

Managing ambient air quality at King Shaka International Airport

CPT Jones

 **orcid.org 0000-0001-7989-5916**

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Supervisor:

Dr RP Burger

Co-supervisor:

Dr JA Wessels

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Abstract

This study was undertaken to gauge the effectiveness of environmental management interventions at the King Shaka International Airport (Durban) by investigating the source of noted exceedances in Particulate Matter (PM₁₀) concentration. The land-use immediately adjacent to the site is predominated with sugarcane cultivation that is burned annually during the winter and spring months. An experiment was conducted to compare the Particulate Matter concentration during the burning and non-burning seasons, and to verify the differences by means of a *t*-test. Further isolation of the sugarcane burning events were undertaken by using the HYSPLIT trajectory model. The information from these exercises was reviewed alongside the management procedures for sugarcane burning, to confirm adherence. The results of the study indicated that while there is existing functional management of the air quality impacts from sugarcane burning there is still a marked difference in the ambient air quality when the burning occurs. The burning season had an almost twofold increase in the mean daily Particulate Matter concentration as compared to the non-burning season (29.60 µg/m³ vs 18.30 µg/m³). The study considered the impacts of individual burn events to the noted exceedances of the National Ambient Air Quality Standards (NAAQS), but the modelling was inconclusive, suggesting that the impacts noted are from cumulative burning over the season rather than individual burns. The study concludes that the existing management measures provide assurance to legal compliance, but that this may not be enough in terms of duty of care and environmental best practice. There is a need for the scope of the Environmental Management System to be reassessed for the inclusion of other activities within its land parcels, and how these can be monitored in terms of air quality impacts. The study provides insight into the existing management of sugarcane burning and identifies the current impacts as a possible bottleneck to future development within the area. The study also highlighted the need to speed up the current cane removal within the conservation area to minimise ambient air quality impacts.

Key terms:

Ambient air quality

Environmental management

Particulate Matter

International airport

Sugarcane burning

Preface

This mini-dissertation would not be possible without the support of the Airports Company South Africa and the staff at the King Shaka International Airport; as such the bulk of the acknowledgment must be made to them.

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Table of Contents

Abstract	i
Preface	iii
Chapter 1: Introduction	1
1.1 Problem statement and substantiation.....	1
1.2 Research aims and objectives.....	5
1.3 Central theoretical statement and study design	5
1.4 Format of the study and choice of the research methods	5
Chapter 2: Literature study	7
2.1 Air quality impacts.....	7
2.2 Managing ambient air quality.....	8
2.2.1 Air quality monitoring	8
2.2.2 Managing emissions	9
2.2.3 Dispersion modelling.....	10
2.3 South African approach to managing air quality	10
2.3.1 South African environmental legislation	11
2.3.2 Air quality management plans.....	12
2.3.3 Atmospheric Emissions Licence	12
2.3.4 Emissions standards.....	12
2.3.5 National Ambient Air Quality Standards.....	13
2.3.6 Penalties	13
2.3.7 Uncontrolled contributions	13

2.4	Overview of ambient air quality in South Africa.....	14
2.5	Dispersion and transport of pollution.....	14
2.6	Sources of pollution	15
2.6.1	Road vehicles	16
2.6.2	Domestic burning and veld fires.....	16
2.6.3	Coal-fired power stations and other industrial sources	16
2.6.4	Airport emissions	17
2.6.4.1	Air quality at airports	17
2.6.4.2	Aircraft emissions.....	17
2.6.4.3	Other emissions at airport level	20
2.6.4.4	Confounding factors.....	21
2.6.4.5	Conclusion	21
2.6.5	Sugarcane burning.....	22
2.6.5.1	Rationale for burning.....	22
2.6.5.2	Impacts from burning	23
2.7	Conclusions	24
	Chapter 3: Data and methods.....	26
3.1	Site location – King Shaka International Airport.....	26
3.2	Characterising ambient air quality at King Shaka International Airport ...	27
3.2.1	Introduction	27
3.2.2	Data capture	27
3.2.3	Data processing and analysis	29

3.2.3.1	Data analysis – Characterisation of PM ₁₀ trends	29
3.2.3.2	Data analysis – Identification of the exceedance incidents	29
3.3	Analysis of variability to identify major sources of Particulate Matter	29
3.3.1	Introduction	29
3.3.2	Data capture	29
3.3.3	Data processing and analysis	30
3.3.3.1	Data analysis – Spatial relationships	30
3.3.3.2	Data analysis – Statistical comparison between treatments	30
3.3.3.3	Data analysis – Graphical comparison between treatments	31
3.3.3.4	Data analysis – Trajectory modelling	31
3.4	Reviewing efficacy of ambient air quality management practices at King Shaka International Airport	33
3.4.1	Data capture	33
3.4.1.1	Observation records.....	33
3.4.2	Data processing and analysis	33
3.5	Quality control.....	33
3.5.1	Particulate Matter data from analysers	33
3.5.2	Burn information.....	36
3.6	Limitations and assumptions	36
3.6.1	Burn locations	37
3.6.2	Air quality monitoring results	37
3.7	Conclusion	37

Chapter 4: Ambient air quality at King Shaka International Airport	38
4.1 Characterisation of ambient air quality.....	38
4.1.1 Wind speed and direction	38
4.1.2 Characterisation of Particulate Matter trends.....	40
4.1.3 Identification of the exceedance incidents	42
4.2 Consideration of location and timing of sugarcane burning events	42
4.2.1 Spatial relationships.....	42
4.2.2 Separation of burning season from non-burning season	45
4.2.3 Statistical comparison between treatments: <i>t</i> -test results	47
4.2.4 Graphical comparison between treatments.....	48
4.2.5 Burning events during periods of exceedance	49
4.2.6 HYSPLIT output.....	49
4.3 Adherence to the use of the management tool	53
4.3.1 Cane burns conducted without notification	53
4.3.2 Information recording	54
4.3.3 Smoke interference.....	54
Chapter 5: Managing ambient air quality at King Shaka International Airport.....	55
5.1 The characterisation of the ambient air quality at the King Shaka International Airport	55
5.2 To identify major sources that are impacting on the ambient air quality at the King Shaka International Airport	56

5.3	Review of efficacy of existing environmental management measures at the King Shaka International Airport to minimise air quality impacts from the sugar cane burning	58
5.4	Implications for ambient air quality management at the King Shaka International Airport	60
5.5	Implications for ambient air quality surrounding the King Shaka International Airport	62
5.6	Long-term plans for sugarcane burning on site	64
5.7	Conclusion	65
	Chapter 6: Conclusion	66
6.1	Characterising the ambient air quality at the King Shaka International Airport.....	66
6.2	To identify major sources that are impacting on the ambient air quality at the King Shaka International Airport	66
6.3	Existing management measures to minimise the incidence of pollution from the sugar cane burning	67
6.4	Contribution of this study to the broader pool of knowledge.....	68
	Bibliography.....	69

List of Tables

Table 1: The National Ambient Air Quality Standards with pollutants, averaging periods, limit values and permissible exceedances.	2
Table 2: The instrument specification for the continuous monitoring station at King Shaka International Airport.	28
Table 3: The details of the information used to develop t-test for comparison of the treatments.....	31
Table 4: Dates of exceedances of the threshold concentrations of Particulate Matter, as per the National Ambient Air Quality Standards.....	42
Table 5: Output from the Welch Two Sample t-test.....	47
Table 6: Table of days with Particulate Matter exceedances.....	49

List of Figures

Figure 1: A map indicating the location of the King Shaka International Airport, and the continuous ambient air quality monitoring station.	27
Figure 2: Summary Plot of data over the period July 2014 – June 2015, indicating the missing data and general trends.....	35
Figure 3: A seasonal wind rose based on observed weather at the continuous monitoring station for the period July 2014 – June 2015.	39
Figure 4: A bar graph indicating the mean daily concentration of Particulate Matter over the study period	41
Figure 5: A map indicating the location of the King Shaka International Airport (aircraft logo), the continuous monitoring station (black dot), and the burn locations (red dots)	43
Figure 6: Seasonal pollution roses denoting the concentration of Particulate Matter per wind direction.....	44
Figure 7: A bar graph indicating the mean daily concentration of Particulate Matter over the period, colour-coded to denote burning occurrence.....	46
Figure 8: Boxplot indicating distribution of Particulate Matter concentrations for the two treatments: Burning season and non-burning season.....	48
Figure 9: HYP SLIT output for 18 July 2014	50
Figure 10: HYP SLIT output for 18 July 2014 (zoomed in).	51
Figure 11: HYP SLIT output for 1 August 2014.	52
Figure 12: HYP SLIT output for 1 August 2014 (zoomed in).....	53

Chapter 1: Introduction

1.1 Problem statement and substantiation

Airports Company South Africa at the King Shaka International Airport has a duty of care to manage its operations in terms of any possible impacts to ambient air quality. This duty of care is manifest from various sources, ranging from International obligations as specified by the International Civil Aviation Organisation (ICAO), to the legal duties stipulated within section 28 of the National Environmental Management Act (Act 107 of 1998), and finally to the ISO 14001 system operated by the Airports Company South Africa, and its commitment from leadership to minimise pollution. To this end active air quality management is practiced on site. Shortly after commencing operations in May 2010 an emissions inventory was developed to identify all sources of emissions on site, and to gauge the impacts of the operations on the environment.

This inventory considered the following sources of emissions on site (WSP, 2012):

- Air fleet (Landing/ Take-Off Cycles)
- Vehicles (operating in the public and restricted areas)
- Fuel Storage and refill points
- Generators
- Waste Water Treatment Works

The emissions inventory quantified moderate emissions on site, with the highest proportion of emissions from vehicles and aircraft (specifically related to Oxides of Nitrogen (NO_x) and Carbon Monoxide(CO)). This inventory formed the basis of an application for an Air Emissions Licence (AEL) for the site (based on the volumes of Jet A1 fuel stored on site).

Further to the emissions inventory that was conducted, and in line with the conditions of the AEL, ACSA installed a continuous monitoring system to sample the ambient air quality at the airport. After the first year of monitoring there were some concerns noted in the levels of the observed parameters. The airport was built on a greenfields site, with very little residential nor industrial activity in close proximity, and it was considered that the ambient air quality would reflect, for the most part, the results obtained from the air emissions inventory (WSP, 2012).

The air quality obtained over the period was analysed for compliance to the National Ambient Air Quality Standards (NAAQS) (South Africa, 2009), and the following is a summary of the 2014/2015 data.

Table 1: The National Ambient Air Quality Standards with pollutants, averaging periods, limit values and permissible exceedances.

Pollutant	Averaging Period	Limit Value	Number of permissible exceedances	Max in hourly data	Exceedances in data (2014-2015)
Sulphur Dioxide (SO ₂)	10 minute	191 ppb	526	N/A	N/A
	1 hour	134 ppb	88	68.35	0
	24 hour	48 ppb	4	27.02	0
	1 year	19 ppb	0	3.07	0
Nitrogen Dioxide (NO ₂)	1 hour	106 ppb	88	93.25	0
	1 year	21 ppb	0	7.24	0
Particulate Matter (PM ₁₀)	24 hour	75 µg/m ³	4	95.52	0/3 ¹
	1 year	40 µg/m ³	0	20.72	0
Carbon Monoxide (CO)	1 hour	26 ppm	88	1.58	0
	8 hour (running average)	8.7 ppm	11	1.53	0
Ozone (O ₃)	8 hour running average	61 ppb	11	48.96	0
Benzene (C ₆ H ₆)	1 year	5 µg/m ³	0	0.32	0

¹ The regulations which specify the 24-hour limit of 75 µg/m³ for PM₁₀ came into effect on 1 January 2015, and the previous limit of 120 µg/m³ was in effect prior to that. The readings that were over the 75 µg/m³ limit were recorded prior to 1 January 2015, but were included under the new regulations to indicate that there are possible future concerns in the Particulate Matter at the Airport

From Table 1 it can be noted that there are exceedances based upon the sampled concentrations of Particulate Matter. The other priority pollutants are not at levels above (nor even close) to the regulated thresholds to be of particular concern.

These results were not in line with the projected outcomes of the emissions inventory. The sources of Particulate Matter in the inventory were mainly attributed to vehicular usage (approximately 75% of the contribution), with the balance being attributed to the aircraft (the generators on site, while sources of PM₁₀, produced comparatively insignificant emissions) (WSP, 2012). If these activities were the source for the high Particulate Matter there would be a consequent correlation with the NO_x, but this was not observed in the data (EASA, 2017).

In order to remain compliant with the conditions of the Air Emissions Licence, ACSA needs to understand the source of the noted exceedances, and confirm that it is not linked to its activities.

It was hypothesised that there was an external source, in close proximity to the airport, that was introducing this high Particulate Matter load into the airshed of the airport. The land-use immediately adjacent to the airport is predominated by sugar cane production, and there is seasonal burning of the sugarcane before harvesting.

In terms of parsimony this biomass burning would be the most likely source of the elevated Particulate Matter. Given that the burning takes place only during part of the year an experiment can be performed where the ambient air quality in terms of Particulate Matter was characterised and correlated to the incidence of burning. This study was conducted in order to investigate if there was any credibility to the hypothesis that the sugarcane burning was contributing towards to the high Particulate Matter loading.

It must be noted that the risk of high emissions from sugar cane burning was flagged during the Environmental Impact Assessment for the construction of the airport (INR, 2007), and a mitigation plan was implemented to reduce the impact of this. This management tool is known as the Cane Burning Procedure (ACSA, 2008).

The procedure outlines the operational requirements for sugarcane burns to take place adjacent to the airport. The procedure was developed by the Fire Prevention Association which was formed between the sugarcane farmers, ACSA, and the Air Traffic and Navigational Services (ATNS). The basic premise of the operational plan is that the

further away from the runway the fire is taking place the less stringent the requirements and regulations. The area of jurisdiction of the plan is an oval which extends 10 kilometres out from the runway centreline in all directions. This polygon is further sub-divided into three separate zones (ACSA, 2008):

Zone A

This encompasses the entire area of the oval and the requirement is that notification is sent to the Airport of all burns that are to take place.

Zone B

This zone comprises an area that extends 2 kilometres out from the runway centreline, and burning can only commence if the wind is blowing away from the airport and that the cloud base is higher than 1500 feet AGL (Above Ground Level). It must be noted that the decisions around the wind and cloud cover are based on the observation of the sugar cane farmers, and not the ACSA nor ATNS staff.

Zone C

This is the area in line with the runway and extends out into the approach and departure corridors of arriving and departing aircraft. Burning is only allowed within this area with consent from ACSA.

The Airports Company South Africa operates an Environmental Management System (EMS) based upon the ISO 14001 standard (International Organisation for Standardisation [ISO], 2015), and this requires demonstration of continuous improvement in its environmental Key Performance Indicators. Adherence to the regulations for the National Ambient Air Quality Standards (NAAQS) forms part of these Key Performance Indicators, and the management interventions will need to be improved if a current gap is observed. Furthermore, with regards to its legal and other responsibilities ACSA needs to demonstrate its legal compliance to the Air Emissions Licence.

The final consideration with regards to the operation of the EMS, the new version of the Standard (ISO 14001:2015) increases the scope of the EMS to include all operations that impact upon its interested and affected parties, with a focus on stakeholder engagement in this regard. Much of the sugarcane that is farmed directly adjacent to the airport site is undertaken on land that belongs to the airport (there are long-term leases with the sugar farmers), so there is a certain responsibility from ACSA to ensure that impacts emanating

from its land are not deleterious to the local community. This means that ACSA has both controllable areas, which it owns (closest to the airfield) as well as influence over the areas that are not directly owned, through the action of the integrated management.

1.2 Research aims and objectives

The aim of the research is to investigate the management of ambient air quality at the King Shaka International Airport.

Objective 1: To characterise the ambient air quality at the King Shaka International Airport

Objective 2: To identify major sources that are impacting on the ambient air quality at the King Shaka International Airport.

Objective 3: To review the efficacy of existing environmental management measures at the King Shaka International Airport for air quality

1.3 Central theoretical statement and study design

The study design is based upon an empirical data collected *in situ* under specific circumstances, so it can be considered a mixture of a descriptive study and an experimental design.

The study includes both quantitative measures, in terms of direct recording of climatic and air quality information, as well as qualitative measures with regards to the perceived efficacy of management systems, so can be considered a mixed method approach.

1.4 Format of the study and choice of the research methods

This study is broken down into five sections. The first of these is this introductory chapter which is followed by the literature review (Chapter two) that aims to place this study within the broader context of the current research. The next chapter relates to Data and Methods, where the sources of data are described as well as the manner in which the data are analysed in order to develop meaningful results. The broad method of comparing burning regimes is in line with research undertaken by Cristale *et al* (2012) and de Andrade *et al* (2010) who conducted *in situ* sampling of Particulate Matter during both the burning season and non-burning season to look for any significant deviations/differences.

The fourth chapter considers the output from the methods presented in the previous chapter. The proceeding chapters discuss the implications of the results and how they provide insight into the stated objectives. The final chapter concludes on the objectives and outlines to what degree the aim of the study has been fulfilled.

Chapter 2: Literature study

2.1 Air quality impacts

Poor air quality is less obvious than other forms of pollution to the casual observer, given that many of its most damaging constituents are colourless and odourless. The capacity of the air we breathe, much like the water in the oceans, has historically been considered as a source with an endless buffer to deal with pollution or perturbation. With the advent of the technological capacity to understand what is occurring within our airsheds, and understanding the medical consequences of living within these areas, the global perception of the importance of air quality is increasing (Suk *et al*, 2016, Preker *et al*, 2016, Landrigan *et al* 2015).

The ultimate impact of exposure to ongoing poor air quality is declining health, and possible death (Lim *et al*, 2012, Suk *et al*, 2016, Butt *et al*, 2015). Landrigan *et al* (2015) list that there are toxicological effects of many pollutants found in the air and how these not only effect individuals but rather entire communities, and their collective ability to remain productive in an economic sense. This burden of disease associated with poor air quality creates a vicious cycle where the impacted (mainly the poor) are forced to spend their meagre resources on medical care, which then presents an associated financial load (Preker *et al*, 2016). This financial decline results in forced choices in terms of habitation-location, means of food preparation, and remaining warm, which then results in even worse exposure to air pollutants (Henneman *et al*, 2016).

Suk *et al* (2016) presented World Health Organisation data that indicated that an estimated 7 million deaths per year are attributed directly to poor air quality (this was based on both indoor and ambient air quality). Their study concluded that pollution effects are not simply acute, but that there is damage caused during the developmental stages of childhood, where irreparable neurological problems manifest. Butt *et al* (2015) conducted a global study on the effect of Particulate Matter (with a diameter of less than 2.5 microns) from residential burning, in both developed and developing countries. Their models point towards Particulate Matter as a driver for premature mortality in developing countries, especially China and India.

With this background the need to understand air quality, such that its impacts can be lowered by appropriate management interventions, is essential.

2.2 Managing ambient air quality

The basic premise behind managing air quality is to remove the sensitive receptors from experiencing the bulk of the impact from sources of pollution, and their emissions. Bluntly put, if there is separation of source and receptor the overall health impacts are greatly reduced. The methods of separation include limiting emissions from sources (Naiker *et al*, 2012), changing the amount of dispersion, or moving receptors to areas of lower emissions.

There are passive solutions to limiting dispersion of pollutants by utilising meteorological conditions to maximise transport, and hence increase dilution rates. There are also options of changing where emissions sources exit into the receiving environment. Van der Hoven (1975) demonstrated the principal of that the emission height (in this case the stacks of a large industrial complex) increases the overall dispersion of a pollutant, which results in lower deposition rates over larger areas. While this approach is not always possible, given the source of emissions (e.g. road vehicles), it can be a useful management approach from large industry.

If the emission height and meteorological conditions are not factors that are under control, then the most effective solution is to reduce the rate of emission, or the concentration of emission.

In their review paper on how air quality management functions, Gulia *et al* (2015) proposed that there are a number of iterative steps that are required to realise effective Air Quality Management. The first of these is that there needs to be a manner of procedural or legislative control. This can take the place of legislation within a country, or group of countries, that outlines the acceptable limits of certain pollutants, as well as how industries manage their specific emissions. This can be taken from a country-wide scale down to procedures within an organisation or site.

The following are the components necessary for effective Air Quality Management according to Gulia *et al* (2015):

2.2.1 Air quality monitoring

Monitoring of the ambient air quality provides an empirical metric for the impacts of any polluter (large industrial processes, roads, biomass burning, etc). The monitoring can be

done over a large range of temporal scales, and this relates to the nature of the pollutant and its interaction with the receptor. This is seen with the monitoring of carbon monoxide typically being measured on an 8-hour rolling average as it is usually associated with work day exposure and the effects of elevated levels can be acute over a short time frame (Garsik, 1995). Other pollutants are averaged over much longer periods, such as benzene which is measured over an annual timeframe. The rationale for this is that benzene is a pollutant with chronic effects that are developed over prolonged exposure.

Ideally pollutants should be monitored over as high a temporal resolution as possible, as this can demonstrate trends in terms of diurnal variation, but this is often too costly to implement over long monitoring studies.

The actual physical monitoring is done by means of specialised equipment that is developed to quantify constituents of the pollutants (Cancado *et al*, 2006, Cristale *et al* 2012). There are chemical tests that provide the most accurate results but these are time-consuming and are not practical for in-field assessments. Most of the monitoring equipment will use proxies such as light scatter or absorption, from spectrophotometry or chemiluminescence, to analyse pollutant concentrations (Carslaw *et al*, 2006, Environnement-sa, 2017).

Given that air quality monitoring is most effective within close proximity to receptors, there is a need for a large network of monitoring to understand how air parcels laden with pollutants interact with the topology and meteorology of any given area (Gulia *et al*, 2015). Gulia *et al* (2015) reported that there were 94 stations sited within South Africa to monitor ambient air quality trends, as of 2011.

The other means to measure air quality is to conduct stack testing. Stack testing involves monitoring the emissions directly from the source of pollutants. This allows for the information to be built into models to quantify how the pollutant loads will impact on surrounding areas (Atkinson, 2014).

2.2.2 Managing emissions

Gulia *et al* (2015), Naiker *et al* (2012) and Wright and Diab (2011) considered the use of emissions inventories as a means of managing emissions. The inventories are based on known rates of emission at a quantified concentration. This is typically done at a site or facility level, where all machinery and equipment are categorised in terms of the types of

pollutants they emit, their operational hours, and the absolute output of pollutants. These are then summed to account for the combined output from a facility. The emissions inventory allows users to gauge what their impacts are, and then these can be verified by means of stack testing or ambient air monitoring, as described above. The use of both the theoretical output and empirical monitoring can assist in identifying pollutant sources that were not previously known. Umoya-NILU (2015b) used an emissions inventory for the eThekweni municipality, in Durban, to quantify the impacts from road vehicles, airport and harbour for various pollutants.

2.2.3 Dispersion modelling

The final component essential to air quality management, per Gulia *et al* (2015) is the use of dispersion modelling. This is production of mathematical models that predict the flow of pollutants from a source over time, based upon factors such as meteorology (wind speed and direction, temperature, etc.), topography, and the nature of the chemical pollutant (in terms of reactivity and the conversion of one pollutant form to another in the presence of light and other reactants) (Gulia *et al*, 2015, Rolph *et al*, 2017). There are numerous models available that can help to predict movement for forecasting, or to calculate how a particle would have moved at a given historical time (Carslaw *et al*, 2015, Rolph *et al*, 2017).

Commonly used dispersion models are: AERMOD, CALPUFF, CALINE, HYSPLIT, CMAQ (Gulia *et al*, 2015, Rolph *et al*, 2017).

2.3 South African approach to managing air quality

As mentioned by Gulia *et al* (2015) the basis for robust air quality management within a country, or area of jurisdiction, is a set of specific legislation with associated regulations.

Within South Africa there is a cascading set of environmental laws, which include air quality management. The approach is typified by the following brief summary of the air quality legislation as enforced within South Africa.

2.3.1 South African environmental legislation

All South African environmental legislation is adopted from the Constitution of the Country and the intrinsic environmental rights of its citizens (Naiker *et al*, 2012, Humby, 2015). This is stated quite simply within the Constitution as:

"Section 24. Everyone has the right—

(a) to an environment that is not harmful to their health or wellbeing; and

(b) to have the environment protected, for the benefit of present and future generations, through reasonable legislative and other measures that—

(i) prevent pollution and ecological degradation;

(ii) promote conservation; and

(iii) secure ecologically sustainable development and use of natural resources while promoting justifiable economic and social development." (Act 108 of 1996)

The National Environmental Management Act (Act 107 of 1998), commonly referred to as NEMA, is the primary piece of legislation that enacts the environmental right entrenched within the Constitution as dictated above. This framework legislation outlines principles for sound environmental management within the country (Humby, 2015).

There are specific laws that were formed under the umbrella of NEMA, one of which is the National Environmental Management: Air Quality Act (Act 39 of 2004) (NEM:AQA), that governs air quality management within the country. The act specifies the provision of the environmental rights of the Constitution by means of norms and standards for air quality monitoring as well as the management and control of these measures by all spheres of government.

NEM:AQA provides a completely new way of looking at air quality in South Africa and introduced the concept of management (Chapter 4 of NEM:AQA) rather than simply command and control, as compared to the previous legislative framework of the Air Pollution Prevention Act (Act 45 of 1965) (APPA)(Naiker *et al*, 2012).

NEM:AQA shifted the power of jurisdiction competence to all spheres of government. This means that management of air quality matters are done in a bottom up approach where the first line of management is conducted at the municipal level. This is where the pollutants are being produced and it make sense for these to be under the jurisdiction of

the local government. This is noted in section 36 of NEM:AQA where the powers of issuance of atmospheric emissions licences are vested with the District and Metropolitan Municipalities. According to Naiker *et al* (2012) the National government is responsible for the setting of the regulated standards which are applicable across the provinces. They are also responsible for the development of policies and the meeting of international obligations for air quality. The Provincial and Municipal functions are shared (depending on the size and capabilities of the municipal offices), and these entail the preparation of Air Quality Management Plans and the issuing of Air Emissions Licences, as mentioned above. These legislative tools are further explained below:

2.3.2 Air quality management plans

As per the requirement of Section 15 of NEM:AQA, Air Quality Management Plans are developed at a municipal and provincial level based upon guidance material from the National Department. These plans inform the requirements of each municipality in terms of its pollutant sources and mitigation. The plans are developed as part of the municipal Integrated Development Plan, and cover the control measures needed to implement the principles of NEM:AQA (Wright and Diab, 2011).

2.3.3 Atmospheric Emissions Licence

Within the regulations of NEM:AQA there are listed activities that trigger the need for an Air Emissions Licence. The application process for these licences provides information in terms of the pollutants that will be emitted and what the required mitigation will be for the operations to be licenced. This process is carried out entirely at the municipal level (where there is capacity) so that the emitters and regulators are able to foster functional relationships to minimise pollution events (Naiker *et al* 2012).

2.3.4 Emissions standards

The NEM:AQA regulations do also stipulate the performance of large emitter, such as power stations or smelters in terms of Minimum Emissions Standards (MES). These are legislated output rates of specific pollutants from each kind of industry. The MES include values for both existing infrastructure, which is less stringent (following the principle of “existing lawful use”) than the requirements for new infrastructure (Naiker *et al*, 2012). The current infrastructure in terms of coal-fired power stations in South Africa are not able

to meet the MES (due to the make-up of coal deposits that are mined (Makgato and Chirwa, 2017)) and this has resulted in many of the MES not being adhered to.

2.3.5 National Ambient Air Quality Standards

The purpose of the Air Emissions Licences and Minimum Emissions Standards are to ensure that the pollution loading within each airshed does not result in ambient air conditions that are harmful to those living within them. To this end the National Ambient Air Quality Standards were developed. The standards use a set of priority pollutants (Sulphur Dioxide, Nitrogen Dioxide, Particulate Matter (PM₁₀), Ozone, Benzene, Lead, and Carbon Monoxide). Each of these pollutants have concentration thresholds tied to specific averaging times (from 8 hourly to annual averages), and permissible exceedances (GNR 1210, 2009). The National Ambient Air Quality Standards (NAAQS) are used in conjunction with ambient air quality monitoring to understand where certain pollutants concentrations are too high. This then informs the issuing of new licences to industries within the airshed, as when the NAAQS are exceeded it is indicative of the airshed having reached its carrying capacity.

2.3.6 Penalties

The requirements of NEM:AQA, its tools and regulations are managed as per the Compliance and Enforcement tenets of NEMA. This provides a fiscal instrument for the compliance as there are hefty fines and/or jailtime associated with non-compliances (Humby, 2015, Naiker *et al*, 2012). There is also a possibility of industries being shut down if they are not able to comply with the MES, so there is market pressure within industry to self-regulate to remain competitive.

2.3.7 Uncontrolled contributions

There are certain emissions whose management falls outside of the ambit of readily applicable legislation. These are emissions tied to the socio-economic state of the country (Jafta *et al*, 2017), and to some degree natural phenomena. The South African government cannot regulate the use of solid fuel burning within low income households, as there is simply not an alternative to many of the users (Jafta *et al*, 2017). The other source of emissions that are not controlled with legislative tools are matters such as natural veld fires, where emissions can be transported over large distances (Keywood *et*

al, 2011). Both of these sources can introduce variability into ambient air quality monitoring when the most notable direct sources have been quantified.

2.4 Overview of ambient air quality in South Africa

This study of air quality around the King Shaka International Airport is contextualised according to the observed air quality within the broader eThekweni Municipality (this is the municipal area the airport is situated in). Umoya-NILU (2015b) reviewed the air quality within the eThekweni Municipality as part of the emissions inventory that was carried out during the update of the municipal Air Quality Management Plan.

They concluded that the largest sources of pollutants were as follows:

- Industry (the combination of the facilities with an Air Emissions Licence, and the Controlled Emitters) accounted for more than 50% of the Sulphur Dioxide load (Umoya-NILU, 2015b)
- Motor Vehicles were the major sources of Oxides of Nitrogen, Carbon Monoxide, Particulate Matter, and Volatile Organic Compounds (Umoya-NILU, 2015b).

In terms of the ambient air quality within the municipal boundaries the adherence to the NAAQS are noted but for instances of high Sulphur Dioxide levels in the Durban South Basin (a heavily industrial area ~40km South from the airport). Particulate Matter and Oxides of Nitrogen are well controlled but for high traffic areas. Benzene and Ozone are exceeded in industrial areas, and dust has posed a nuisance in one area (Umoya-NILU, 2015b).

2.5 Dispersion and transport of pollution

The concentrations of pollutants present in any region at a particular time are the result of the interaction with the local meteorology. This has the highest influence on the behaviour of pollutants over time (Thambiran and Diab, 2010).

Thambiran and Diab (2010) discussed how temperature has an influence on those pollutants, such as ozone, that react with other chemicals in the air in the presence of radiant energy. With a lower temperature, the reaction speeds reduce, so this could result in persistence in cooler months of the year.

Thambiran and Diab (2010) looked at precipitation as the main driver for reduction in airborne pollutants as the water droplets in rain cleanse the air by means of adsorption and dissolution of particles in the air. This can of course have negative consequence due to the fallout of pollution onto the ground, in the case of acid rain formation. The precipitation cycle can also be influenced by the pollutants, specifically Particulate Matter which can form nucleation sites for water in the air to conglomerate into droplets (Thambiran and Diab, 2010).

Wind has a definite impact on the local concentration of pollutants, especially when there are clean sources that can dilute the air. Umoya-NILU (2015b) observed a lowering of the pollutant loads in eThekweni when there are offshore winds that blow clean air in from the Indian Ocean. The caveat here is that with certain wind directions, pollutant from remote areas can be introduced into local airsheds (Thambiran and Diab, 2010).

Thambiran and Diab (2010) reviewed the mixing of the various vertical air layers as a driver for the movement of ground level pollution out and away from sources. When there are very stable vertical layers, the pollution generated closer to the ground layers remains there; this is because they are effectively trapped by a blanket of air above them. This is noted in cooler months where a temperature inversion can form. Umoya-NILU (2015b) demonstrated this in their baseline assessment of air quality in the eThekweni Municipality where the pollutant concentrations were the poorest during the winter months. The opposite is noted during the summer months where there is active mixing of the air layers and pollutant dispersion can be facilitated easily. Umoya-NILU (2015b) noted the following parameters as the most important in terms of the stability of air layers: Wind speed, topography (specifically the roughness of the surface), and solar radiation (the temperature increase reaction times and kinetic speed). Given these parameters a clear trend can be noted diurnally where daytime temperatures result in turbulent unstable air, but at night when there is a general cooling the air layers become more stable.

2.6 Sources of pollution

Within the context of reviewing the inputs of Particulate Matter within an airshed, there needs to be an understanding of the common sources of this pollutant. The following are sources, as per the literature, within South Africa.

2.6.1 Road vehicles

The internal combustion engine found in all vehicles (regardless of fuel type) is based upon the principle of the ignition of fuel and air within a temporarily sealed vessel to produce power. The results of the combustion include a number of air pollutants, including Carbon Monoxide, Oxides of Nitrogen and Sulphur, and Particulate Matter (Thambiran and Diab, 2011). The sources of vehicles as a significant polluter in Durban has been identified since 2007 as per Thambiran and Diab (2011), with the municipality noting exceedances of the ambient standards based on heavily trafficked areas (Umoya-Nilu, 2015b, Thambiran and Diab, 2011).

2.6.2 Domestic burning and veld fires

Jafta *et al* (2017) outlined the sources of pollutants in urban areas in South Africa primarily from combustion within homes, from the burning of solid fuel (wood and paper) and paraffin. They also noted the impacts from tobacco smoking in indoor areas as significant contributor to indoor air quality. Further to the identified fuels for domestic burning, Butt *et al* (2015) added that coal, charcoal, agricultural residue and animal waste are also burnt. Aurela *et al* (2015) presented information on the use domestic burning for heating as a source of Particulate Matter within the cooler regions of the country, with a peak in the winter seasons.

This source is generally considered important for indoor air pollutant rather than ambient air quality, but it still provides an input of Particulate Matter into the airshed, so should be considered valid.

Veld fires are prevalent in much of South Africa, due to the semi-arid nature of much of the vegetation. The grasslands that occur within many of these habitats have evolved with the incidence of fire, and utilise it as a means to retain species diversity and stop the succession of grassland into forest (Breedt *et al*, 2013). Uncontrolled veld fires can be periodic but large source of Particulate Matter given the volume of biomass that can be burnt during these events.

2.6.3 Coal-fired power stations and other industrial sources

Aurela *et al* (2015) conducting sampling within an area deemed to be free from major sources of air pollution, to look at the background effects of, among other sources, coal-

fired power stations. Their results indicated that there was a clear input of these pollutants to the airshed of the study site. Given that over 90% of energy production within South Africa is tied to coal burning this impact is expected to be consistently present (Makgato and Chirwa, 2017).

There are sources of Particulate Matter from the manufacturing and other industrial sectors (Adewale *et al*, 2014) but these are too manifold to list. Their contribution is not a major factor for this study given that the study site resides within an area with very little industrial activity.

2.6.4 Airport emissions

2.6.4.1 Air quality at airports

The last decade has seen air quality around airports being scrutinised more comprehensively in terms of the impacts of aviation on both the immediate scale (within the boundaries of the airport) and the more local/regional context (communities downwind of the airports) (Wolfe *et al*, 2014, Fluenti, 2001).

The bulk of the research has considered sources of pollution derived from the operations associated with an airport, with very few looking at any external sources of pollution into the airport's airshed. This includes the emissions from aircraft engines (direct and indirect) as well as the ancillary emissions tied to the non-aircraft operations of an airport (Pecorari *et al* 2016, Yilmaz, 2017, Zhu *et al*, 2011, Simonetti *et al*, 2015, Maisol & Harrison, 2015).

2.6.4.2 Aircraft emissions

Majority of the papers that look at the emissions from aircraft are based upon a tool developed by the International Civil Aviation Organisation (ICAO) called the ICAO Engine Emissions Databank (EASA, 2017). This databank was put together from specifications submitted by manufacturers and includes emissions factors for the following variables: Smoke Number (SN), Hydrocarbons (HC), Carbon Monoxide (CO), and Oxides of Nitrogen (NO_x). For the purpose of this study the Smoke Number is the most important as it is used as a proxy for Particulate Matter. The ICAO Engine Emissions Databank defines Smoke Number as follows:

“The dimensionless term quantifying smoke emissions. Smoke Number is calculated from the reflectance of a filter paper measured before and after the passage of a known volume of a smoke-bearing sample” (EASA, 2017).

The basic premise for this, as described by Vujovic and Todorovic (2017) and Pecorari *et al* (2016), is that aircraft engines are not optimised for ground- and low-level operation but rather for operations at cruising altitudes. This means that there is incomplete combustion of Jet A1 (which has a very similar make-up to kerosene) which generates, among other by-products, soot (which is one of the constituents of Particulate Matter).

The authors use the Databank in conjunction with the four stages of flight associated with aircraft-use around an aerodrome. This is known as the Landing Take-Off (LTO) Cycle, and includes “idle” (when the aircraft are on the aprons), “taxiing” (movement from apron to taxiway/runway), take-off (once aircraft has achieved rotation and commenced climb to 3000 feet), and landing (final descent to runway) (Yilmaz, 2017). Simonetti *et al* (2015) added a fifth stage separating take-off and climb-out.

Wolfe *et al* (2014) looked at all stages of LTO to quantify the emissions of PM_{2.5} at 84 airports looking at “near-airport” impacts. These impacts were confined to within 6km of the airport and the results indicated that the airport had a significant impact on the receptors within this area but that the severity was tied to relative operational size of the airport (number of Air Traffic Movements (ATMs)).

Penn *et al* (2017) looked at contributions from airports at large spatial scales. They surmised that with the longer-range transport there was need to incorporate atmospheric chemistry in the modelling to further understand the pollutant loading. They used the Community Multiscale Air Quality (CMAQ) model to understand the contribution of the largest individual airports across a large regional area made up of many airports. Among other pollutants Penn *et al* (2017) looked at PM_{2.5}, with the movement of these from each of the largest airports in the study area. This model only included the LTO cycle which caps the emissions from aircraft at 3000 feet AGL. Their study also did not include any of the indirect airport emissions which will be discussed below. This means that the contributions from the airports were conservative.

Fang (2007) took a different approach to Wolfe *et al* (2014) and Penn *et al* (2017) by looking at the make-up of the Particulate Matter from the airport. The focus of the research

was on the deposition of fine particle into the alveolar portions of recipients' lungs and the effects of this. The fine particles had heavy metals present in them that posed both a toxic and mutagenic risk to the receptors. Majority of the authors noted the increasing understanding of the dire health risks associated with the inhalation of Particulate Matter and ultrafine particles (Fang 2007, Pecorari *et al* 2016, Fluenti 2001, Zhu *et al* 2011, Powell & Lee 2014).

Pecorari *et al* 2016 quantified the total contribution of the Marco Polo Airport in Venice to the air pollution present in the overall Venetian archipelago. Their results indicated that overall contribution of aircraft air pollution to the Venice area was very low, in the range of 0.1-0.3% (this was Carbon Monoxide, Hydrocarbons and Oxides of Nitrogen) of total air pollution in the area. It must be noted that they did not explicitly look at Particulate Matter, but they used the ICAO Engine Emission Databank, which includes this (by means of the Smoke Number mentioned above), so it can be inferred.

Helmis (2011) considered the Athens airport, in Greece, and its contribution to local air quality. They found a seasonal variability that tied the severity of impact to the velocity and direction of the wind, concluding that the bulk of the pollutants remained within and adjacent to the airport.

Vujovic and Todorovic (2017) looked at seasonality of impact at the airport and community level. They found that during cold weather events with associated temperature inversions, there was a trapping of the pollutants closer to the ground. They noted that even with the recent and increasing trend of more flights the situation at an airport level is not serious. This is likely due to aircraft operations introducing small periods of peak pollution which are quickly dispersed.

Hsu *et al* (2013) concluded that there is a peak of Ultra Fine Particle (UFP) emissions in very close proximity to the runway, but that this reduces very rapidly as one moves away from the runway. Zhu *et al* (2011) had very similar findings with UFP emissions highest within the Take-Off phase of flight within the airport boundaries. They concluded the direct impacts would be at an airport scale, which could have health concerns for workforce within the open environment of the aprons and ramps (Moller *et al*, 2017).

The ultimate consensus from the authors considered was that there is a definite source of Particulate Matter emanating from airport sites due to aircraft movements into and out

of the airsheds. From the papers scrutinised it can be summarised that the impact from aircraft emissions are dependent upon the size of the airport, number of air traffic movements, and the prevailing weather. Considering the bulk of the airports investigated, it would seem that the pollution in terms of Particulate Matter from aircraft is not a major overall contributor to the ambient air quality.

2.6.4.3 Other emissions at airport level

Penn *et al* (2017) noted that their study excluded the emissions from ground operations at the airports in their study. A similar trend was noted with Wolfe *et al* (2014), Harrison (2015), Simonetti *et al* 2015 among others.

Simonetti *et al* 2015 observed that at airports there are certain ancillary activities that are common. They discussed the Ground Service Equipment (GSE) such as refuelling vehicles, aircraft tugs, baggage dollies, etc, as well as Ground Access Vehicles, which are those transport vehicles such a buses and staff transport present on the ramp and apron. These are generally diesel-powered vehicles and they contribute to the particulate emissions at an airport site. Harrison (2015) mentioned the same sources but also added the impacts of runway wear, aircraft brake-dust and tyre wear. The other large airport-specific source of Particulate Matter that was noted by Harrison (2015) was the number of private vehicles that access the airport to facilitate the movement of passengers and associated logistics (catering companies, car rental, aviation business, etc).

There is another aircraft emission that was not considered above, and will be referred to as an “other emission”. This is the use of Auxiliary Power Units (APU) in aircraft on aprons. These burn fuel to provide power to the aircraft for essential services such as lighting and air conditioning while docked. These emissions are sometimes not present, as many airports are configured with Ground Power Units (GPU) and Pre-Conditioned Air (PCA) units which allow for aircraft to be “plugged-into” the airport’s infrastructure so that fuel is not used to generate electricity (Fluenti, 2001, Harrison, 2015, Simonetti *et al*, 2015). Simonetti *et al* (2015) noted that there are large outputs of Particulate Matter from the use of APU. This is also tied to the On-Time Performance (OTP) of airports, where aircraft could remain on the aprons for extended periods, which would result in higher emissions.

These emissions can add noise to the signal of aircraft contributions when ambient air quality monitoring is done on airport sites. Its lack of inclusion in the emissions inventories of many of the mentioned studies results in underrepresentation of the impacts of airports.

Maisol and Harrison (2015) conducted a number of pairwise comparisons with ambient air monitoring in and around London Heathrow airport (LHR). They looked at eight years of data from LHR and seven other monitoring stations in varied proximity to the airport in an effort to isolate airport contributions to the ambient air quality. They concluded that it was difficult to isolate the airport with the inputs of roads and other industry in the area. Ultimately, they conceded that airports and roads had a combined moderate impact in terms of Particulate Matter.

2.6.4.4 Confounding factors

As mentioned above, the authors such as Maisol and Harrison (2015) had limitations in their studies with regards to the ring-fencing of sources of Particulate Matter. Given the plethora of emissions sources and the mixing of air within airsheds (even over very large spatial scales (Penn *et al* 2017)), there could not be robust source apportionment. Authors such as Hsu *et al* (2013), Simonetti *et al* (2015), Fluenti (2001) used measurement of emissions very close to the airport to try and minimise the interactions of other emissions, as well as using baselines from other areas to normalise their data.

Fang (2007) attempted to correlate the air quality in the area around the airport to the airport operations but this was confounded by the presence of both vehicle freeways and industry (in this case a foundry in close proximity to the airport).

2.6.4.5 Conclusion

From the studies examined it can be seen that there are significant sources of Particulate Matter emanating from airports (based on their aircraft and associated activities). Friedl (2003) describes the historical growth of the aviation sector and the predicted rampant growth in future (Pecorari *et al* 2016). This means that there is potential for the existing, somewhat smaller contribution, to grow in magnitude. There are operational procedures to lower the impacts moving forward and these are tied to more efficient LTO cycles. Yilmaz (2017) cited reduced taxiing time as having the largest practical potential to reducing existing emissions.

2.6.5 Sugarcane burning

The production of sugar is tied to the growing and processing of the grass species *Saccharum* (Ripoli *et al* 2000). Mashoko *et al* (2010) conducted a Life Cycle Assessment of the sugar cane industry in South Africa and outlined the production practice for this crop. At its most basic process flow the cane are grown, burnt pre-harvest, cut, transported to mills, and processed into granulated sugar. South Africa is one of the largest sugar producers in the world, with approximately 85000 direct jobs associated within the industry, and it draws a revenue of roughly R6 billion per year (Mashoko *et al*, 2010). The literature was reviewed in terms of research into sugar burning practice, and the impacts from sugarcane burning in relation to Particulate Matter.

2.6.5.1 Rationale for burning

The basis for the burning of sugarcane is tied to both efficiency of harvest, and the lowering of costs to transport the mills (Ripoli *et al* 2000). Within the context of the KwaZulu-Natal sugar industry the majority of cane is burnt before harvest (80-90%)(INR, 2007, Hiscox *et al*, 2015). The prevalent sugarcane production company in KwaZulu-Natal, Tongaat-Hulett's Sugar (THS) have considered the option of harvest prior to burning but at present the sugarcane mills are also designed to process burnt cane (INR, 2007). When cane is burned pre-harvest the resulting products are just the stalks (80% of the “trash” (tops, leaves) are burnt off (Ripoli *et al*, 2000) which means that there is a lower mass of product being shipped to the mills. The other benefit of burning cane is that the heat drives the moisture out of the cane, so the sugar is already condensed, and more cane can be shipped to the mill per unit effort (Mashoko *et al*, 2010, Cristale *et al*, 2012). This means that for the given weight of a shipment there is a higher sugar output. The corollary of this is that if cane are not burned the transport costs are higher and the mills will need to process more cane for the same sugar output.

Hiscox *et al* (2015) investigated an alternate method for the burning of cane, and experimented on the use of burning before and after cutting. The usual practice for cane harvesting is to burn the trash off the cane then cut the stalks (“Standing Burn”). There is an option to cut the stalks and strip the trash, which is then burnt on the ground (“Ground Burn”). Hiscox *et al* (2015) modelled the plumes of burns under both regimes then used Lidar to measure the plumes, and ground-truth their models. It was noted that there was a discrepancy between the standing model and empirical testing. Ultimately it was

decided that a post-harvest burn offers the best adherence to the model and keeps the impacts to a more local scale. Both the standing and ground burns showed very high Particulate Matter impacts within 200m of the burn location.

According to Hiscox *et al* (2015) if the cane trash is not burned there are considerable costs associated with it as it can have negative soil consequences both in terms of soil moisture and allelopathy (chemical toxicity introduced by the plant as a defence mechanism). Hiscox *et al* (2015) did however note that the negative associations of trash are dependent on the region in question, and that certain areas need the trash to remain on the ground to reintroduce nutrients into the soil (this was specifically an Australian context, but reinforced by Mashoko *et al* (2010) for the South African situation). Mashoko *et al* (2010) and Ripoli *et al* (2000) advocated the use of the trash as an input into power generation. Within the South African context there is already use of the milled byproducts (known as “bagasse”) in furnaces to power the mills (Mashoko *et al* 2010).

2.6.5.2 Impacts from burning

In the LCA undertaken by Mashoko *et al* (2010) there was an estimate of 280kg of cane burned per hectare of field. This equates 90 720 tonnes of biomass being burned per year. They did not quantify the impacts of this in terms of Particulate Matter as their focus was on Green-House Gas (GHG) emissions, but they anecdotally indicated that the polluting emissions from cane are not sustainable.

Cristale *et al* (2012) considered the impacts of cane burning in Brazil, in terms of Particulate Matter (especially the Polycyclic Aromatic Hydrocarbons (PAH)). Given that cane is only harvested for approximately six months of the year (INR, 2007, Cristale *et al*, 2012), an experiment was undertaken to gauge the PAH concentrations during the harvest “Burning season” and the non-harvest “Non-burning season”. The results of their study indicated that there was an order of magnitude increase in the levels of PAH in the burning season, and concluded that the incidence of sugar cane burning presented a high public health risk, noting the carcinogenic potential of high levels of PAH (Cristale *et al*, 2012). Similar findings were noted by De Andrade *et al* (2010) who investigated the levels of Particulate Matter in cities within 5km of dense sugar cane farms. They looked at four sites, noting the differences in Particulate Matter between burning and non-burning seasons. Their results indicated a 300-500% increase in Particulate Matter during the burning season, but this includes all sources within the city. They utilised a Principle

Component Analysis and Varimax Rotation model to try and quantify the contribution of this increase to sugar cane emissions. They had some success in isolating the cane signature, but the results were not particularly robust. They were interference in the quantification from the emissions from home-cooking and vehicles, but they concluded the sugarcane was a large contributor to the overall high levels of Particulate Matter in the ambient air.

Cancado *et al* (2006) followed a similar methodology to Cristale *et al* (2012) and De Andrade *et al* (2010) but added a layer of public health responses to the higher levels of Particulate Matter. They noted an increase of roughly three times the level of Particulate Matter during the burn season. Cancado *et al* (2006) added that the burn season had additional Particulate Matter sources associated with the cane burning as there was a large increase in vehicular movement to transport the cut cane during the period. There were also higher levels of airborne particles due to the exposed soil left after sugar cane harvesting. Cancado *et al* (2006) correlated the high levels of Particulate Matter with hospital admissions for respiratory disorders. They found that there was an associated increase in admissions when the Particulate Matter levels were high, most notably in the cohorts of children and the elderly.

2.7 Conclusions

The aim of the literature review was to provide some context for the rest of the study by presenting the current literature around topics of air quality management, both internationally and locally. This was done by focussing on the sources and consequences of poor air quality, and what the current best practices ascribes as to how these can be managed effectively.

The literature reviewed denoted a number of salient points that are important for this study. The first of these is that the impacts of poor ambient air quality are more severe than previously considered. This was especially evident in the case of Particulate Matter and how this contributes to growing public health concerns. The response to these concerns by the South African Government was in the development of Air Quality Management Legislation, firmly grounded within the Constitution of this country, to reduce the impact of poor ambient air quality on the population.

The tools developed by this legislation include ambient air quality standards to act as the proverbial canary in the mineshaft; to indicate where certain pollutants are being noted in higher concentrations over specific time periods. The observation of exceedances to these standards act as an early warning of where management action should be focussed.

While considering the means to reduce the impacts of pollution, the sources of pollutants were reviewed, with a focus on Particulate Matter. Given that the study location is an airport, the typical sources of Particulate Matter pollution were investigated both from an aircraft viewpoint as well as a more holistic airport-wide stance. This was done at an international level, reviewing the air pollution impacts from a number of airports, of different sizes and management regimes.

Noting the hypothesis of the sugarcane burning around the study site possibly having an influence on the ambient air quality in terms of Particulate Matter, a number of specific impact assessment studies were engaged with. This was done in order to understand what the typical emissions from sugarcane agriculture are.

The culmination of this review paints the scene for the investigation of the management of ambient air quality at the King Shaka International Airport, and how it may be affected both by its aviation operations and the surrounding sugarcane agriculture. This all resides within the framework of management ensuring both legal compliance, and best environmental practice.

There is the potential for tension between the adherence to compliance obligations around air quality management, and the spirit of the legislation. We have noted that the legislation in South Africa focusses on the impacts upon the most vulnerable, and that the management interventions for emitters are tied mostly to pollution in the immediate vicinity of the source. To this end there may be a disjoint where the ring-fencing of a management system to the boundaries (or just further out) of an emitter does not consider the true cumulative impacts on vulnerable communities. There may be a need for the scope of environmental management systems to be expanded to cater not simply for legal compliance but for environmental best practice.

Chapter 3: Data and methods

3.1 Site location – King Shaka International Airport

The King Shaka International Airport (29°36'42"S, 31°07'09"E – La Mercy, Durban, South Africa; IATA: DUR, ICAO: FALE) is built on an elevated platform (~90m AMSL) along the South East coast of Durban. It caters for both Commercial Passenger Travel and Cargo, with a small number of private operations. It has an annual throughput of approximately 5 million passengers.

The airport construction commenced in 2007 and was completed in May 2010, the site was built in an area with very little prior development. It is surrounded by sugarcane farms, with a small residential area to both the North (Herrwood) and South (Mt Moreland). The closest major towns are Tongaat (4km North), La Mercy (3.5km South), Westbrook (3.5km East), and Verulam (6.5km West).

There is a National Road (N2) which runs along the Eastern boundary of the property. There is a provincial road (R102) that runs along the Western boundary of the property. These roads run parallel to each other and are connected by the M65 road which grants access to the airport from either of these main roads. The Watson Highway runs to the North of the airport site.

The continuous ambient air quality monitoring station is situated towards the southern end of the runway (29°37'22"S, 31°06'09"E), as noted in Figure 1 below.

During the study period of July 2014 to June 2015 the temperature variance was from 9.14 - 39.5°C (as measured on an hourly basis). The mean temperature was 21.21±3.8°C. The predominant wind direction is NE-SW as per the runway alignment of 60/240 degrees on RWY06 and RWY24 respectively.

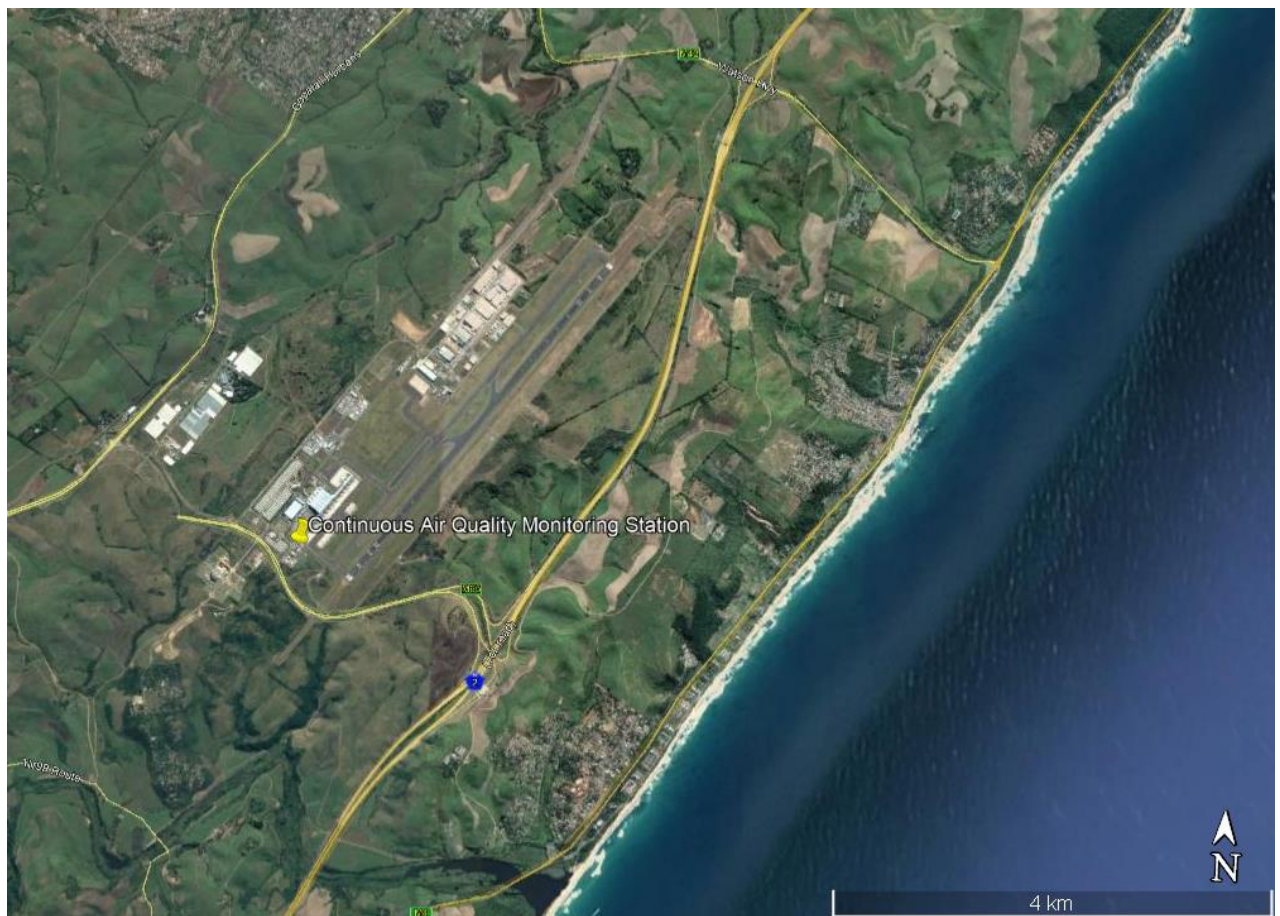


Figure 1: A map indicating the location of the King Shaka International Airport, and the continuous ambient air quality monitoring station (Google Earth, 2017).

3.2 Characterising ambient air quality at King Shaka International Airport

3.2.1 Introduction

Ambient air quality sampling was conducted using an automatic continuous monitoring station located at the King Shaka International Airport, as noted in Figure 1 above.

3.2.2 Data capture

The station was operated on a 24-hour basis during the study period, and was managed by an external service provider with the expertise to ensure that the system consistently performed. The station comprises several instruments, outlined in Table 2 below.

Table 2: The instrument specification for the continuous monitoring station at King Shaka International Airport.

Determinand	Instrument model
Carbon Monoxide (CO)	Environnement S.A IR Gas Filter Correlation Carbon Monoxide Analyser CO12M
Particulate Matter (PM ₁₀)	Environnement S.A Continuous Automatic Suspended Particulate Monitor MP101M
Nitrogen Oxide (NO)	Environnement S.A Chemiluminescent Nitrogen Oxides Analyzer AC32M
Nitrogen Dioxide (NO ₂)	Environnement S.A Chemiluminescent Nitrogen Oxides Analyzer AC32M
Nitrogen oxides (NO _x)	Environnement S.A Chemiluminescent Nitrogen Oxides Analyzer AC32M
Sulphur Dioxide (SO ₂)	Environnement S.A UV Fluorescent Sulphur Dioxide Analyzer AF22M
Ozone (O ₃)	Environnement S.A Ozone Analyzer O342M
Weather (Temperature, Humidity, Solar Radiation, Wind Speed, Wind Direction)	Young Instruments

The instruments covered in Table 2 were calibrated as per the manufacturer's requirements. This included an auto-calibration each evening, and twice a month a zero and span check was conducted by a qualified technician. In the event of instruments being out of calibration they were serviced, and brought back into required calibration tolerances. During the period of study the instruments remained within the required tolerances of the calibration (Umoya-NILU, 2014, 2015a).

The sampling from the continuous monitoring station was conducted on an hourly basis for the duration of the study. While the station monitors a wide array of variables, for the purpose of the study only the Particulate Matter was scrutinised in depth. This was due to the comparatively low values noted in the other parameters (see table of adherence to the NAAQS above)

The instrument which measures the Particulate Matter is based on the ISO 10473:2000 standard and uses beta attenuation to quantify the PM₁₀ concentration. This is a reference method compliant with the US-EPA (EQPM-0404-151) and the EN 12341 (I-CNR 087/2004, F-LCSQA). The instrument has a detection limit of 0.5 µg/m³ to 10 000 µg/m³ and it accurate to 5% of the reference standard (Environnement-sa, 2017)

3.2.3 Data processing and analysis

3.2.3.1 Data analysis – Characterisation of PM₁₀ trends

The statistical program *R* was used for the bulk of the analyses, with all air quality related calculations being conducted through the *OpenAir* plugin (Carslaw and Ropkins, 2012). The pollutant and meteorological data from the continuous monitoring station was formatted as per the requirements of *OpenAir*, such that it could be used to analyse the information. The *OpenAir* manual was used to ensure that all the correct steps were followed when analysing the data and presenting the results (Carslaw, 2015).

3.2.3.2 Data analysis – Identification of the exceedance incidents

The daily mean data were screened using the appropriate thresholds in the NAAQS to identify on which days there were exceedances of the thresholds for the Particulate Matter.

3.3 Analysis of variability to identify major sources of Particulate Matter

3.3.1 Introduction

Given the hypothesis that the sugarcane burning may have an influence on the higher concentrations of Particulate Matter an experimental approach was developed to compare the ambient air quality both during and outside of the seasonal burning events.

3.3.2 Data capture

At the King Shaka International Airport the Aerodrome Rescue and Fire Fighting Services (ARFFS) are responsible for the management of communication around sugarcane burning. They provide an intermediary between the Sugar Cane Farmers and Air Traffic and Navigational Services (ATNS) as per the Cane Burning Procedure. Prior to any cane burning taking place within a 10km radius of the airport a “request to burn” is issued to

the Air Traffic Controller (ATC) from the cane farmer. Depending on the weather conditions and air traffic volumes the ATC will give confirmation of the burn to go ahead, or request that it is conducted at a later stage. During the course of any burn there is communication maintained between the two parties via ARFFS, such that if the smoke from the fire is causing operational consequences a request for cessation of burning can be issued.

The communications between the cane farmers and ATC are recorded in a daily log at the Airport's Fire Station. During each request the proposed location of the burn as well as the planned starting time is recorded.

The dates, times and locations of the burns conducted during the period were recorded. The locations were converted from a grid reference to a geo-referenced co-ordinate. The presence/absence of a burn was added to the continuous monitoring dataset so that days could be filtered for a burn having occurred or not.

3.3.3 Data processing and analysis

3.3.3.1 Data analysis – Spatial relationships

The locations of the identified burns were plotted onto a map in *R*, to visualise the spread of burns and the proximity to the airport. This map was compared with a pollution rose (produced in *R*), to confirm if the directions of high impact correlate with the location of the burns.

3.3.3.2 Data analysis – Statistical comparison between treatments

To compare the difference in Particulate Matter concentrations between the burning season and non-burning season the year was divided into two treatments, and the daily means per day were compared.

A Welch Two Sample *t*-test was conducted to evaluate if there was a significant difference between the daily mean concentration in Particulate Matter during the burning season versus the non-burning season. This was conducted in *R*, with assumed unequal variance.

Table 3, below, outlines the two sample treatments, including the treatment periods, and valid data points per treatment.

Table 3: The details of the information used to develop *t*-test for comparison of the treatments

Treatment	Period	Days	Data points
Burning season	June-November	183	182
Non-burning season	December-May	182	113

The null hypothesis for the *t*-test is that the difference in means between the populations is zero.

3.3.3.3 Data analysis – Graphical comparison between treatments

A boxplot was produced in *R* to display the variation between the two treatments to see if there is suitable separation between them.

3.3.3.4 Data analysis – Trajectory modelling

Trajectory modelling was used to identify if known sources of pollution could have an effect on the ambient air quality within a short time frame (within the course of a day). The only readily identifiable sources were the sugar cane burns as they had accurate location information as well as a rough timeframe. This was most useful to be done on those days when there was an observed exceedance to the thresholds stipulated in the NAAQS. The days where the exceedances were noted were placed in a trajectory model to understand whether or not the weather on the day would have caused any pollution to move from the source site towards or away from the airport.

3.3.3.4.1 Model - HYSPLIT

According to Rolph *et al* (2017), the READY (Real-time Environmental Applications and Display sYstem) offered by NOAA includes tools for modelling the trajectory of air parcels, and is used in “forest fire and prescribed burn smoke forecasting”. The system functions both forwards and backwards in time allowing for the modelling of historical burns as well as predicting where plumes may travel. The Hybrid Single-Particle Lagrangian Integrated Trajectory model (HYSPLIT) as described by Stein *et al*, 2015, underpins the READY.

HYSPLIT is based on a langrangian puff/particle model and can be used for simple trajectories from a single source to large groups of simultaneous sources (Rolph *et al*, 2017).

Given that the need to look at the effects of sugar cane burns on the air quality at the airport it was decided to use the HYSPLIT for each individual burn that occurred on days where the NAAQS were exceeded. The purpose of this was to understand if the prevailing meteorology on the day of each burn resulted in the pollutant (Particulate Matter) being transported over the airport, and specifically towards the continuous air quality monitoring station. A similar methodology was used by Tsai *et al*, 2015, for the back trajectory of pollutants from fires during a festival in Tainan.

HYSPLIT is a web-based application which has integrated meteorological data. For the study site, the Global Data Assimilation System (GDAS) was used, as it covered the airport in the highest spatial resolution of the options available (its utilises a grid array of 0.5 degrees)(Rolph *et al* 2017). For the days in question the model was setup using the “ensemble” trajectory. According to Rolph *et al*, 2017, the ensemble model is useful when there is uncertainty in the trajectory of the particle. It was decided that as a sugar cane burn would represent highly turbulent air, given its heat, there would likely be numerous possible trajectories. The ensemble runs the model three times simultaneously, with a slight shift in the meteorological data to account for possible variance.

For each of the identified burn events the model was set to run from 12:00-20:00 (GMT+2), as the cane burns historically took place during the afternoon until early evening. The specified height of the source of the particle was set at 251m AGL as according to Stein *et al* (2015) the ensemble model is more robust with a source height of more than 250m. Given that the cane fires were not once off releases of emissions, but rather a prolonged burn with residual emission the model was set to start a new trajectory every hour during the eight-hour runtime.

The model output was in the form of a Google Earth .kmz file which depicted the trajectories from the source moving out to the end of the eight hours of the simulation. The numerous trajectories were scrutinised both for consistency (as the ensemble model can result in output with no consistent flow, and very little robustness) (Rolph *et al* 2017), as well as whether or not the trajectories intersected the airport.

3.4 Reviewing efficacy of ambient air quality management practices at King Shaka International Airport

The King Shaka International Airport has a procedure in place to manage the sugarcane burning as this can have a major impact on aviation operations. This information will be used to understand what impact this has on the ambient air quality.

3.4.1 Data capture

3.4.1.1 Observation records

The adherence to the existing procedure was reviewed by scrutinising the information recorded in the daily observation logs at the Fire Station and comparing it to the requirements of the procedure.

3.4.2 Data processing and analysis

To investigate for instances of the following:

- Cane burns conducted without notification
- Information not recorded accurately in the Observation Book
- Smoke from Cane Burns interfering with air traffic operations

3.5 Quality control

During the course of the study the data collected were scrutinised for robustness to ensure that any artefacts or non-representative data did not skew any of the results. This section covers the methodologies employed to ensure that all anomalous data were removed prior to any of the analyses.

3.5.1 Particulate Matter data from analysers

The information from the analysers were time corrected and placed within a single dataset for review. The system includes automatic flagging of data that it detects as non-representative. The dataset was reviewed for these flags and all such data were marked as missing (in the code the signifier “NA” was used as per the *R* convention).

The second round of quality control was to remove the data that occurred during the calibration events. These were artefacts both from the daily system-based calibrations as

well as the bi-monthly span and zero check calibrations. These were manually converted to missing data.

There was a check for sensibility of data observations. Here there was a discrepancy with the PM₁₀ data during the months of March and April. While the system passed all the calibration tests during the period the levels of PM₁₀ were much too low. The average value during the period was $0.67 \pm 0.60 \mu\text{g}/\text{m}^3$ and this was too close to the lower detection limit of $0.5 \mu\text{g}/\text{m}^3$ to be used with confidence. The max during this period was $5.72 \mu\text{g}/\text{m}^3$. It was decided to remove these data from the analyses as it would highly skew the results. This was further decided after consulting the baseline assessment that was conducted for the eThekweni Municipality that quantified a background PM₁₀ level of $16 \mu\text{g}/\text{m}^3$ (Umoya-NILU, 2015b).

Spikes in the data that had no preceding nor proceeding continuity were removed.

The data capture rate post quality control for PM₁₀ was 75.2% and thus considered robust.

Figure 2 below indicates the data visualised over the period. The red bars indicate where data was removed during the quality control process. The blue bars indicate where data was kept after the quality control. The green bars on the left indicate the frequency distribution of values noted with the bulk noted between $10\text{--}40 \mu\text{g}/\text{m}^3$. Please note that the red blocks are only visible for those days where significant data loss occurred.

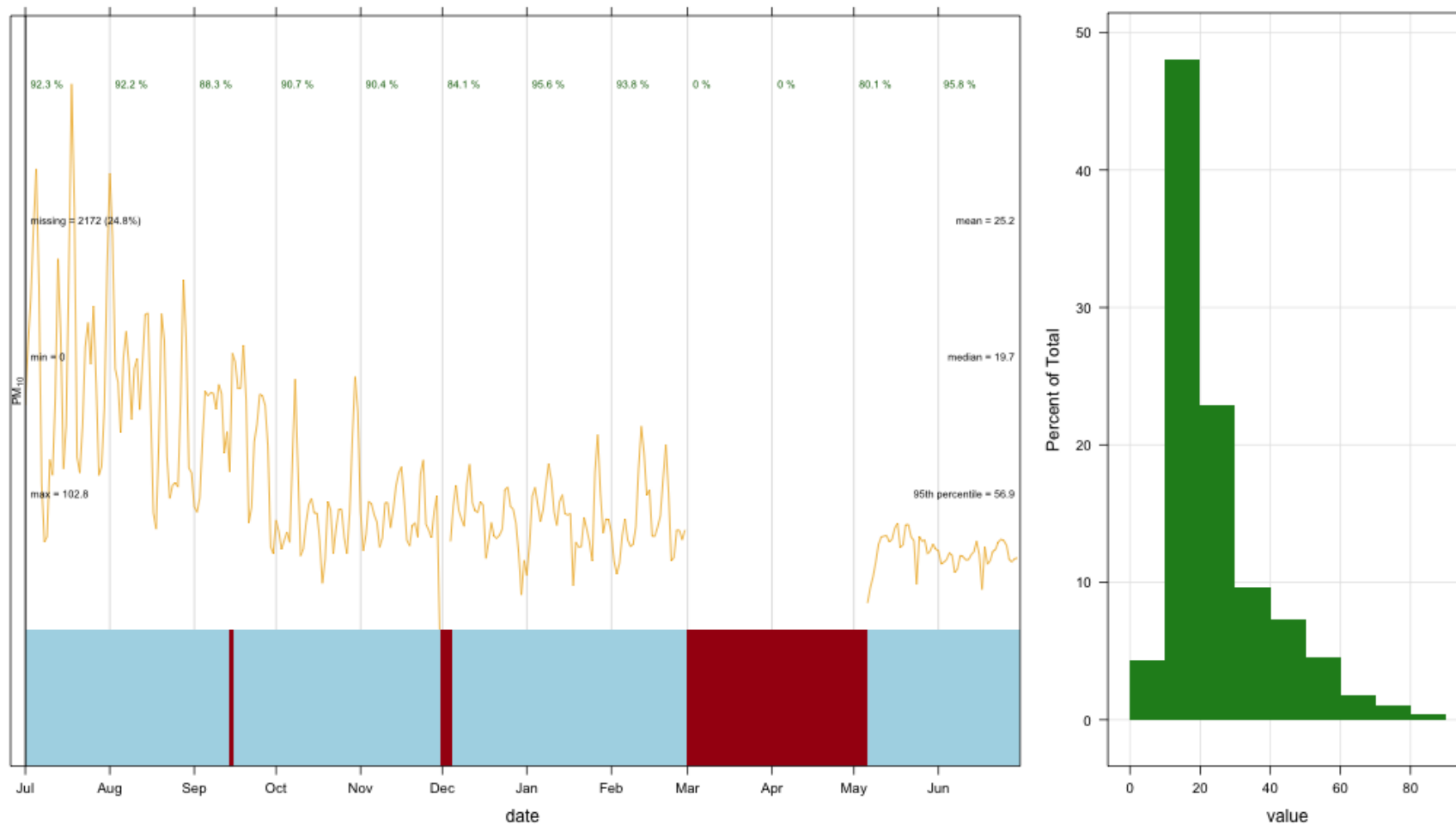


Figure 2: Summary Plot of data over the period July 2014 – June 2015, indicating the missing data and general trends.

3.5.2 Burn information

The process for the recording of the information on the burns is manually filled in and kept on hardcopy in the Observation Book at the Fire Station on site at the King Shaka International Airport. The Observation Book was reviewed for burn information and this was digitised with the details from each day. While copying the information, there were several logs that did not have legible location information, so these were excluded from the dataset. Of the 190 burns that were recorded only 172 had valid location information. This gave a data capture-rate of 90.53%.

Not all entries included a confirmed start and end time of the burn; many were requesting instantaneous burns, or burns that would occur within the next few hours. Due to this it was decided that the information on the burns would be tied not to hourly presence/absence data but rather each day would be considered as having had a burn conducted or not. The burns are conducted in the afternoons, so for the purpose of further use of these data the burns were binned into a single time of between 12:00-20:00 local time (GMT+2)

The location of the burn was based upon a map within the Cane Burning Procedure divided into a grid outline with corresponding polygons being identified by letters and numbers, e.g. A13, B17, etc. Each of these blocks is 100 hectares in size, and if any burning is to be undertaken within those 100 hectares the grid would be identified as the burn location. Where a burn was referenced as a single grid the centre of the grid was used as the location reference. Where the burn was referenced as spanning more than one grid cell, the centre of the shape was considered as the location of the burn.

3.6 Limitations and assumptions

The study aims to understand the roles of certain agents acting upon a complex air transport and dispersion system. The empirical nature of study seeks to maintain objectivity so that the results are not auto-correlated, nor to allow bias to skew the conclusions of the study. The approach is one of reductionism, and to this end there are certain limitations that have been considered. These are listed below.

3.6.1 Burn locations

The exact location of each burn has a fairly large error given that the burn could be occurring anywhere within a 100-hectare area. There is no prescribed size of burn either, so in theory it could be possible that for any burn there could be a range from <1 hectare to 100 hectares being burned. This means that each burn location does not necessarily produce the same volume of emissions nor burn for the same period of time. For the purposes of this study the burns were assumed to be of the same size and burn for the same duration.

The other error associated with the location of the burns is that for the purpose of HYSPLIT modelling; there is some uncertainty around the exact starting location of the model's trajectory source. This error is significantly minimised given the spatial resolution that the model utilises. The smallest block of weather effects that the model uses is normalised for a 0.5 degree x 0.5 degree area. This is larger than the airport site in its entirety, so the start location of each burn within a grid location should not affect the output.

3.6.2 Air quality monitoring results

It is noted that the results are somewhat positively biased towards the airport as a receptor for pollution from the sugarcane burning. This is because there is already active management in place to reduce emissions passing over the runway (especially smoke that may cause visual obstruction to the pilots). This means that the impacts on other potential receptors within the area are not represented by the results of this study, and cannot be used as such. The impacts on the community surrounding the airport are likely increased due to the exclusion of the airport site from assumed direct impacts associated with the burning.

3.7 Conclusion

The specific methodologies prescribed above are considered the best practicable techniques to provide meaningful results that can be used to quantify the ambient air quality as well as the management interventions in place. This will allow for robust decisions on the efficacy of the existing management at the airport.

Chapter 4: Ambient air quality at King Shaka International Airport

This chapter outlines the results obtained from the various data analyses conducted. The results from each analysis are broken down in terms of how they relate to the objectives in a sequential order.

4.1 Characterisation of ambient air quality

4.1.1 Wind speed and direction

In terms of characterising the ambient air quality at the King Shaka International Airport, the first matter to consider is the prevailing wind during the period. Figure 3 below is a wind rose that was constructed from the weather data recorded over the duration of the study.

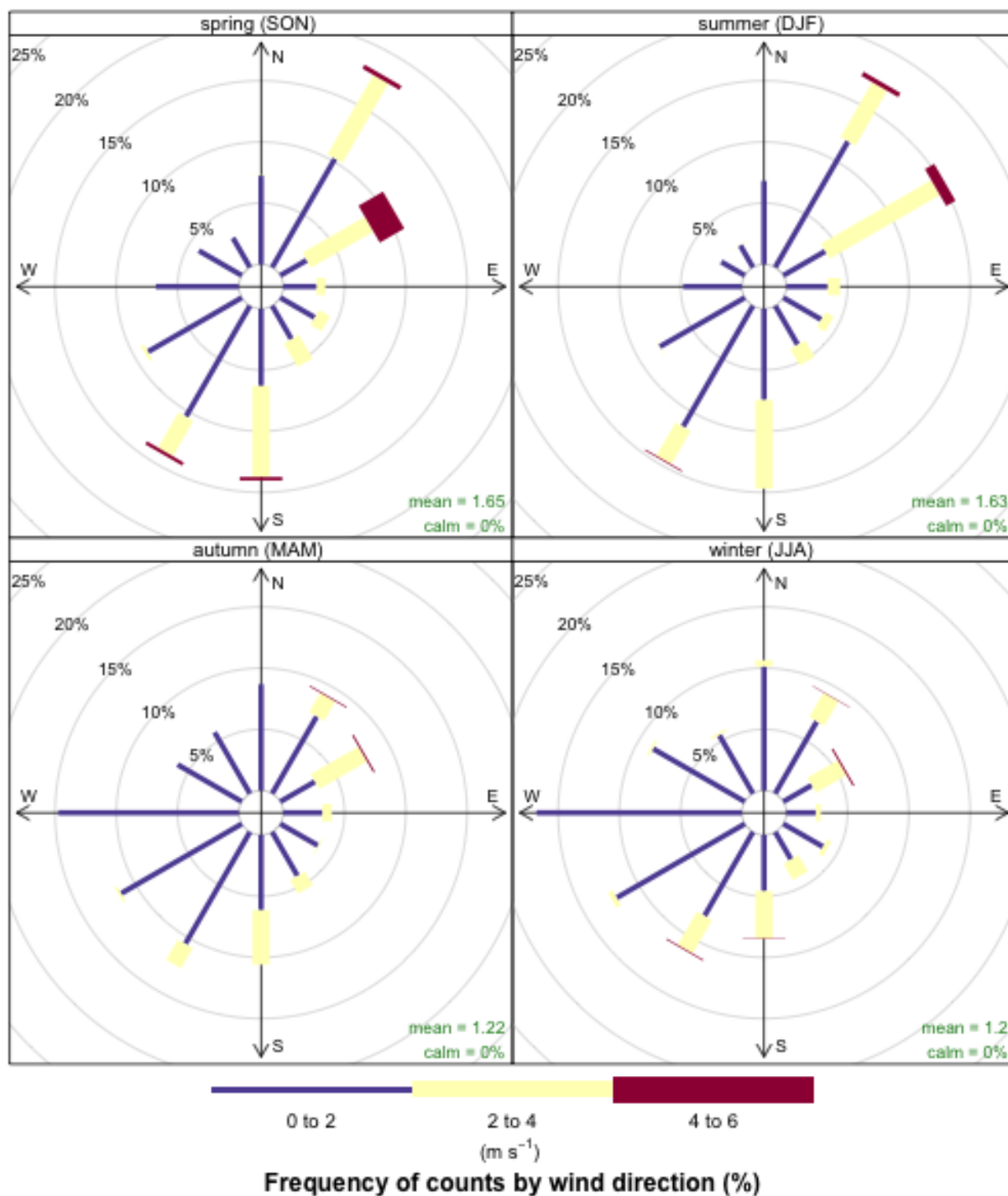


Figure 3: A seasonal wind rose based on observed weather at the continuous monitoring station for the period July 2014 – June 2015.

Figure 3 above displays a pattern of two distinct wind regimes. During the spring and summer months the wind directions and speeds are fairly closely aligned with slightly higher wind speeds noted from the North East in spring. The predominant wind direction

is the North East to South West (with some further wind noted from the South). This is to be expected given the alignment of the runway.

In the Autumn and Winter months the pattern is again aligned, but not a match to the previous two seasons. We note a lowering of the overall wind speed over these months, and there is less of a clear wind pattern, with slower winds originating from all directions. The North East, South West trend is still noted, but there is also a stronger westerly noted, which was absent in the spring and summer months.

4.1.2 Characterisation of Particulate Matter trends

The Particulate Matter concentration was plotted as a daily mean (as this is the averaging period that the NAAQS require adherence to) for the duration of the study.

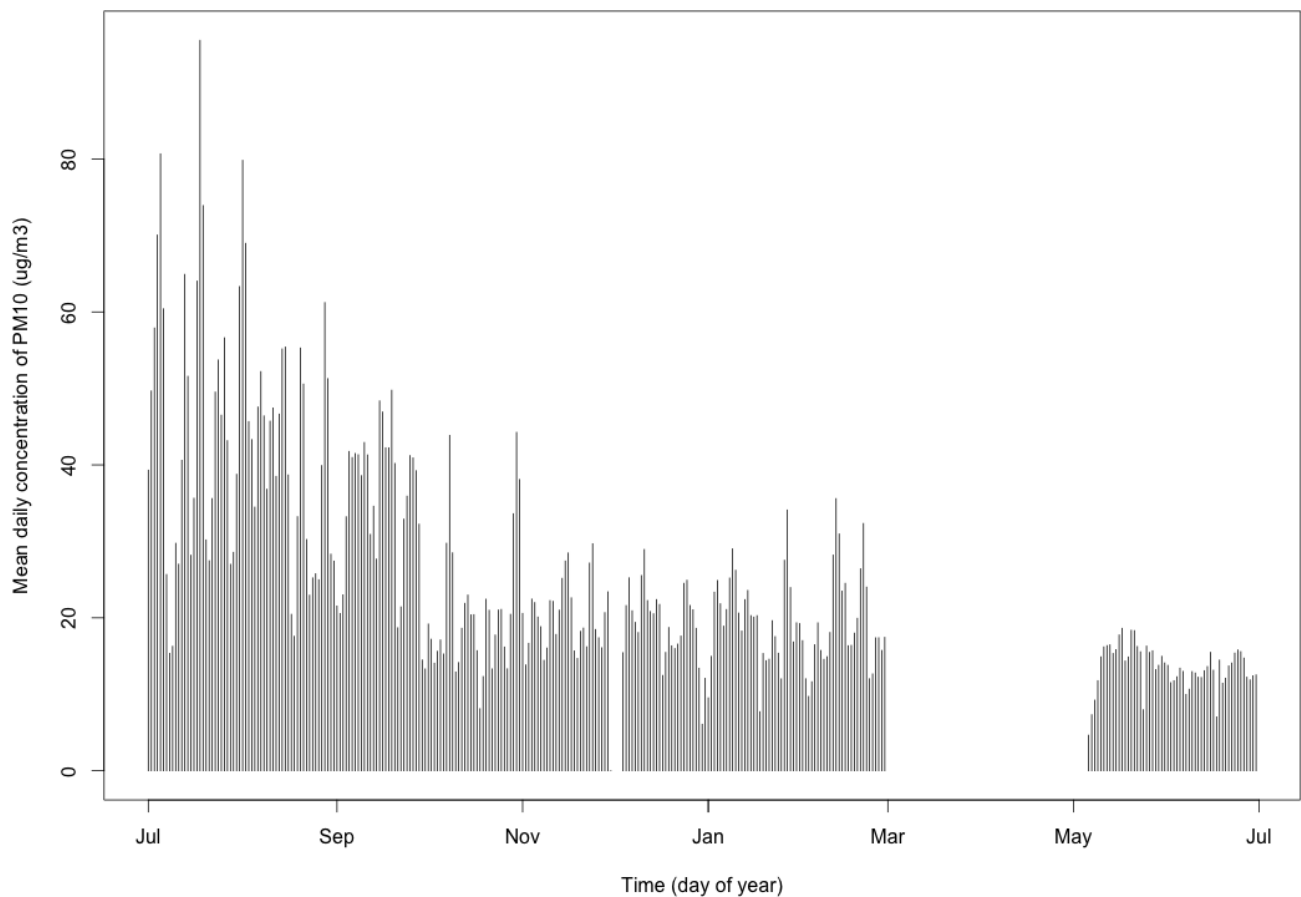


Figure 4: A bar graph indicating the mean daily concentration of Particulate Matter over the study period

From figure 4 we see that there is a portion of data missing from March and April, with smaller gaps noted in December and May. The remaining data indicate a baseline of approximately 15-20 $\mu\text{g}/\text{m}^3$ per day. This is in line with the results from Umoya-NILU (2015b) who quantified the baseline PM concentration for the entire eThekweni Municipality. There is higher variability in the concentrations during July to December, with higher spikes noted during this period. The highest spike is observed in July which is in excess of 100 $\mu\text{g}/\text{m}^3$. The concentrations become more consistent from January onwards. There is an overall decrease in the concentration of Particulate Matter from the start of the monitoring towards the end.

The data presents a trend of highest concentrations of Particulate Matter during the winter months.

It must be noted that the output from the *timeVariation* function from *openAir* was not utilised as the results indicated that the system did not take distinct hourly readings, but rather binned four results per day into a mean that was presented in an hourly format. This meant that the daily variation in concentration was not possible to observe. For the purpose of this study it is not a material failure of the monitoring system, as the adherence to the NAAQS is based upon a 24-hour average, which the instruments have provided. It was thus decided to exclude diurnal variation of concentration in the characterisation of the Particulate Matter.

4.1.3 Identification of the exceedance incidents

Table 4: Dates of exceedances of the threshold concentrations of Particulate Matter, as per the National Ambient Air Quality Standards.

Date	Particulate Matter Concentration ($\mu\text{g}/\text{m}^3$)
5 July 2014	80.67
18 July 2014	95.52
1 August 2014	79.82

4.2 Consideration of location and timing of sugarcane burning events

4.2.1 Spatial relationships

The location of each burn was placed within a database and this was plotted onto a map (Figure 5) to indicate the spread of burns around the airport. It was observed that certain locations had multiple burns occurring on it during the course of the study. When the map was produced each burn location was denoted by a dot, and the more burns that occurred in an area the larger the dot was produced (the size of the dot was proportional to the number of burn iterations - dot size ranges from 1 burn - 9 burns). This allowed for a quick means to observe where the most activity took place. During the course of the study the maximum number of burns in a single location was nine.

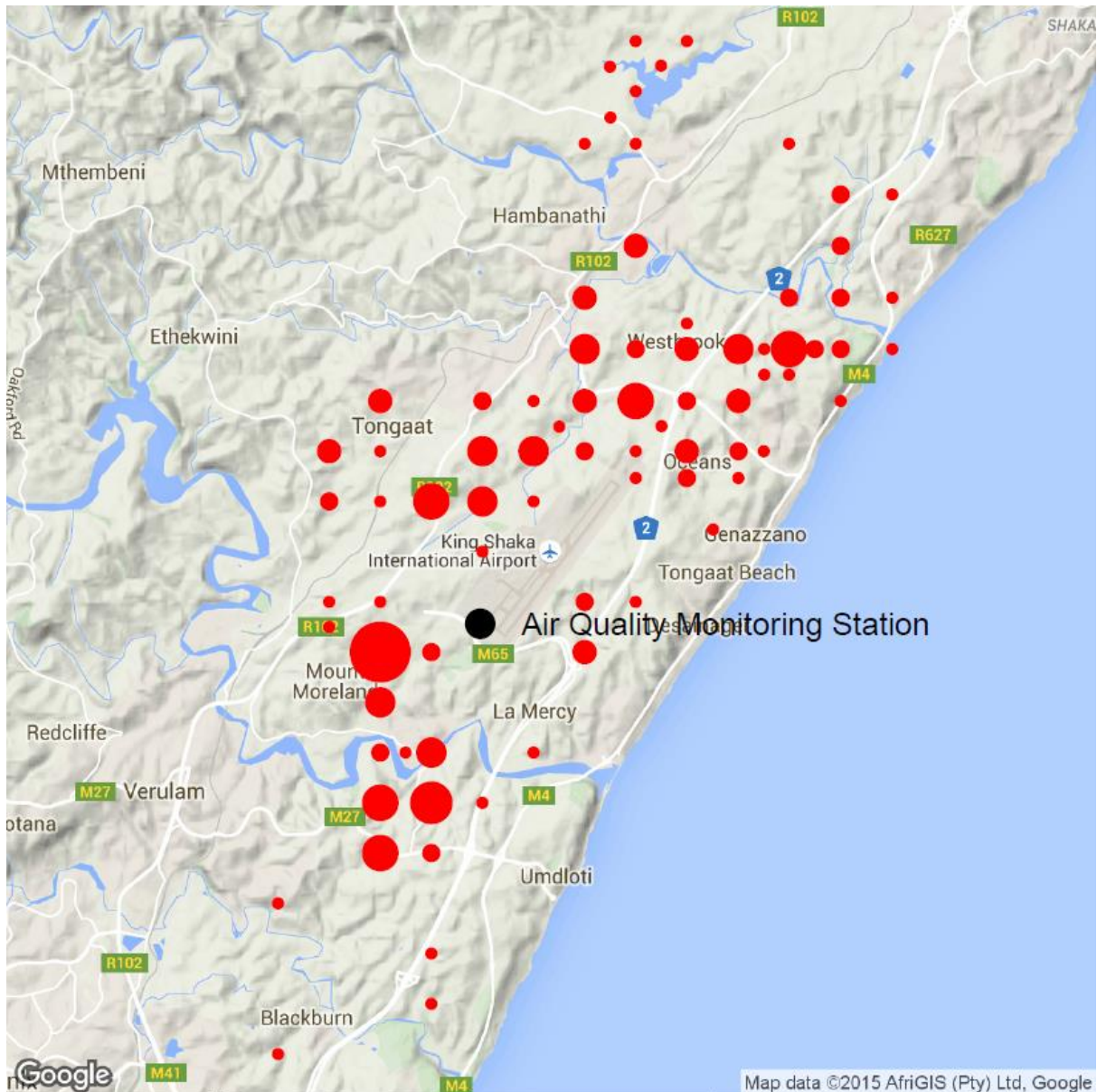


Figure 5: A map indicating the location of the King Shaka International Airport (aircraft logo), the continuous monitoring station (black dot), and the burn locations (red dots)

Figure 5 above displays that there is non-uniform distribution of burn locations around the airport site. There are more distinct burn locations that occur north of the airport than south, and that the frequency of burning at single locations decreases with an increase in distance from the airport. There are comparatively fewer burns that occur on the Eastern side of the airport, given the proximity to the sea. While the spread of burns is shifted towards the North, those burns to the South and West of the airport have a greater number of burns at each location. The largest dot, which represents 9 burns over the

period is in close proximity to the continuous monitoring station. There is a concentration of burns along the extended runway line.

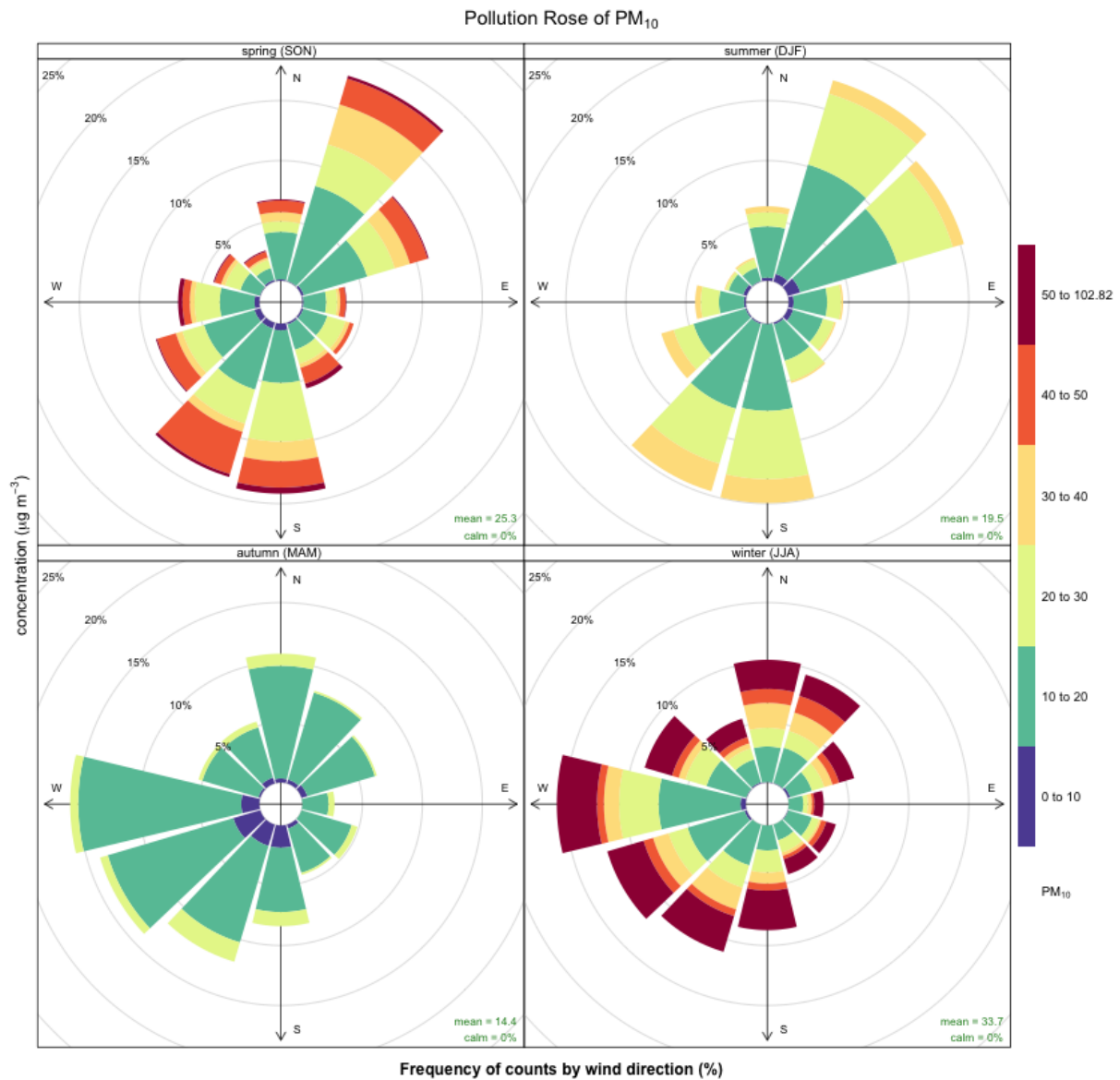


Figure 6: Seasonal pollution roses denoting the concentration of Particulate Matter per wind direction.

Figure 6 shows a similar trend to the wind roses in figure 3 above in terms of dichotomy of wind patterns, with spring and summer, and autumn and winter, sharing similar profiles. The highest concentrations of Particulate Matter occur during winter, with the highest proportion of Particulate Matter coming from the West and South West. The next largest contributor is spring where there is an overall lower concentration but it is more even spread to the North East and South West. The remaining months of the year show low

concentrations of Particulate Matter. The pollution rose for autumn should not be considered as a robust reflection of the seasonal pattern as it was based only on data from May 2015. The worst conditions, as noted within the winter and spring months, indicate that impacts are from all directions, and hence not a direct single source, but rather multiple sources.

4.2.2 Separation of burning season from non-burning season

The burning season runs from June – November and the non-burning season runs from December to May. The days when sugarcane burning occurred during this period are highlighted in figure 7 below.

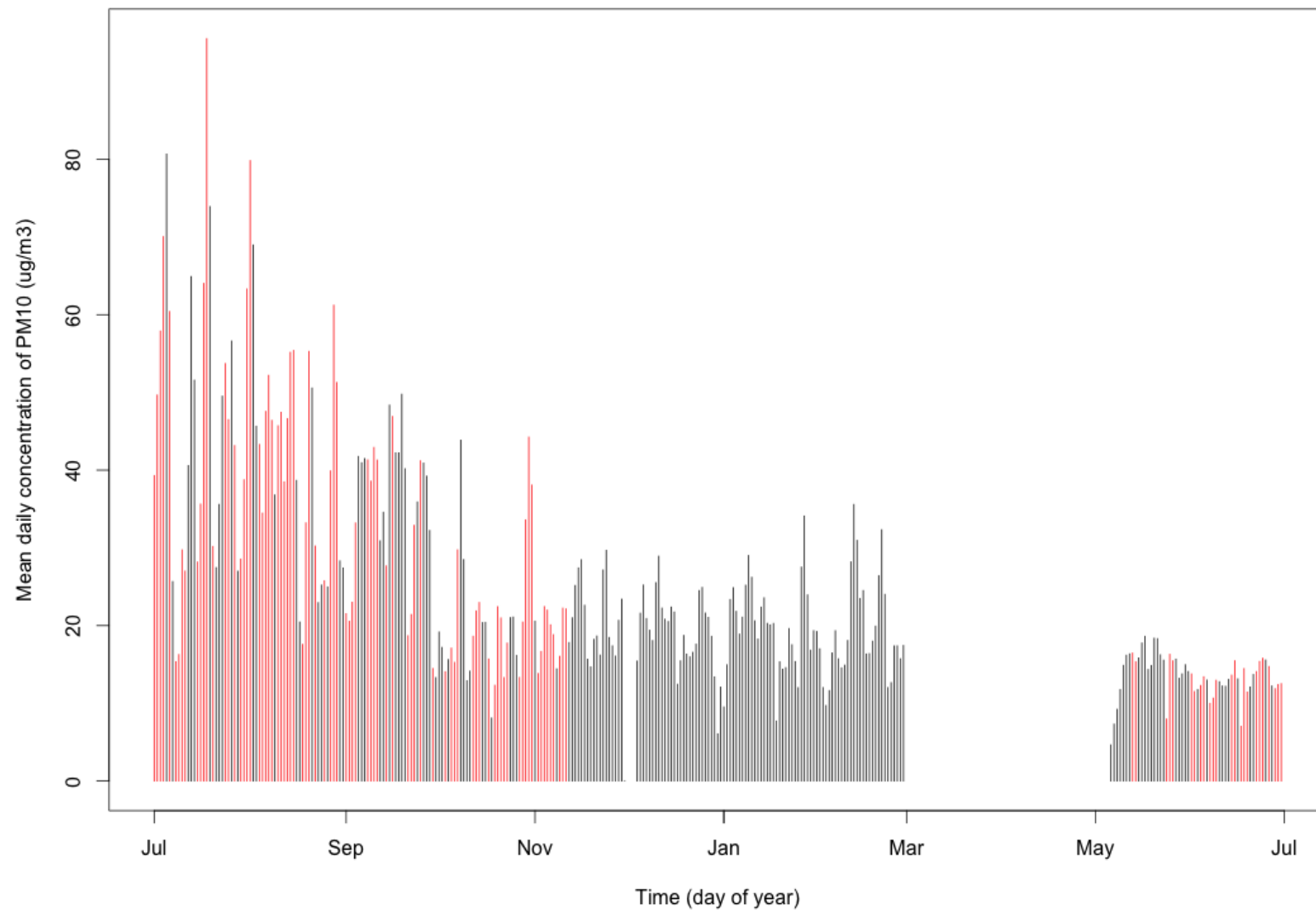


Figure 7: A bar graph indicating the mean daily concentration of Particulate Matter over the period, colour-coded to denote burning occurrence.

Figure 7 depicts that there is a clear separation of the burning season and non-burning season, with the bulk of the burning occurring in June to November. The Particulate Matter concentration is elevated during the burning season, especially during the months from July to August. It is observed that not all the spikes in Particulate Matter occur on days of burns, but the general trend is that the higher values during the burning season are attributed to days when burning occurred.

4.2.3 Statistical comparison between treatments: *t*-test results

Table 5: Output from the Welch Two Sample *t*-test

Output	Value
<i>t</i> value	8.3602
Degrees of freedom	240.88
<i>p</i> value	5.046×10^{-15}
Mean concentration: burning season	29.60 $\mu\text{g}/\text{m}^3$
Mean concentration: non-burning season	18.30 $\mu\text{g}/\text{m}^3$

From Table 5 the calculated *p*-value is less than 0.05 thus the null hypothesis is rejected, and there is a statistical difference in the Particulate Matter concentrations between the burning season and the non-burning season. The comparative means between each treatment indicate that there is on average a 61.8% increase in the Particulate Matter concentration in the burning season.

4.2.4 Graphical comparison between treatments

The boxplot below depicts the variability between the data in the two treatments.

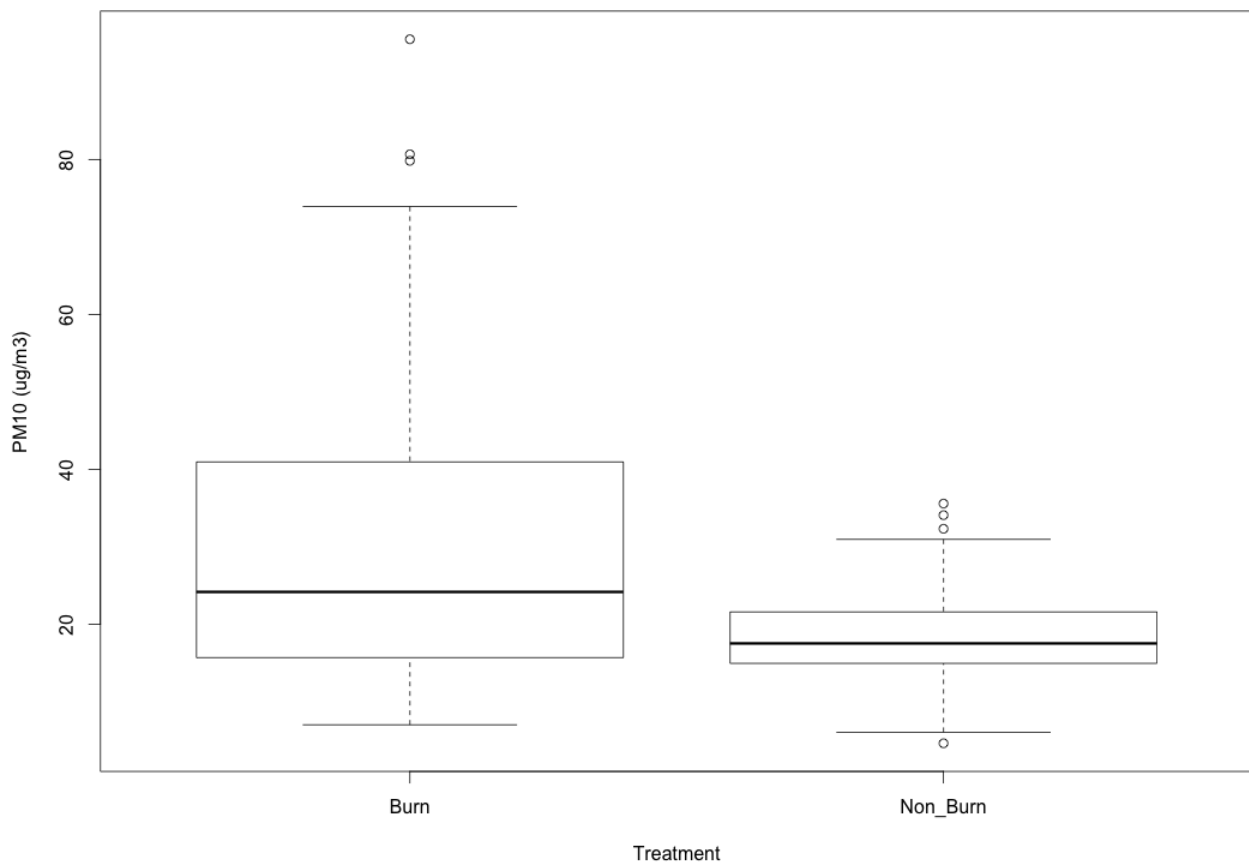


Figure 8: Boxplot indicating distribution of Particulate Matter concentrations for the two treatments: Burning season and non-burning season.

In figure 8 above there is a clear distinction between the two treatments. The thick black line indicates the median for each treatment, the whiskers outline the minimum and maximum, and the circles indicate potential outliers. The burn season has a much higher spread of data as compared to the non-burning season, with maximum values almost double that of the non-burning season. The third quartile of data associated with non-burning season is below the median of the burn season, indicating that more than half of the days in the burning season had higher Particulate Matter concentrations than three quarters of the non-burning season. It is interesting to note that the three exceedances of the NAAQS are highlighted as outliers within the burning season.

4.2.5 Burning events during periods of exceedance

As the basis for this study was the adherence to the NAAQS, there needed to be consideration of those burn events that coincided with the Particulate Matter concentrations exceeding the allowances in the regulations. During the period of study there were three instances where the 75 $\mu\text{g}/\text{m}^3$ thresholds were exceeded. They occurred on the following days:

Table 6: Table of days with Particulate Matter exceedances

Date	Burn Event	Location of burn
5 July 2014	No	-
18 July 2014	Yes	29.5748 S 31.1548 E
1 August 2014	Yes	29.6191 S 31.1341 E

In Table 6 it can be seen that there were only two of the three days where the burns coincided with the exceedances. These events were modelled using the HYSPLIT software to understand if the trajectory of the emissions from the burns would have blown the pollution towards the airport and the monitoring station.

4.2.6 HYSPLIT output

In figures 9 to 12 the trajectory model outputs are presented. The coloured plumes indicate the trajectory of a particle moving from the source, out over 8 hours.

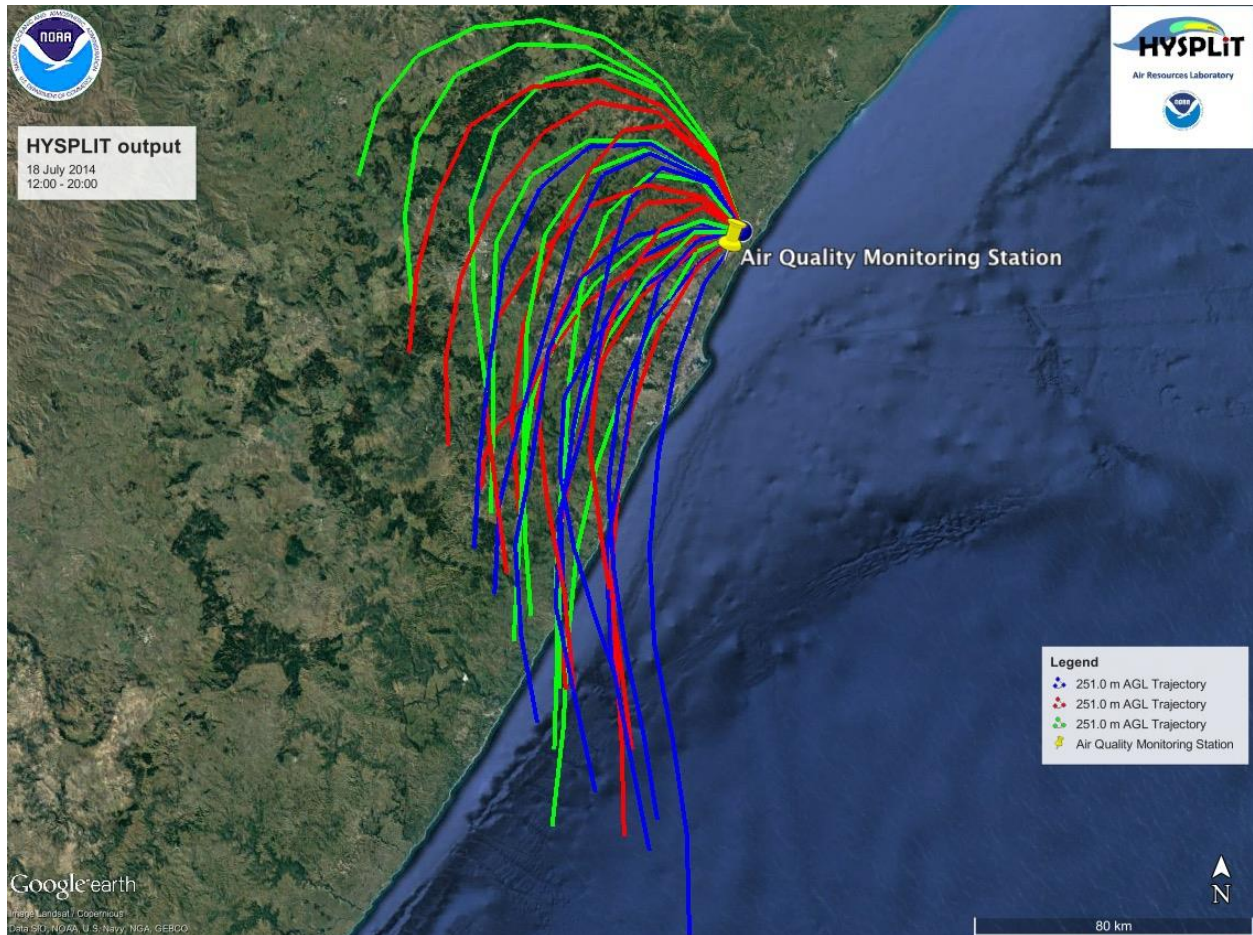


Figure 9: HYSPLIT output for 18 July 2014

Figure 9 above displays that all the calculated trajectories followed a similar trend with initial movement west, and then ultimately heading south. The plume size is wide but does not seem to intersect the airport site fully. Figure 10 below depicts the same trajectories, but zoomed in closer to the airport site, for better visualisation.

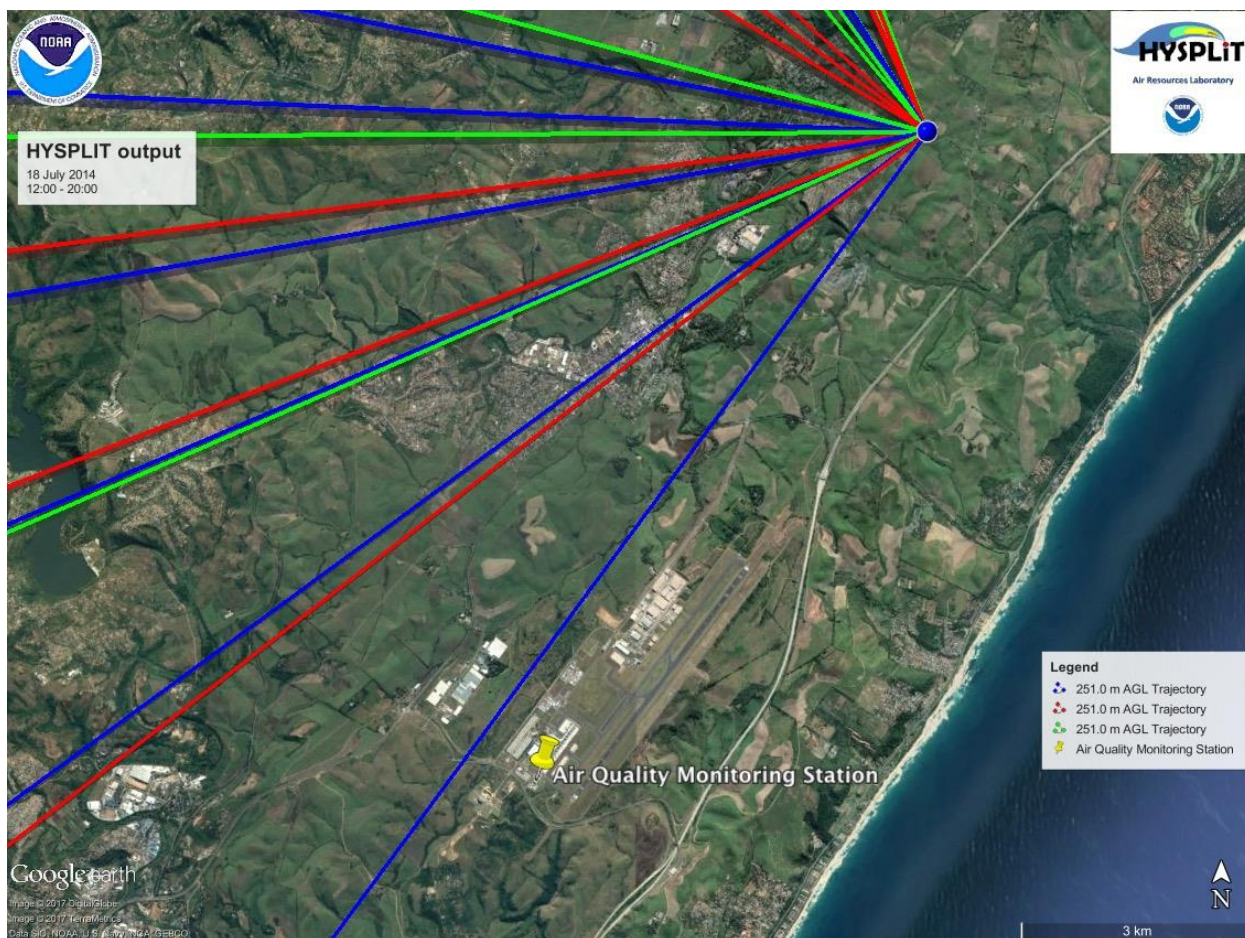


Figure 10: HYPsLIT output for 18 July 2014 (zoomed in).

Figure 10 above shows that only one of the calculated trajectories came within close proximity to the airport site. There is thus high uncertainty that the plume from the sugarcane burning would have passed directly over the airport.

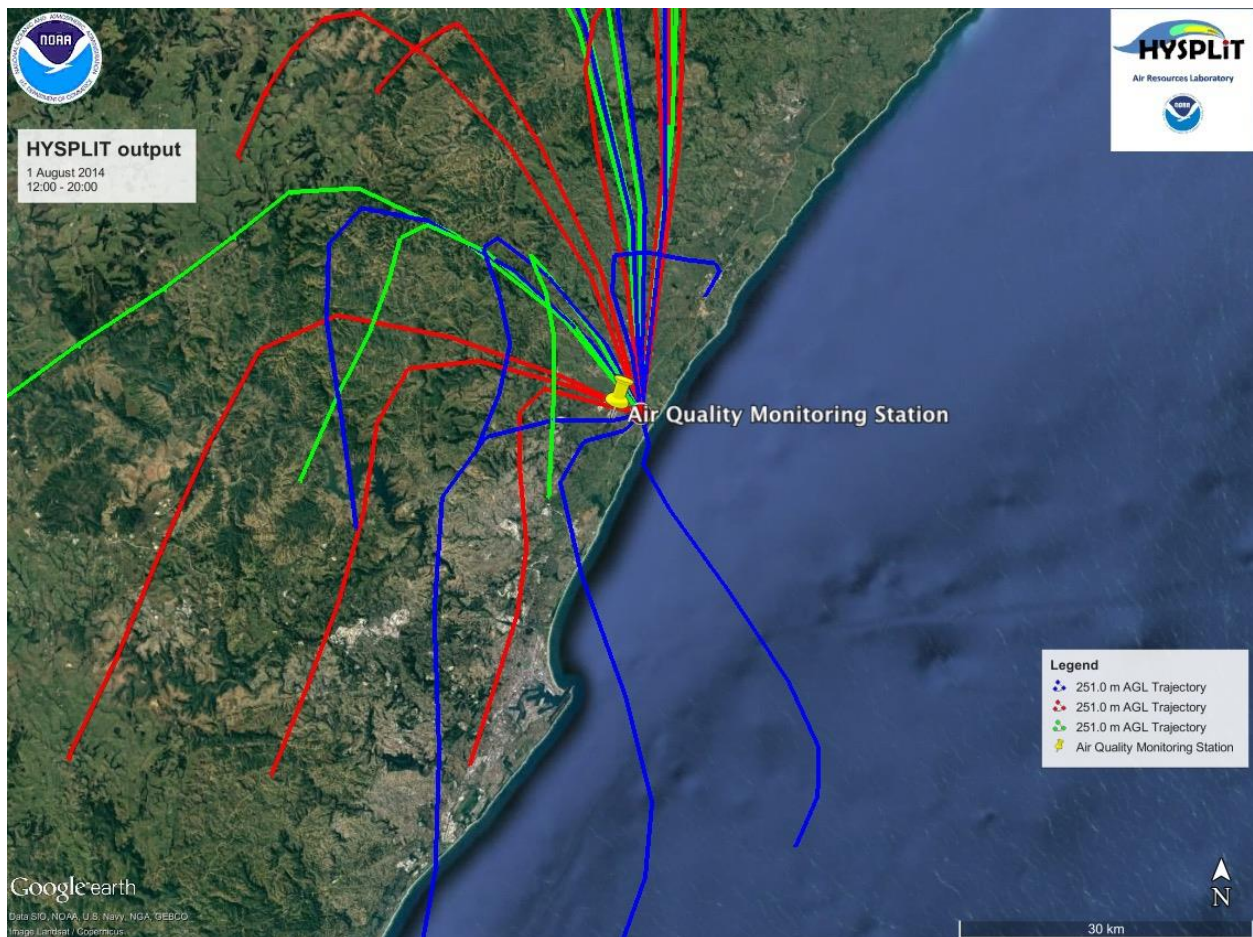


Figure 11: HYPPLIT output for 1 August 2014.

Figure 11 above displays all the calculated trajectories followed a dissimilar trend with initial movement in many directions between the North, South and East. The plume size is wide and does intersect the airport site fully. Figure 12 below depicts the same trajectories, but zoomed in closer to the airport site, for better visualisation

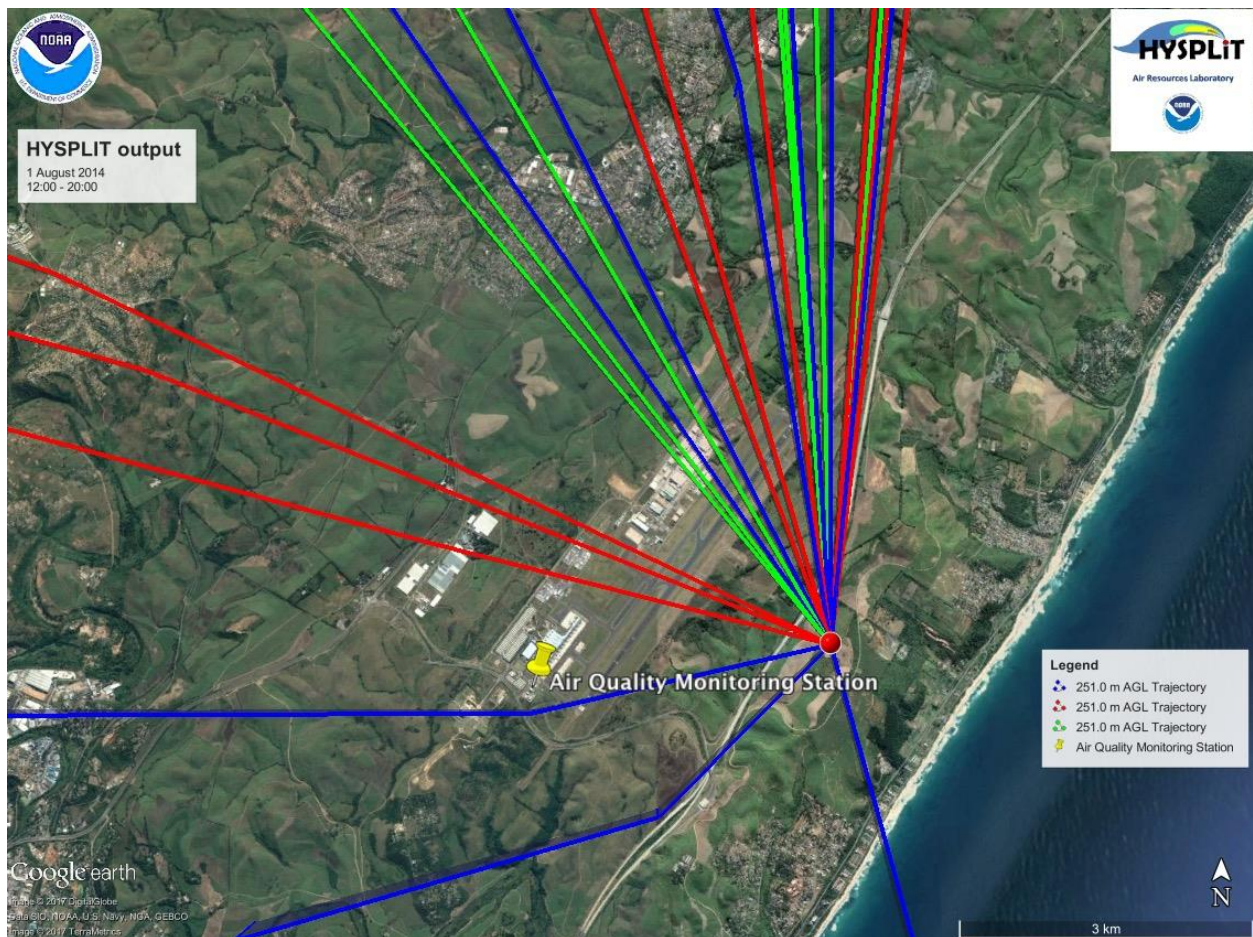


Figure 12: HYPPLIT output for 1 August 2014 (zoomed in).

Figure 12 shows that the trajectories intersecting the path of the airport in multiple instances, thus there is less uncertainty about the burn on 1 August 2014 resulting in a plume that travelled over the airport site.

4.3 Adherence to the use of the management tool

A quantitative assessment of the adherence to the cane burning procedure was not carried out, but the results of the scrutiny of the recorded details of the burns are as follows:

4.3.1 Cane burns conducted without notification

The information in the Observation Book described ten instances of cane burning being reported by the Air Traffic Controller, without having been requested prior. This amounts to notification 95% of the time. This would indicate that there is use of the procedure by

the sugarcane farmers, and that it is used consistently. Given that the operational area of the procedure covers a 10km radius, and this is not visible from the Fire Station' Watchroom there may have been incidents of burning that took place in the periphery of the notification zone that were conducted without prior arrangement. The areas closer to the airport site were well documented in the records and this indicates that the management of communication between the farmers and ATNS (via ARFFS) is working adequately.

4.3.2 Information recording

The information in the Observation Book did not follow a consistent pattern in what was recorded. The full extent of parameters noted were:

- Date
- Time of communication
- Name of Farmer
- Contact number of Farmer
- Location of burn
- Time of start (estimated)
- Time of end (estimated)
- Duration of burn
- Hectares to be burned
- Confirmation with Tower Controller

From the above parameters noted in the Observation Book the only consistent data was the Date, Time of Communication, Location of Burn, and Hectares to be burned.

4.3.3 Smoke interference

The reports of sugarcane fires that had not been requested, as per 4.3.2 above, did not explicitly specify that the smoke emissions were obstructing visual operations of the airport. If the worst case is considered and all of these were obstructions to the pilots, it only presents as 5% of the time (during the burning season).

Chapter 5: Managing ambient air quality at King Shaka International Airport

This chapter considers the results of the analyses presented above and discusses their implications in relation to the three objectives and aim of the study concerning the management of ambient air quality at the King Shaka International Airport, specifically relating to the impacts of sugar cane burning. These objectives are discussed chronologically below:

5.1 The characterisation of the ambient air quality at the King Shaka International Airport

The objective to characterise the ambient air quality in terms of the Particulate Matter has been achieved with the results presented above. There is a clear pattern in the observed Particulate Matter concentrations as they change over the course of the year. The summer and spring months present as very low mean daily concentrations, while in autumn and winter the concentrations increase. This is to be expected to some degree given the meteorological regime in South Africa. Lourens *et al* (2011) described that during the wet warmer months there is unstable air which allows for rapid mixing and dispersion of pollutants away from sources. This typically results in lower pollutant concentrations around pollutant sources as compared to times of year when the weather conditions are more stable (winter). The other factor that results in summer and spring concentrations being lower than winter is the rainfall associated with the warmer months. The pollutants are adsorbed or dissolved into the rain droplets and these are then deposited on the ground (Lourens *et al*, 2011) The temporal pattern observed at the King Shaka International Airport are in line with observations by Vujovic and Todorovic (2017) who quantified higher concentrations of pollutants at the Nikola Tesla International Airport in Belgrade during the cooler months of the year.

The pollution rose in Figure 6 indicates that for the months with the highest concentration of Particulate Matter there is not a single defined direction of impact, which would have been indicative of a single source. There are instead high levels of pollution noted in all directions, which would suggest that there are multiple sources of pollution. This could be the sugarcane burning, along with other seasonal specific inputs such as veld fires (given

the dry conditions) and biomass burning for heating (given the cool conditions). The characterisation of the ambient air quality suggests that the impacts are a cumulative one from manifold smaller sources, which lends credence to the sugar cane theory.

5.2 To identify major sources that are impacting on the ambient air quality at the King Shaka International Airport

The objective to identify the major sources that impact ambient air quality at the King Shaka International Airport has been done through an iterative process. The seasonal variation noted above indicated that there were changes in the concentration of Particulate Matter over the year. This means that a possibility for seasonal pollutant input could not be ruled out (this of course assumes that the trends are not solely driven by meteorology).

With this possibility open, the timing of the sugar cane burning events were overlaid on the seasonal trends. It was observed that there was a strong correlation with the higher episodes of Particulate Matter concentration occurring during the sugar cane burning season (this trend was most convincing during July to September). The overlap however was based upon a visual comparison of the two treatments, and a more objective means was required to account for the possibly statistically significant differences between them. The results of the *t*-test indicated that a significant difference existed between the burning and non-burning season (Table 5). The difference in the two treatments was further graphically noted in the box and whisker plots (Figure 8) that illustrated a comprehensive shift from the burning to non-burning season.

With the statistical comparison providing a difference between the burning season and non-burning season there needed to check whether the influence of burn location had an observable effect on the Particulate Matter concentrations. This was to look for any unknown sources of Particulate Matter, as if the main sources of pollution were originating from directions other than the cane burning it would confound the study.

The map (Figure 5) that displayed the location and frequency of burning was compared to the pollution rose (Figure 6), as it would show the direction of the highest pollutant loading. There was alignment of the longest rays (with highest pollutant concentration) during the winter months (when the burning took place) and the clustering of burn sites

on the map. This was evident in the pollution rose where the highest source of pollution occurred in the ray directly to the west of the monitoring station (and hence airport). This is aligned to the site that had the most frequent number of burns during the duration. Similar (though damped) trends were noted in the other predominant rays and the clusters of burning. The opposite was also noted where the lowest proportion of Particulate Matter came from the East, where there was comparatively fewer burn events. The eastern data are less robust, given the proximity to the sea, as the offshore winds would have carried clean oceanic air into the airshed which would mask any burning from that sector (Umoya-NILU, 2015b).

The final consideration was to look at the effects of single burns during episodes of exceedance to the regulated thresholds. This was done by isolating burns that took place on days when the exceedances were noted and these were modelled. The information derived from the models were not very robust, with too much variation in the directions and spread of pollutants. What these data would suggest is that there is not so much an impact on a burn-by-burn basis, but rather that the cumulative impact of frequent burns keep the local level of Particulate Matter high enough that there can be periodic exceedances.

This cumulative effect is quite clear in the data when there is a temporal shift in the observed timeline. The monitoring started in the middle of a burn season and ended in the middle of the next burn season. If the graph is instead viewed from the start to the end of the burn season there is initially no observed effect of the burning on the overall ambient air quality. As the season progresses, however, there are higher and higher general concentrations with associated spikes becoming more prevalent. A decline in the ambient concentration is observed as the season draws to a close and fewer burns occur. The addition of Particulate Matter from sugarcane burning would seem to follow a normal distribution over time, but the amplitude of this bell-shaped curve has a ceiling that is too high for the airshed.

The iterative investigations of the ambient air quality in terms of Particulate Matter during both burning and non-burning seasons would indicate that there is a causal link between the sugarcane burning and periods of poor air quality at the King Shaka International Airport.

The study does not suggest that the sugarcane is the only source of Particulate Matter during the observed period, but that it seems to account for a large proportion of the signal. The other contributors to Particulate Matter, as noted in the Emissions Inventory related to the aircraft and road vehicles. These sources would not show such marked differences over time given that the airport has a consistent passenger load over the year. The expected peak periods for the aviation sector are around major holidays, as the business travel is constant throughout the year. The peak in aviation (and consequently road usage to and from the airport) are expected around April, June, and December. If the Particulate Matter concentrations are viewed during this time it's noted that they are at the lower end of the spectrum observed during the study. Another contributor, which could be present within the airshed is the incidence of biomass burning for heat generation during the cooler months. While the Durban winter is cool, it is not cold enough for the need of constant external heating. This means that the Particulate Matter loads from biomass burning for heat from the local community are probably lower than many other parts of the country (Aurela *et al*, 2015). The smaller proportion of pollutants from the biomass burning for heating are likely adding to the general circulation within the airshed but this is contributing only a small percentage to the exceedances noted. In terms of management of the sources of pollutants there is more feasible control over the burning practices and regimes of commercial farmers than trying to manage the use of alternate fuel sources within the informal sector.

The results obtained from the difference between the burning and non-burning season were in line with the studies by De Andrade *et al* (2010) and Cristale *et al* (2012).

5.3 Review of efficacy of existing environmental management measures at the King Shaka International Airport to minimise air quality impacts from the sugar cane burning

In terms of the objective to review the efficacy of the existing management measures at the King Shaka International Airport to minimise the incidence of pollution from the sugar cane burning, there are clearly some effective controls in place. The management tool that was investigated within this study related to the Cane Burning Procedure; this is the end-result of a host of management approaches and decisions.

The Cane Burning Procedure was developed after a risk assessment had been carried out under the ambit of the Environmental Impact Assessment for the airport development. This involved the use of public participation with the interested parties most proximal to this matter (this culminated in the development of the local Fire Protection Association). The use of the plan in the operational airport was then incorporated into the ISO 14001 system to ensure that there was adherence to its tenets. This was done by adding it to the Environmental Management Plan related to Air quality and noise, and a clause was added to review the plan on an annual basis.

The recording of the incidence of burning times and locations is robust with evidence of 95% of burns within the vicinity of the airport being accounted for by means of the successful implementation of the Cane Burning Procedure. The bulk of the adherence to the management procedures seems to be from the sugarcane farmers and less from the other two parties (ATNS and ARFFS). This is most probably a matter of self-regulation that has developed over the course of the years of operation since the airport opened. The farmers likely do not want to exert the energy to start the logistically complex of setting up a controlled burn only to have it stopped prematurely. It is assumed that over the 4 years before the study was conducted there was auto-correction of the request to burn occurring during periods when the wind would not blow the smoke towards the airport. This would seem to indicate that the current management practice is a modified fiscal instrument as it benefits the farmers to spend the required time and resources only when it benefits the airport's ambient air quality.

The study has indicated that there is effective monitoring of the sugar cane burning by the ACSA ARFFS, but this is only the first layer of effective management. With the results of this study, during the next review, there is a need for a more formal reporting system that incorporates all the necessary information related to the burn (specifically those that were deficient in this study, i.e. start times of burns, hectares burnt, and contact details of the responsible farmers). The plan also needs an adaptive management component, where the continuous monitoring should be used in conjunction with the requests to burn. At its most basic this could mean that in the event of the four allowable exceedances being recorded, there would be a cessation of sugar cane burning within the close proximity of the airport until the next year had started. This would be controllable on the land that ACSA owns, and the overall impact on the airshed (as being demonstrated by

ACSA and its monitoring) will have a strong influence on the owners of those land parcels not owned by ACSA.

5.4 Implications for ambient air quality management at the King Shaka International Airport

The study points a conclusive finger at the sugarcane burning as being responsible for the exceedances in the Particulate Matter concentrations observed over the study period. With a viewpoint of strict legal compliance it means that the existing controls, that ensure that burning only occurs during periods when the smoke (and hence Particulate Matter) would be transported away from the airport, are functional. This is demonstrated by the pollutant levels remaining at just below the stipulated legal threshold (there are four exceedances of the Particulate Matter thresholds allowed per year, and the study identified only three). With the status quo being maintained, in terms of sugar cane agricultural practice and the current flight schedules, the airport should remain in compliance with its legal obligations.

The long-term vision of ACSA is to be “a world-leading airport business” (ACSA, 2017) and this involves increasing the frequency of flights, to and from as many destinations as possible. King Shaka International Airport is built upon a 50-year master-plan (INR, 2007) that includes the development of a second runway in 2035. Given that the airport is striving to grow its footprint in terms of number of flights on its existing routes, and to develop new routes, it means that the ambient air quality is currently a limiting factor. With the addition of more aircraft, the added Particulate Matter may well push the ambient air quality regime to above the allowable four exceedances.

It would make business sense to manage the sugarcane burning more effectively to allow for a larger window of opportunity for further development of aviation related activities. This would also allow for the business ancillary to the airport to develop.

The competent authority for Air Quality Management in this region is the eThekweni Municipality, and they may not approve development around the airport if they consider the airshed to be saturated with pollutants in terms of Particulate Matter. This has severe consequences for the region, given the push to develop an aerotropolis in the area. The concept of the aerotropolis is to develop a region surrounding an airport for the purpose

of aviation related business; specifically, logistics (and its integration to bring road, rail and air together), industry, tradezones, office space, and mixed residential spaces (Flores-Fillol *et al*, 2016). An aerotropolis associated with the North of Durban around the King Shaka International Airport would serve to boost the local and national economy. Flore-Fillol *et al* (2016) reviewed existing cities with an aerotropolis and concluded that 10-30% of the employment in each region was tied to the aerotropolis.

The management response to the confirmation of the sugarcane burning as a major contributor will be to adjust the mitigation measures for the treatment of the risk. The results point to the sugarcane fields closest to the airport as being responsible for the highest Particulate Matter concentrations (as noted in the correlation of the map of burn locations, and the pollution rose). It would make sense to lower the impacts from these areas first, as they pose not only an ambient air quality risk, but also a safety risk due to the proximity of the airfield.

It would be best practice to engage with the farmers to explore options such as green harvesting (INR, 2007), where burning is excluded from the harvesting process. If this is not possible given the current configurations of the sugarcane mills (Cristale *et al* 2012, Mashoko *et al*, 2010), then there could be a variation in the methodology of how the burns are carried out, with possibilities to burn the trash after harvest (Hiscox *et al*, 2015), or to not burn at all, and use the trash as a means of fertiliser or feedstock for electrical generation (Mashoko *et al*, 2010, Hiscox *et al*, 2015). The basis on this would be to ensure that ACSA understands the need and expectations of the sugar cane farmers, as per ISO 14001, and what the area of influence and control really are.

A possible future scenario could be that with the increase aviation impacts the matter of Particulate Matter becomes a legal non-compliance. To this end ACSA will need to undertake its due diligence to rectify the matter of its compliance obligations. If this path would be to lower the impacts from sugarcane burning it would start with the land it owns, and review the terms of lease agreements with the farmers operating on those land parcels. This would be a controllable factor that could be resolved within the short to medium term. On the other hand, if ACSA was to influence the sugarcane farmers in the proximity of the airport, but not on ACSA land, they would need to look at influenceable measures such as how the Cane Burning Procedure could be adapted for the interested

and affected parties. For this kind of engagement to be successful the compliance monitoring in relation to sugarcane burning, as started by this study, would need to be continued moving forward such the responses of any changes in burning regimes could be performance-monitored.

For environmental management to be truly effective it needs to be a business enabler, such that the ultimate business path is one of sustainability. To this end this study provides tangible evidence that for the business to fulfil its strategy and accomplish its vision, it needs to adapt the current regime around Particulate Matter levels on site. With an updated Cane Burning Procedure based upon the outcomes of this study there will be enhanced performance of the Environmental Management System (ISO 14001) and this will ensure that legal obligations are met while providing an opportunity to further allow development within the airshed. Through the notion of continuous improvement inherent with ISO 14001 the annual review of the Cane Burning Procedure means that the best practice environmental strategy will be developed, and this will also make the most business sense.

5.5 Implications for ambient air quality surrounding the King Shaka International Airport

As discussed previously, the current (and now confirmed effective) management interventions in place control the ambient air quality at the airport. If the broader region is considered there is a possibility that the burden of the Particulate Matter impacts from sugarcane burning may be unequally distributed to the other receptors in the area. With burning only taking place when smoke would be blown away from the airport (and with the predominant air flow being to the North East and South West) there is a strong likelihood that the communities in these areas are experiencing higher impacts.

The spirit of the air quality legislation (as outlined in the National Environmental Management: Air Quality Act, Act 39 of 2004) is that of reducing impacts on the sensitive receptors, which in the context of South Africa are the population. For holistic Air Quality Management to be realised there needs to be consideration of the societal aspects of the impacts and an alternative sought to the current burning regimes.

Using the methodology of Christopher (2014), and the data from the South African Census (Wazimap, 2017) the demographics of the area around the airport can be reviewed. It is noted from Wazimap (2017) that of the housing types in the area 21.8% are classified as informal dwellings (shacks), which is close to double the rate of other areas in KwaZulu-Natal. This coupled with a low employment rate in the area describe a community that are economically destitute. This status is important as it can be a proxy for other metrics, like healthcare, which are negatively affected by poor ambient air quality (Cristale *et al*, 2012). The impacts of poor air quality exacerbate existing medical conditions, especially those relating to pulmonary distress and heart conditions (Jafta *et al*, 2017). In their iterative assessments (1990 – 2010) on the burden of disease Lim *et al* (2012) has increased the effect of poor air quality (specifically around Particulate Matter) on the life expectancy of individuals with conditions such as TB and ischaemic heart disease. They increased the percentage effect of Particulate Matter on the “Disability Adjusted Life Years” from 0.4% to 3.7% in the space of 10 years due to the increasing knowledge base of the detrimental effects of Particulate Matter on a range of diseases. This is an important risk factor when the other comorbidities in the KwaZulu-Natal context are considered. According to Ramjee *et al* (2016) KwaZulu-Natal is the region most affected by HIV in South Africa, and the link with HIV/AIDS and Tuberculosis are well documented (Simon *et al*, 2015).

Thus, the unequal burden of Particulate Matter may possibly be impacting on the local communities in a more comprehensive manner than previously deemed true. Given that ACSA is the land-owner of some of the areas currently being burned, there is a burden of responsibility upon ACSA to ensure that current practices are amended to reduce their liability to the local community. This is especially important when considering the life cycle of the airport operation, as many of the staff who work at the airport reside within the community surrounding it, and this could affect the performance of the airport realising its vision.

The Environmental Management System, as it stands, considers the boundaries of the airport. This is further reinforced by the fact that the monitoring is only conducted within the boundary of the airport. With the possibility of impacts outside of the airport footprint there is a need to monitor the ambient air quality in the potentially affected communities. While this monitoring is a municipal function, ACSA has a vested interest in understanding

its impacts as it owns some of the land that the sugarcane burning is undertaken on. A pilot study could be undertaken where air quality is simultaneous monitoring both at the airport and in the most proximal communities of Herrwood and Mount Moreland (as per section 3.1 above), and the differences quantified.

The scope of the EMS is therefore in need of a review, where the air quality impacts downwind of the airport are considered.

5.6 Long-term plans for sugarcane burning on site

The airport, as mentioned previously, was developed as a greenfields site and is to be the flagship “green” airport in the country. Part of the management of the site, in relation to this goal, is the development of a large-scale conservation area. This conservation area is set aside to offset the habitat loss from the development of the airfield and associated infrastructure. The delineated area has large portions of sugarcane agriculture on it at present and this land-use will be amended over the next decade into a habitat more representative of the historical natural ecosystem. There is an objective to restore the indigenous grasslands within the site, in the order of hundreds of hectares. For this grassland to be managed in an ecologically functional manner there is a requirement to burn the grasses at a regular frequency (Fynn *et al*, 2004). Monitoring protocols much like those developed in this study should be used to quantify the impacts of the grassland burning, and this will allow for continuous improvement of the impacts as per the requirements of ISO 14001:2015.

There are existing plans for the phasing out of the sugarcane agriculture within the conservation area over the next 3-10 years. This study has provided evidence that the speed at which this phasing out should occur needs to be reviewed and that timeframes condensed. This does pose a concern for the labour force currently employed to farm the land, but as the land is leased by a large farming interest, there is more than likely scope for the employees to be redeployed to other portions around the airport site, or to other farms within the KZN farming belt (INR, 2007).

In the event that the grassland burning occurs before the sugarcane has been entirely removed there may need to be some manner of temporal shifting in the time of the grassland burns. Fynn *et al* (2004) present the case that for maintaining grassland

biodiversity, fire management is essential, but that the time of burn during the year does not have a large effect on the community structure. This means that the grassland burning can take place during the summer months when the unstable meteorological conditions will disperse the Particulate Matter over a short space of time. This could pose a problem given the restrictions around the municipal burning season, and as such the grassland burning may need to be done at the beginning and end of the sugarcane season, where the numbers of burns are still relatively low.

The major implication from this study is that the current land-use has been identified as a chief contributor to the Particulate Matter pollution within the airshed in and around the airport. For the benefit of the airshed as a whole, including both the Airport and the surrounding communities, there is a need to review the land-use management. The alternative strategies can be driven in part by ACSA, on the land parcels it owns, as well as by engaging with the other local landowners to understand the desired future plans for the area. The implementation of active air quality management can ensure that the planned future is a sustainable one.

5.7 Conclusion

The conclusion of the study points to there being a potential problem with Particulate Matter pollution considering the developmental agenda in the area, as well as the vulnerable communities residing in it.

The airport has an effective management tool in its toolbox that ensures that legal compliance is maintained by limiting the transport of Particulate Matter from sugarcane burns directly into its operational areas. This tool has the potential to skew the distribution of pollutants, which may affect local communities. In order to fully quantify this there is a need for the scope of the existing Environmental Management System to be expanded to include these impacts.

The solution would seem to be for the land-use management in the broader area to be converted from sugar cane cultivation, where possible, to a more compatible use. This can only be done by engaging with the relevant interested and affected parties responsible for these land parcels.

Chapter 6: Conclusion

The aim of this study; to investigate the management of ambient air quality at the King Shaka International Airport, has been fulfilled.

The objectives were chosen to demonstrate from a top-down approach how the management interventions have shaped the ambient air quality around the airport. The first objective of characterisation was chosen to confirm whether or not there were any trends to the ambient air quality over the year. The second objective took these trends and interrogated the sources responsible for defining them. The third objective considered whether the approach to deal with the pollutants in the airshed is functional, and what it means for both the airport and the broader community.

The conclusions based upon each objective are described below:

6.1 Characterising the ambient air quality at the King Shaka International Airport

The ambient air quality at the King Shaka International Airport is adequately managed for the priority pollutants except for Particulate Matter. The trends in Particulate Matter denote a low concentration during the spring and summer months, in line with general observations noted elsewhere within the municipality during these times of year. The Particulate Matter concentration does elevate significantly during the Autumn and Winter months (an average of 62% higher than the rest of the year) with exceedances of regulated thresholds being noted. There is an expectation of elevation during the cooler months of the year because of more stable air layers keeping pollutants from dispersing, but the magnitude of the difference observed is indicative of an external factor. While there are currently no exceedances over and above the allowable number this remains a potential risk in future, as there is a more than likely occurrence of further exceedances given the development agenda within the broader airport locality.

6.2 To identify major sources that are impacting on the ambient air quality at the King Shaka International Airport

The trends described above, of the seasonal variability of Particulate Matter, mirror that of the seasonal incidence of sugarcane harvesting, and consequently sugarcane burning. The statistical analyses performed indicate that there is significant difference (p -value <

0.05) in the Particulate Matter concentrations during the periods of sugarcane burning as opposed to those times of year when there is no burning. The non-burning season had a mean daily concentration of 18.30 $\mu\text{g}/\text{m}^3$ as compared to the burning season that had a value of 29.60 $\mu\text{g}/\text{m}^3$.

6.3 Existing management measures to minimise the incidence of pollution from the sugar cane burning

The existing management practices are being adhered to, and the overall efficacy of the system is sound, given that the airport remains legally complaint. The exceedances noted in the NAAQS are skewed due to the existing management interventions, but these are not fully able to reduce the impacts into the area. This means that for the other receptors within the airshed (specifically the residential areas and staff on the agricultural land) the impacts are likely higher.

There is a need to redress the current shortfall within the management intervention to ensure that the impacts of the Particulate Matter are reduced. This is further reinforced by the tenets of the new ISO 14001:2015 Environmental Management System standard, that calls for leadership to consider its impacts upon its interested and affected parties. Part of this responsibility lies with the sugarcane farmers, but there is a portion that the Airports Company is responsible for, given that they are landowners (or part of joint venture that owns the land) upon which a portion of the sugar cane cultivation takes place.

There is a requirement to revisit the needs and expectations of the sugarcane farmers, through the review of the Cane Burning Procedure, to ensure that they are aware of the implications of the burning, and how this impacts both upon the health of the community at large, as well as the developmental objectives of ACSA (and any other industry that wishes to develop within the airshed).

The actions noted form part of the requirements of ISO 14001 and as such for ACSA to demonstrate its continuous improvement there will need to be cognisance of the findings of this study in relation to how it manages its landholdings with sugarcane agriculture on it, as well as how it seeks to influence the other landowners through the sharing of scientific knowledge.

6.4 Contribution of this study to the broader pool of knowledge

This study is the first of its kind to be conducted at an airport managed by the Airports Company South Africa, and it provides essential confirmation of the impacts the surrounding land-use on its operations. The results of this study will be shared with the competent authority in terms of the contribution of the Particulate Matter load from sugar cane burning.

The information presented in this study gives baseline quantification of the ambient air quality at the airport in the absence of major industry. With the plans to develop the surrounding area into an aerotropolis, this baseline will assist in noting any future impacts and will allow for adaptive management to maintain ambient air quality as practicably as possible.

In terms of the need to burn grasslands on site in future, this study shows that the impacts of biomass burning can have serious consequences. This means that when the grassland burning regimes and procedures are developed, they should be looked at in a manner where they will contribute the least impact. This study indicates that the time periods on either side of the peak sugarcane burning season have sufficiently low Particulate Matter concentrations to allow for additional burning to be conducted during those times without exceeding the thresholds.

The final contribution of this study is that it has indicated that the speed of rehabilitation of sugarcane fields from agriculture to restored habitat is not fast enough. The sooner the land can be converted the lower the impacts on the airshed. The current timeframes should be condensed, to within an order of 3-5 years rather than the 3-10 initially envisaged.

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