (United States of America). 1997. *Smart Growth and Neighbourhood Conservation Initiative: Annapolis*. Baltimore, United States of America.

Stavins, R., Zou, J., Brewer, T., Conte Grand, M., den Elzen, M., Finus, M., . . . Winkler, H. 2014. International Cooperation: Agreements & Instruments. In Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Farahani, E., S. Kadner, Seyboth, K., Adler, A., Baum, I., Brunner, S., Eickemeier, P., Kriemann, B., Savolainen, J., S. Schlömer, Stechow, C.V., Zwickel, T., Boncheva, J.C.M.I. & Morgan, J., eds. *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press. pp. 1001-1082.

Steytler, N. & De Visser, J. 2007. *Local Government Law of South Africa*. Vol. 7. Johannesburg: Lexis Nexis.

Steytler, N., Visser, J.d. & Mettler, J. 2000. *Making Law: a Guide to Municipal Councils*. Cape Town, South Africa.

Superczynski, S.D. & Christopher, S.A. 2011. Exploring land use and land cover effects on air quality in Central Alabama using GIS and remote sensing. *Remote sensing*, 3(12):2552-2567.

- Susanto, A.D., Winardi, W., Hidayat, M. & Wirawan, A. 2021. The use of indoor plant as an alternative strategy to improve indoor air quality in Indonesia. *Reviews on Environmental health*, 36(1):95-99.
- Tang, G. 2010. Masdar-The sustainable desert city: A theoretical mirage or a realistic. In: Lehmann, S., Waer, H.A. & Al-Qawasami, J. *Conference proceedings*. 7th International Conference of the Centre for the Study of Architecture in the Arab Region, Amman, 12-14 Jul. CSAAR Press. pp. 175-189.
- Taylor, J., Shrubsole, C., Davies, M., Biddulph, P., Das, P., Hamilton, I., . . . Oikonomou, E. 2014. The modifying effect of the building envelope on population exposure to PM_{2.5} from outdoor sources. *Indoor Air*, 24(6):639-651.
- Thambiran, T. & Diab, R.D. 2010. A review of scientific linkages and interactions between climate change and air quality, with implications for air quality management in South Africa. *South African Journal of Science*, 106(3):1-8.
- Thambiran, T. & Padayachi, Y. 2017. Air quality. In Mambo, J. & Facer, K., eds. *Understanding the Social & Environmental Implications of Global Change*. 2nd ed. Pretoria: Department: Science and Technology (South Africa). pp. 36-43.
- The Climate Institute. 2010. *The Cancun Agreement: A Preliminary Assessment*. Washington, United States of America.
- Thomas, R.G. 2008. *An Air Quality Baseline Assessment for the Vaal Airshed in South Africa*. Pretoria: University of Pretoria. (Thesis - MA).
- Tiwari, R., Kaushik, U. & Devadaru, L.R. 2021. *Effect of Public Transportation on Urban Sprawl in the City of Bhopal, India*. Paper presented at the 57th ISOCARP World Planning Congress, Doha, Qatar, 8-11 November.
- Todes, A. 2012. Urban growth and strategic spatial planning in Johannesburg, South Africa. *Cities*, 29(3):158-165.
- Todes, A. 2017. Shaping peripheral growth? Strategic spatial planning in a South African city-region. *Habitat International*, 67(1):129-136.
- Tong, D., Zhang, Q., Liu, F., Geng, G., Zheng, Y., Xue, T., . . . Zhao, H. 2018. Current emissions and future mitigation pathways of coal-fired power plants in China from 2010 to 2030. *Environmental science & technology*, 52(21):12905-12914.
- Tshehla, C. & Wright, C.Y. 2019. 15 Years after the national environmental management air

quality Act: Is legislation failing to reduce air pollution in South Africa? *South African Journal of Science*, 115(9/10), art6100. doi:10.17159/sajs.2019/6100.

Tshisi, L. 2023. *Modelling ambient vehicle emissions in Zamdela using AERMOD*. Potchefstroom: North-West University. (Thesis - MA).

Tsoeleng, L.T. & Shikwambana, L. 2020. Impacts of population growth and land use on air quality. A case study of Tshwane, Rustenburg and Emalahleni, South Africa. *South African Geographical*, 102(2):209-222.

Tudi, M., Daniel Ruan, H., Wang, L., Lyu, J., Sadler, R., Connell, D., . . . Phung, D.T. 2021. Agriculture development, pesticide application and its impact on the environment. *International journal of environmental research and public health*, 18(1), art1112. doi:10.3390/ijerph18031112.

Turok, I. 2001. Persistent polarisation post-apartheid? Progress towards urban integration in Cape Town. *Urban studies*, 38(13):2349-2377.

Turok, I. 2012. *Urbanisation and Development in South Africa: Economic Imperatives, Spatial Distortions and Strategic Responses*. London, England.

Turok, I. & Borel-Saladin, J. 2014. Is urbanisation in South Africa on a sustainable trajectory? *Development Southern Africa*, 31(5):675-691.

Tyson, P., Garstang, M., Swap, R., Kallberg, P. & Edwards, M. 1996. An air transport climatology for subtropical southern Africa. *International journal of climatology*, 16(3):265-291.

Tyson, P.D. & Preston-Whyte, R.A. 2000. *The Weather and Climate of Southern Africa*. Cape Town: Oxford University Press.

Ugo, P.D. 2014. The bus rapid transit system: A service quality dimension of commuter uptake in Cape Town, South Africa. *Journal of Transport and Supply Chain Management*, 8(1):1-10.

Ul Haq, A., Nadeem, Q., Farooq, A., Irfan, N., Ahmad, M. & Ali, M.R. 2019. Assessment of AERMOD modeling system for application in complex terrain in Pakistan. *Atmospheric Pollution Research*, 10(5):1492-1497.

UN-Habitat. 2014. *The State of African Cities 2014: Re-imagining sustainable urban transitions*. Nairobi, Kenya.

United Nations. 1998. *Kyoto Protocol to the United Nations Framework Convention on Climate Change*. New York, United States of America.

- United Nations. 2015. *Paris Agreement*. New York, United States of America.
- United Nations. 2016. *Urban Air Quality Management Toolbook*. New York, United States of America
- United Nations. 2019. *World Urbanization Prospects The 2018 Revision*. New York, United States of America
- United Nations Environment Programme. 2022. *Integrated Assessment of Air Pollution and Climate Change for Sustainable Development in Africa: Summary for Decision Makers*. Nairobi.
- United States Environmental Protection Agency. 2016b. *User's Guide for the AERMOD Terrain Preprocessor (AERMAP)*. Research Triangle Park, United State of America.
- United States Environmental Protection Agency. 2018. *User's Guide for the AERMOD Terrain Preprocessor (AERMAP)*. Research Triangle Park, United State of America.
- United States Environmental Protection Agency. 2024a. *User's Guide for the AERMOD Meteorological Preprocessor (AERMET)*. Research Triangle Park, United State of America.
- United States Environmental Protection Agency. 2024b. *User's Guide for the AMS/EPA Regulatory Model (AERMOD)*. Research Triangle Park, United State of America.
- Valavanidis, A., Vlachogianni, T. & Fiotakis, K. 2016. *Air Pollution as a Significant Cause of Diseases and Premature Death. Ambient Air Pollution in Urban Areas and Indoor Air Pollution are Associated with Adverse Health Effects and Premature Mortality*. Athens.
- Van der Berg, A. 2017. South Africa's integrated urban development framework and sustainable development goal 11: policy mismatch or success? *Obiter*, 38(3):557-573.
- Van der Gaast, W. & Alessi, M. 2015. *History of the UN Climate Negotiations – Part 1 – from the 1980's to 2010*. <https://climatepolicyinfohub.eu/history-un-climate-negotiations-part-1-1980s-2010.html> Date of access: 15 Apr. 2021.
- Van Niekerk, T., Wesch, N., Mukwevho, P., Burger, R. & Viviers, J. 2024. *Strategic Spatial Planning for Air Quality: Evaluating Policies in South African Urban Development*. Paper presented at the 55th Annual Conference of the National Association for Clean Air, Randburg, South Africa, 4-6 September.
- Van Niekerk, T.J.B. 2019. *The Corridor Densification Option Model as a means for spatial restructuring of South African cities*. Potchefstroom: North-West University. (Thesis - MA).

- Van Wilgen, B.W., Govender, N. & MacFadyen, S. 2008. An assessment of the implementation and outcomes of recent changes to fire management in the Kruger National Park. *Koedoe: African Protected Area Conservation and Science*, 50(1):22-31.
- Van Zyl, B., Cilliers, E.J., Lategan, L.G. & Cilliers, S.S. 2021. Closing the gap between urban planning and urban ecology: A South African perspective. *Urban Planning*, 6(4):122-134.
- Vaz, E. & Venter, C. 2012. *The Effectiveness of Bus Rapid Transit as Part of a Poverty-Reduction Strategy: Some Early Impacts in Johannesburg*. Paper presented at the 31st Southern African Transport Conference, Pretoria, South Africa, 9-12 Jul.
- Venter, Z.S., Hassani, A., Stange, E., Schneider, P. & Castell, N. 2024. Reassessing the role of urban green space in air pollution control. *Proceedings of the National Academy of Sciences*, 121(6), art2306200121. doi:10.1073/pnas.2306200121
- Venter, Z.S., Shackleton, C.M., Van Staden, F., Selomane, O. & Masterson, V.A. 2020. Green Apartheid: Urban green infrastructure remains unequally distributed across income and race geographies in South Africa. *Landscape and Urban Planning*, 203(1), art103889. doi:10.1016/j.landurbplan.2020.103889.
- Veras, A. & Amorim, L. 2005. New Urbanism: ideals and urban configuration. In: Nes, A.V. *Conference proceedings*. 5th International Space Syntax Symposium, Delft, Holland, 13-17 Jun. Amsterdam: Techne Press. pp. 269-282.
- Verdini, G., Woltjer, J. & Cioboata, S. 2025. Localising and reimagining urban planning knowledge for effective Global South climate urbanism. *Planning Practice & Research*, 1(1), art2474817. doi:10.1080/02697459.2025.2474817.
- Vijayalakshmi, M. 2020. *Modern Waste Management Techniques - A Critical Review*. Paper presented at the Innovation and Sustainability through E-Stem, Coimbatore, India, 14th & 15th October 2022.
- Von der Heyde, V.S. 2014. *Towards a sustainable incremental waste management system in Enkanini: A transdisciplinary case study*. Stellenbosch: Stellenbosch University. (Thesis - MA).
- Waisman, H., Bataille, C., Winkler, H., Jotzo, F., Shukla, P., Colombier, M., . . . Kainuma, M. 2019. A pathway design framework for national low greenhouse gas emission development strategies. *Nature Climate Change*, 9(4):261-268.
- Waisman, H., Spencer, T. & Colombier, M. 2016. *Long-term low emissions development strategies and the Paris Agreement – Why, what and how?* Paris, France.

- Wang, F., Dong, M., Ren, J., Luo, S., Zhao, H. & Liu, J. 2022. The impact of urban spatial structure on air pollution: empirical evidence from China. *Environment, Development and Sustainability*, 245531–555010.1007/s10668-021-01670-z.
- Wang, J., Shan, Y., Cui, C., Zhao, C., Meng, J. & Wang, S. 2024. Investigating the fast energy-related carbon emissions growth in African countries and its drivers. *Applied Energy* (357), art122494. doi:10.1016/j.apenergy.2023.122494.
- Wang, P., Zhang, R., Sun, S., Gao, M., Zheng, B., Zhang, D., . . . Zhang, H. 2023. Aggravated air pollution and health burden due to traffic congestion in urban China. *Atmospheric chemistry and physics*, 23(5):2983-2996.
- Wang, X., Khattak, A. & Zhang, Y. 2013. Is Smart Growth Associated with Reductions in Carbon Dioxide Emissions? *Journal of the Transportation Research Board*, 2375(1):62-70.
- Wardner, P. 2014. *Explaining mixed-use developments: A critical realist's perspective*. Paper presented at the 20th Annual Pacific-Rim Real Estate Society Conference, Christchurch, New Zealand, 19-22 Jan.
- Watson, J., Chow, J., Wang, X., Kohl, S., Chen, L.-W. & Etyemezian, V. 2012. Overview of real-world emission characterization methods. *Developments in Environmental Science*, 11(1):145-170.
- West, C.L. 2011. *Teaching Middle School Jazz: An Exploratory Sequential Mixed Methods Study*. Ann Arbor: University of Michigan. (Thesis - PhD).
- Wheeler, S.M. 2002. Constructing sustainable development/safeguarding our common future: Rethinking sustainable development. *Journal of the American Planning Association*, 68(1):110-111.
- Wiedinmyer, C., Yokelson, R.J. & Gullett, B.K. 2014. Global Emissions of Trace Gases, Particulate Matter, and Hazardous Air Pollutants from Open Burning of Domestic Waste. *Environmental Science & Technology*, 48(16):9523-9530.
- Wilkie, A.A., Richardson, D.B., Luben, T.J., Serre, M.L., Woods, C.G. & Daniels, J.L. 2022. North Carolina's Changing Energy Generation Profile and Reductions in Key Air Pollutants, 2000–2019. *North Carolina Medical Journal*, 83(4):304-310.
- Wilkinson, P. 2006. *'Transit Oriented Development': a strategic instrument for spatial restructuring and public transport system enhancement in South African cities?* Paper presented at the 25th Southern African Transport Conference, Pretoria, South Africa, 10-13 Jul.

- Williamson, O. 2023. *"Differensiële verstedeliking in die noordelike Vrystaat: implikasies vir Ruimtelike Ontwikkelingsraamwerke"*. Potchefstroom: North West University. (Thesis - MA).
- Winkel, A. 2016. *Particulate matter emission from livestock houses: measurement methods, emission levels and abatement systems*. Wageningen: Wageningen University. (Thesis - PhD).
- Winkler, S., Anderson, J., Garza, L., Ruona, W., Vogt, R. & Wallington, T. 2018. Vehicle criteria pollutant (PM, NO_x, CO, HCs) emissions: how low should we go? *NPJ Climate and atmospheric science*, 1(1):1-5.
- Wolpe, P. & Reddy, Y. 2015. *The contribution of low-carbon cities to South Africa's greenhouse gas emissions reduction goals*. Cape Town, South Africa.
- Wright, C.Y., Benyon, M., Diab, R.D., Naidoo, N., Kwatala, N., Kunene, S., . . . Panchal, R. 2025. Assessing the human health risks of indoor PM_{2.5} exposure in urban and rural households in two provinces of South Africa. *Atmospheric Environment*, 343(1), art120996. doi:10.1016/j.atmosenv.2024.120996.
- Wüst, F. 2022. The South African IDP and SDF contextualised in relation to global conceptions of forward planning—A review. *Town and Regional Planning*, 80(1):54-65.
- Wyer, K.E., Kelleghan, D.B., Blanes-Vidal, V., Schauburger, G. & Curran, T.P. 2022. Ammonia emissions from agriculture and their contribution to fine particulate matter: A review of implications for human health. *Journal of Environmental Management*, 323(1), art116285. doi:10.1016/j.jenvman.2022.116285.
- Xiang, W., Qi, Q. & Gan, L. 2023. Non-linear effects of green finance on air quality in China: New evidence from a panel threshold model. *Frontiers in Ecology and Evolution*, 11(1), art#1162137. doi:10.3389/fevo.2023.1162137.
- Xianghua, W.E.N. 2009. Point Sources of Pollution: Local Effects and Control In: Yi, Q., eds. *Industrial Pollution*. Encyclopedia of Life Support Systems. pp. 147-170. <https://www.eolss.net/ebooklib/bookinfo/point-sources-pollution-local-effects-control.aspx> Date of access: 27 Apr. 2019.
- Xiao, Y. & Watson, M. 2018. Guidance on Conducting a Systematic Literature Review. *Journal of Planning Education & Research*, 39(1):93-112.
- Xu, G., Jiao, L., Zhao, S., Yuan, M., Li, X., Han, Y., . . . Dong, T. 2016. Examining the impacts of land use on air quality from a spatio-temporal perspective in Wuhan, China. *Atmosphere*, 7(1), art62. doi:10.3390/atmos7050062.

- Yamineva, Y. & Romppanen, S. 2017. Is law failing to address air pollution? Reflections on international and EU developments. *Review of European, comparative & international environmental law*, 26(3):189-200.
- Yang, S. & He, L.Y. 2016. Transport pollution in China – Evidence from Beijing. *Energy & Environment*, 27(3-4):377-388.
- Yin, R.K. 2003. *Case study research: design and methods*. 3rd ed. Thousand Oaks: Sage Publications.
- Yin, R.K. 2012. *Applications of Case Study Research*. 3rd ed. Thousand Oaks: Sage Publications.
- Yuan, M., Song, Y., Huang, Y., Hong, S. & Huang, L. 2018. Exploring the Association between Urban Form and Air Quality in China. *Journal of Planning Education and Research*, 38(4):413-426.
- Zainal, Z. 2007. Case study as a research method. *Jurnal Kemanusiaan* 9(1):1-6.
- Zaręba, A., Krzemińska, A. & Widawski, K. 2016. Green Urbanism for the Greener Future of Metropolitan Areas. *Earth and Environmental Science*, 44(1), art052062. doi:10.1088/1755-1315/44/5/052062.
- Zhao, D., Chen, H., Shao, H. & Sun, X. 2018. Vehicle Emission Factors for Particulate and Gaseous Pollutants in an Urban Tunnel in Xi'an, China. *Journal of Chemistry*, 2018(1), art8964852. doi:10.1155/2018/8964852.
- Zou, B., Xu, S., Sternberg, T. & Fang, X. 2016. Effect of land use and cover change on air quality in urban sprawl. *Sustainability*, 8(1), art677. doi:10.3390/su8070677.
- Zhou, C., Li, S. & Wang, S. 2018. Examining the impacts of urban form on air pollution in developing countries: A case study of China's megacities. *International journal of environmental research and public health*, 15(1), art1565. doi:10.3390/ijerph15081565.
- Zhou, J., Tian, J. & Zhang, D. 2023. Pollution Effect of the Agglomeration of Thermal Power and Other Air Pollution-Intensive Industries in China. *International Journal of Environmental Research and Public Health*, 20(2), art1111. doi:10.3390/ijerph20021111.
- Zhou, S., Hursthouse, A. & Chen, T. 2019. Pollution characteristics of Sb, As, Hg, Pb, Cd, and Zn in soils from different zones of Xikuangshan antimony mine. *Journal of analytical methods in chemistry*, 1(1), art2754385. doi:10.1155/2019/2754385.

Zimmermann, N., Dianati, K., Milner, J., Chege, M., Csuvár, B., Muindi, K., . . . Ucci, M. 2017. *Indoor air pollution as an issue of nonattention in Nairobi's informal settlements*. Paper presented at the 35th International Conference of the System Dynamics Society, Cambridge. <https://www.proceedings.com/content/036/036907webtoc.pdf> Date of access: 26 Sept. 2019.

Zulfikri, A. 2023. Effects of Pollution and Transportation on Public Health in Jakarta. *West Science Interdisciplinary Studies*, 1(04):164-168.

Zwane, M. & Montmasson-Clair, G. 2016. *Climate change adaptation and agriculture in South Africa: a policy assessment*. Pretoria, South Africa: WWF-SA.