Domestic Fuel Combustion in Un-electrified Low-income Settlements in South Africa

Seneca Naidoo

South African Weather Service, Private Bag X097, Pretoria 0001, South Africa

seneca.naidoo@weathersa.co.za

Stuart Piketh

School of Geo- and Spatial Science, Unit for Environmental Sciences and Management, North-West University, Potchefstroom Campus, Private Bag X6001, Potchefstroom 2520, South Africa

stuart.piketh@nwu.ac.za

Christopher Curtis

School of Geography, Archaeology and Environmental Studies, University of the Witwatersrand, Private Bag 3, Wits 2050, South Africa

christopher.curtis@wits.ac.za

ABSTRACT

Domestic fuel combustion in low-income settlements of South Africa has always been a major source of urban air pollution. Low-income households that house a large portion of the South African population consume vast quantities of coal, wood, paraffin (kerosene) and other substances in order to provide for their energy needs. Only a small amount of work has been done in the way of developing any sort of domestic combustion emissions inventory in South Africa. For this reason, a lack of South African literature surrounding this topic breeds uncertainty in not only the fuel types being utilised but also the quantities of these fuels being consumed in low-income settlements, as well as the associated impacts. To better understand the relationship that exists between domestic combustion and the resultant pollutants, a method of quantifying these pollutants has been developed for Zenzele, a completely un-electrified settlement near Johannesburg. This was achieved using the quantities and types of fuel consumed. In un-electrified households, paraffin and liquid petroleum gas, used specifically for cooking and lighting, are the most commonly used fuel types during the warmer months. During winter, low-income households favour solid fuels such as wood and coal. As the temperature decreases, the rate at which these solid fuels are consumed increases. The most significant observations identified in this study are the diurnal and seasonal trends associated with domestic burning. Factors such as seasonality, the availability and price of fuels as well as cultural aspects all have a bearing on residents' fuel choices and the quantity consumed.

INTRODUCTION

Domestic fuel combustion is an activity that has been exercised for centuries and for a range of functions. There are parts of both the developed and developing world that rely on some sort of fuel combustion as a source of energy for their domestic needs. Estimates have suggested that carbon emissions generated from domestic or residential fuels are the second biggest source of biomass burning, on a global scale, and that Africa contributes a great deal to this[1].

Rapid urbanisation and the related growth of low-income settlements have worsened the backlog in the distribution of basic services such as electricity provision. Low-income settlements in South Africa are mainly characterised by low-income households, where domestic fuel combustion is a common practice[2]. In South Africa, and more specifically the city of Johannesburg, there has been a significant flux of people into the city from the surrounding rural areas, in an attempt to find employment opportunities. The most recent census study of 2011 has indicated that there has been a positive net migration of people into the province of Gauteng. With an influx of about 1 million people into the province over the last 10 years, Gauteng has the highest levels of migration and has attracted more people than all the other provinces have lost therefore there are significant levels of immigration particularly from other African countries. This, in turn, places enormous pressure on already dense low-income settlements and a resultant increase in domestic fuel combustion and associated pollutant emissions are witnessed[3].

In recent years, South Africa has undergone mass electrification, through the Department of Energy's Integrated National Electrification Programme (DoE: INEP) and an exponential increase in the number of electrified households has been witnessed[4]. A statement made in line with South Africa's goal to provide some form of energy to the entire country states that "South Africa aims to ensure that by 2030 at least 90% of people have access to grid electricity"[3]. The proportion of households using electricity for cooking has increased by 26.4%, from 47.5% in 1993 to 73.9% in 2011. The number of households using electricity for lighting has also increased, from 57% in 1996 to 84% in 2011[5]. It is, however, still difficult to ascertain whether the amount of domestic fuel burning will decrease and if people will change over completely to electricity as their preferred source of energy[6].

Although previous studies have been carried out within this field of research, relative to the emission inventories that exist for commercial and industrial emissions, little work has been done on domestic combustion emissions inventories[7]. The purpose of this study therefore, was to derive a method to quantify the emissions generated from various burning activities of households situated within a completely un-electrified low-income settlement. It further investigated how different sources of energy contribute to the total amount of emissions released into the atmosphere and finally, examined the potential of being able to relate the emissions from one site to another with similar characteristics. This research aims to contribute towards the already existing research on a domestic fuel combustion emissions inventory for South Africa and clarifying some of the uncertainties that exist within the study area of domestic fuel combustion.

DOMESTIC FUEL COMBUSTION AND RELATED EFFECTS

Fuel Types and their Associated Pollutants

A variety of fuel types are utilised within low-income settlements in South Africa; and each one is associated with resultant emissions. The fuels utilised by a specific community or within a specific settlement are dependent on a number of factors. These factors relate largely to the availability, accessibility and affordability of the fuels[8]. The two major fuel types consumed in these areas during winter have been identified as coal and wood, although other substances such as paraffin, liquid petroleum gas (LPG), animal dung and electricity are also utilised to provide for the energy needs of inhabitants of low-income settlements[9]. Common fuels utilised during the warmer summer months are paraffin, candles, electricity and gas. Gas is also a popular choice for cooking purposes but is often too expensive, in relation to paraffin. Paraffin is the most common fuel within completely un-electrified settlements, as it is used mainly for cooking but also lighting by means of paraffin lanterns[10]. Households tend to utilise coal and wood as a result of its multi-functional nature. These fuels can be used for both cooking and lighting functions, as well as, simultaneously, for space heating purposes[11].

Health Risk Potential

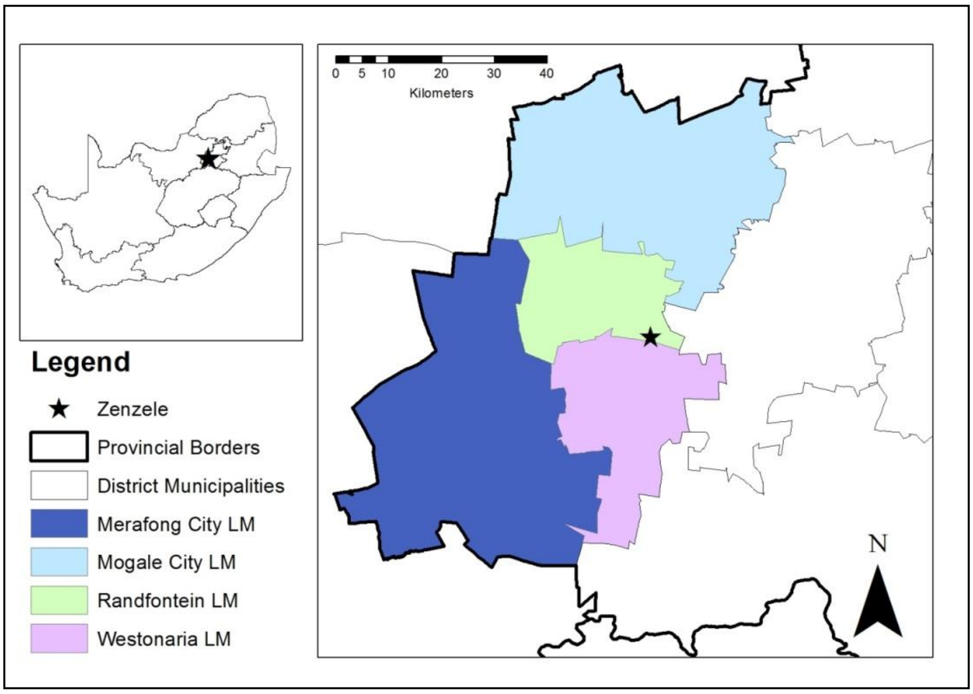
There are numerous health risks associated with domestic burning activities, which act on the respiratory system, as a result of the inhalation of particulate matter and other emitted pollutants. In developing countries, the burning of coal and biomass contribute largely to a range of pollutants that lead to pulmonary and related respiratory diseases[12]. Carbon monoxide poisoning and respiratory illnesses occur as a result of these burning activities, together with poor ventilation, which is a characteristic feature in informal housing[2]. Kerosene or paraffin has been described as a "transitional fuel" that is being made use of more often as a larger percentage of low-income settlements become electrified[13]. Better known as paraffin, this fuel type generates sizeable amounts of a variety of pollutants, which include carbon monoxide, nitrogen dioxide and a host of hydrocarbons and volatile organic compounds[10]. A considerable amount of literature suggests that with respect to domestic combustion, the burden of some of these illnesses fall on women and young children that reside in low-income settlements. They are exposed to the highest levels of resultant pollutants when cooking[14].

METHOD

Study Site Description

Zenzele is a small low-income settlement situated in the south of the Randfontein Local Municipality, in the province of Gauteng, as indicated in figure 1 below. The Randfontein Local Municipality is situated to the south-west of Johannesburg, and is surrounded by the Mogale City, Westonaria and Merafong City local municipalities. It is relatively small in relation to the other three local municipalities but presents high levels of unemployment and poverty. Of the total number of households in Zenzele, 98.7% are classified as "informal" and 98.8% of the households do not have access to electricity[15].

Figure 1. Map showing the location of Zenzele (adapted from Municipal Demarcations Board, municipal data set)



Pilot Study and Analysis of Census Data

A pilot study, carried out at two separate South Africa low-income settlements, Orange Farm and Soweto, highlighted burning behaviours somewhat different to that expected and brought to light in the literature. The literature gave an insight into the burning behaviours of people living in settlements that were more diverse in nature, where researched settlements were either partially or almost completely electrified. For this reason, it was decided that a pilot study would have to be conducted in order to gather further insight into the burning behaviours witnessed in settlements with different characteristics. Analysing and reviewing the census data collected and compiled in 2001, allows for an initial assessment of similar data pertaining to low-income settlements, such as population density and the provision of basic services. Sieving through this data, further allows for an in-depth look at the province of Gauteng and more specifically the area of study, Zenzele.

Questionnaires and Scale Measurements

Questionnaires and hanging scales, distributed to a number of randomly selected households within the settlement, were used to identify and measure the quantities of various fuels being burnt. The fuel consumption rates, and the emission factors for these selected fuels and pollutants, allows for the emissions to be quantified over that specific area. The questionnaires were designed to gather information on the burning behaviours of residents and the specific types of fuel types utilised within the area of study which allows for the most dominant fuel types to be identified. Fifteen low-income households in Zenzele were selected to participate in the fieldwork study. Participants were required to weigh the amounts of wood and/or coal they used on a daily basis for both the morning and evening burning sessions. This study was conducted over a 5 month period, from the beginning of May 2011 until the end of September 2011. Data collected after the 5 month period were analysed and emissions were calculated using emission factors presented in the 2004 FRIDGE (Funds for

Research into Industrial Development, Growth and Equity) Report. The emission rates of SO_2 and PM_{10} were calculated for coal and wood, using these emission factors.

Dispersion Modelling

The air quality modelling system CALPUFF was employed to assess the dispersion of pollutants during the 5 month study period. This tool was also used to determine the fate of the emissions released from the Zenzele and Orange Farm settlements. The emissions from the 15 households were scaled to represent the whole settlement. As Zenzele and Orange Farm exhibited similar characteristics in terms of settlement structure and burning behaviours, the emission rates calculated for Zenzele were applied to Orange Farm. For this research project, the households represented in the two low-income settlements were modelled as volume sources. Emissions data that were used as model inputs for CALPUFF were calculated for the settlements of Zenzele and Orange Farm based on the quantification of emissions from 15 households and 10 households in these settlements respectively.

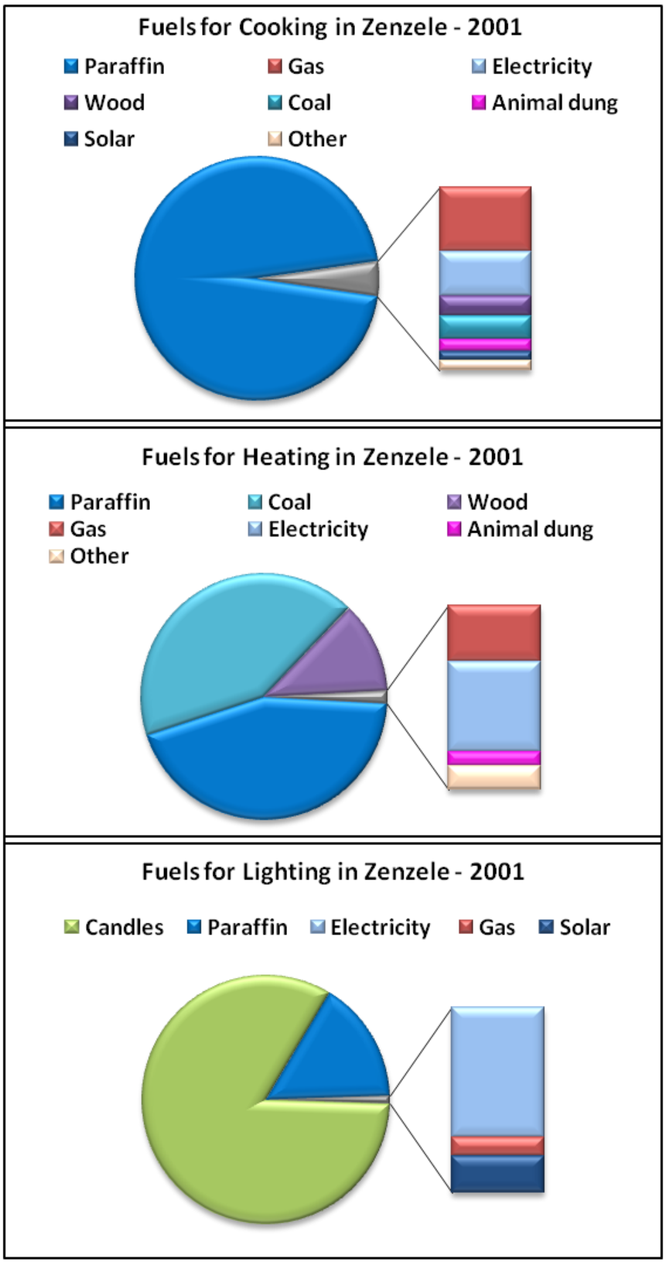
DOMESTIC FUEL USE IN LOW-INCOME SETTLEMENTS

Analysis of Census Data

An analysis of the 2001 census data for Zenzele was done in an attempt to get an overall understanding of the dynamics of this settlement as well as the burning behaviours of residents, before undertaking the field study. Three specific activities in low-income settlements require either electricity or other fuels as an energy source. These activities are: cooking, heating and lighting. There are a range of fuel types that can be utilised in any one of these activities but these will vary according to the season, availability and affordability.

As highlighted in figure 2, for cooking purposes, the fuel types examined were electricity, gas, paraffin, wood, coal, animal dung, solar power and any other fuel that was utilised, which did not fall into one of the specified categories. The most common fuel used by many of the households within this settlement, for cooking purposes, is paraffin. At 95.5%, it constitutes the bulk of the total amount. Far fewer, but a noticeable number of households also make use of gas, electricity, coal and wood for cooking. The fuels used for heating of households in this settlement will vary at different times of the year depending on the season. A very small percentage of annual fuel use is attributable to the heating of houses in the warmer months. Paraffin, coal and wood are the most common fuels used for heating purposes. Often solid fuels used for cooking and heating purposes in completely un-electrified homes do not provide sufficient lighting. Lighting therefore needs to be provided for by other means. According to the 2001 Census study, the most frequently used fuels by households in Zenzele are candles and paraffin. Although candles are seldom used as a fuel of choice for cooking and heating, over 80% of households utilise candles to supply their lighting needs.

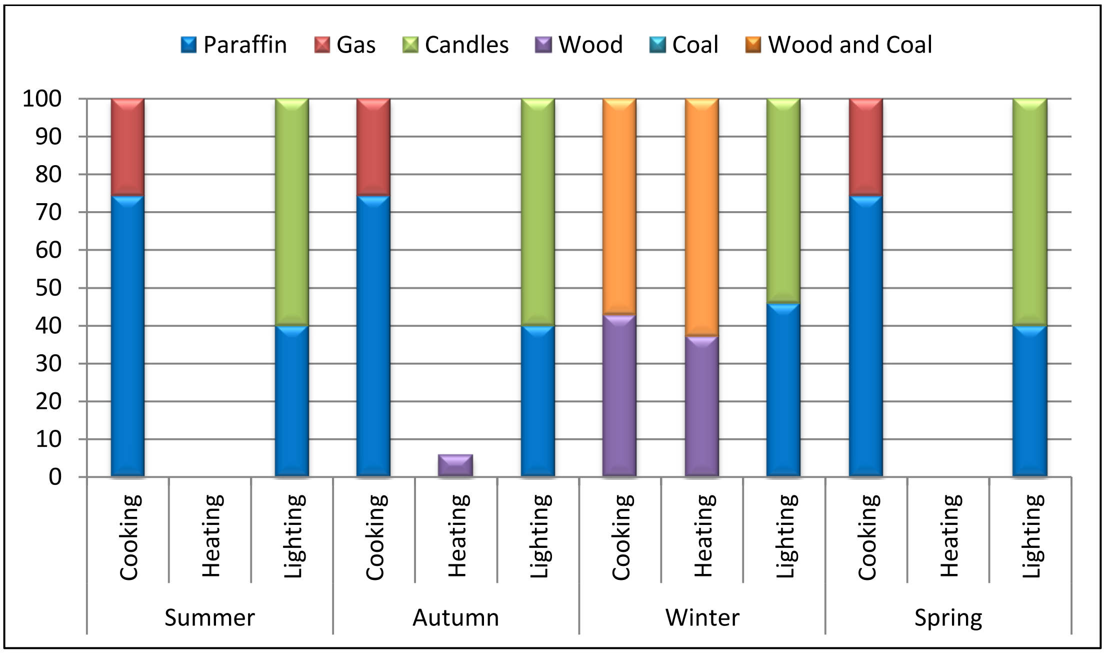
Figure 2. Percentages of fuels used for cooking, heating and lighting in Zenzele (Census 2001)



Questionnaires and Scale Measurements

Feedback from the questionnaires distributed during the study highlighted a number of major seasonal findings. Figure 3 presents the percentages of the different fuels consumed by the 15 households for cooking, heating and lighting purposes over the various seasons. It was discovered that coal and wood are burnt very infrequently during summer. Within most partially or completely electrified households, where household income was somewhat higher than that in un-electrified households, electricity was the preferred source of energy. Although electricity was relatively more expensive than some of the other fuel types, some people opted for the convenience that comes with using this fuel.

Figure 3. Percentages of different fuels consumed by households in Zenzele



The case, however, was a little different for electrified households, in which elderly women reside or those that are run by an elderly head. Families that owned coal stoves that were usually passed down from one generation to the next, preferred to use these stoves during winter when there was a great need for solid fuels that provided more heat. The reasons for this are two-fold: the most obvious one being the multi-functional capabilities of this appliance. Coal stoves are generally used for cooking but also provide large quantities of heat in the process. The second reason is one that is not widely found in the literature as it involves the cultural aspects associated with the combustion of domestic fuels. Within low-income settlements, coal burning instils a sense of family and community amongst residents[16].

Low-income homes, however, that do not have access to this basic service, choose gas or paraffin as their preferred fuel types for cooking and lighting during summer. The amount of fuel required for heating during this summer period is not significant enough to warrant a mention as the residual heat produced from cooking is often sufficient to keep homes warm during summer. Most households, however, will change to other solid fuels, such as coal and wood during winter as larger quantities of energy are required for heating purposes. It is, however, very rare that these households will consume just coal. Coal is generally burnt simultaneously with wood. Reasons relating to both temperature and cost will prompt people to shift to these fuel types. These fuels tend to be relatively inexpensive when compared to the cost of electricity and, with the large quantities required mainly for heating purposes in winter; coal and wood become the more feasible options[17]. If coal stoves are available, people choose to provide for both their cooking and heating needs by this means, otherwise hand-built stoves (figure 4) will also be used. Of the households in Zenzele, participating in the field study, 53% utilised these hand-made stove and 47% used the bigger coal stoves.

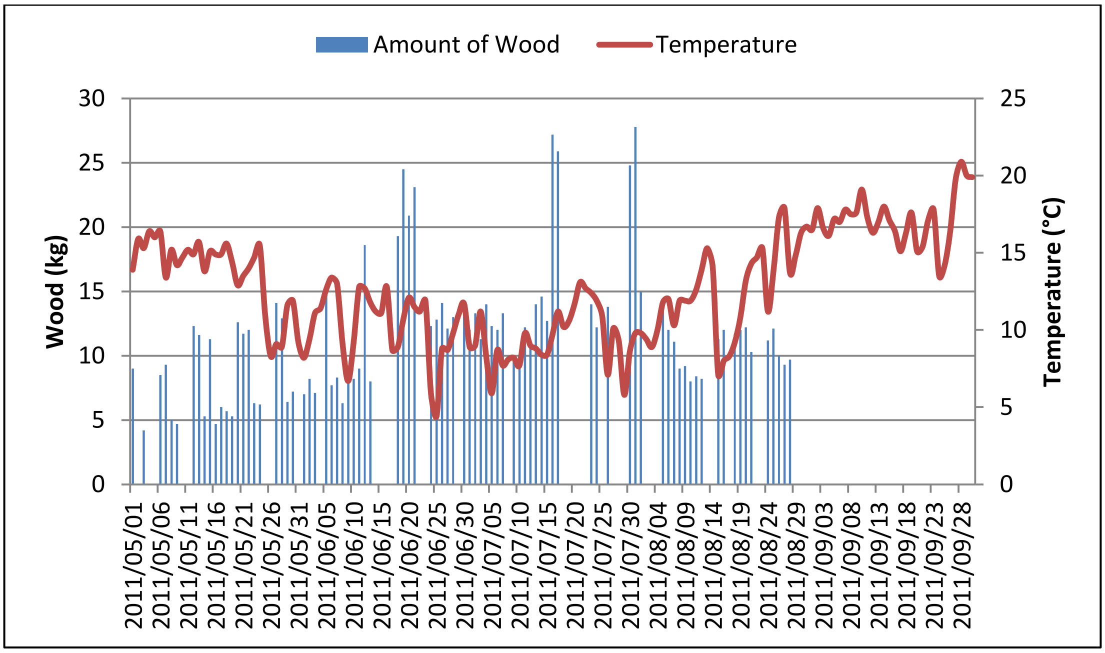
Figure 4. Photograph of a hand-built stove

Imbaulas or braziers are also made use of in low-income settlements for the combustion of residential solid fuels. These are generally hand-built stoves, constructed from a metal drum, with strategically placed holes to filter in air to aid in the combustion process (figure 5). Characteristically, imbaula stoves will differ depending on the number and size of these holes[18]. As imbaulas are not fitted with chimneys fires created in these devices have to be done so outside so as to limit the amount of smoke circulating within households.

Figure 5. Photograph of an Imbaula

The results gathered from the scale measurements of each household participating in this field study, are presented below. The amounts of both coal and wood consumed by each of the fifteen households were measured and then totalled, once the measurement data were collected. Figures 6 and 7 highlight the total consumption of wood and coal for one specific household over the 5 months. The average amounts of wood and coal consumed per day during the morning and evening burning periods by the 15 households are illustrated in figure 8.

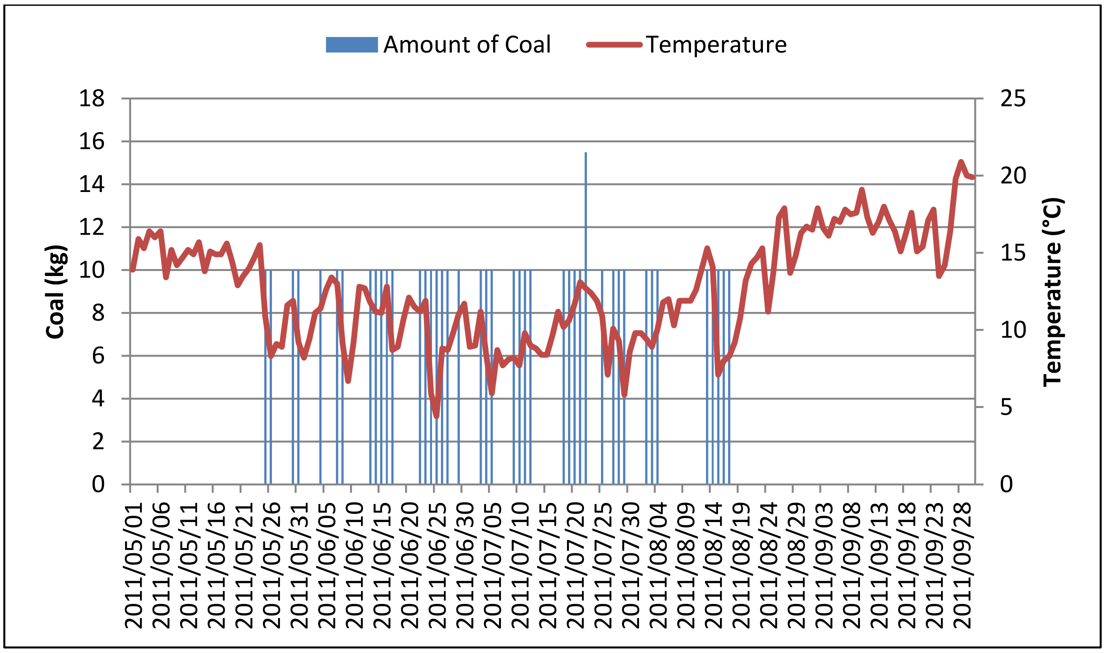
Figure 6. Total amount of wood burnt each day by Household 2 in Zenzele compared with the daily average temperature from May 2011 to September 2011.



This total consumption graph represents a combination of wood consumed in the morning and the evening from May to September 2011. As mentioned in the methodology, this study was done over a 5 month period in order to analyse the seasonal trends that might have arisen over the winter months. The amount of wood consumed by the residents of this household gradually starts to increase from May, into June and further in July, before decreasing in August and no consumption was recorded in September. This figure further illustrates that there is an inverse relationship that exists between the consumption of wood by household 2 and temperature. A large proportion of these households exhibit similar burning behaviours, being larger fuel combustion at lower temperatures. For almost all households, there is a gradual increase in the amount of wood burnt from May to June and a further, often very slight increase from June to July. After peaking around June and July, the amount burned slowly starts to decrease into August and September.

In certain instances, where this pattern was not followed, several explanations can be provided from information gathered from the questionnaires, as well as from conversations carried out with residents during regular visits to the study site. A common explanation for the deviation from this pattern was a variation in the number of people residing in a household from one month to the next, over the 5 month period. Family deaths, cultural gatherings and school holidays, were amongst some of the most common reasons for this variation. It is also interesting to note that the greatest peaks in fuel use occur the day after an unusually large drop in the temperature. When temperatures decrease drastically, people tend to expect similar temperatures the following day and therefore tend to burn more fuel irrespective of whether the temperature decreases or not.

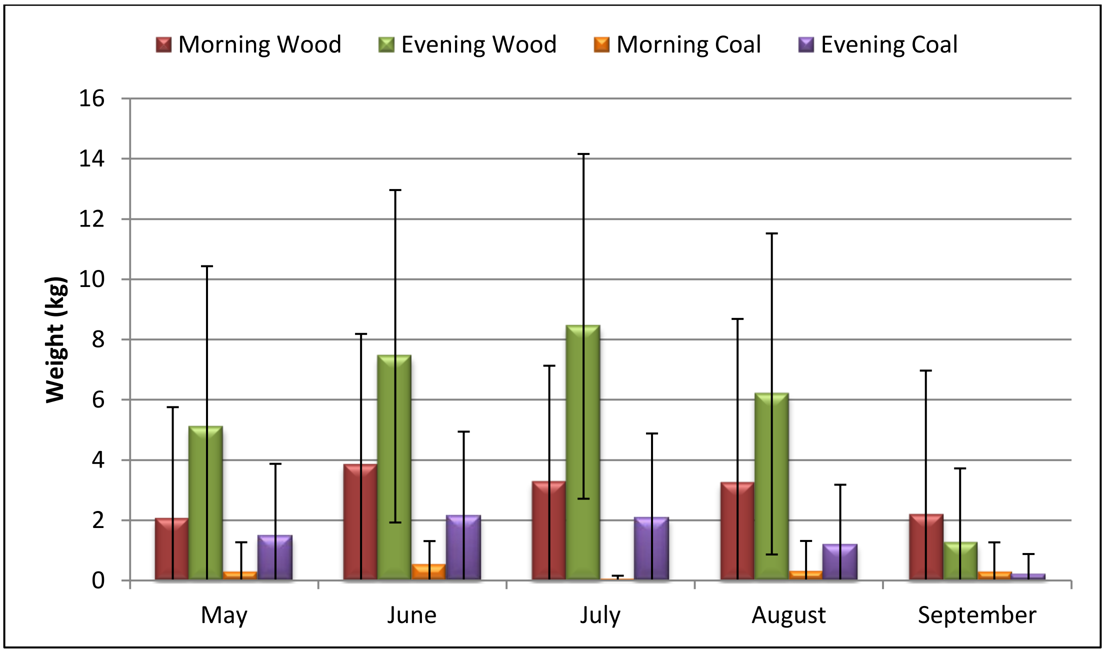
Figure 7. Total amount of coal burnt each day by Household 2 in Zenzele compared with the average daily temperature from May 2011 to September 2011.



A comparison of figures 6 and 7 highlights the total amount of coal burnt over this period is far less than that of wood. It was expected that the combustion of coal would follow the same seasonal trend as that of wood, but this is not the case. Coal is seldom burnt during May and September as these months are generally warmer than the winter months. During the months of June, July and August, however, the combustion of coal shows a very uniform pattern with the total consumption on all days, except one, being recorded at 10 kgs. This suggests that residents will probably limit their usage of coal to one 10kg bag per burning period if the household burns coal during both the morning and evening burning session or per evening. An analysis of the information provided in the two figures above shows that given no variation in the number of people residing in one household, the amount of coal consumed in a fire stays constant and is supplemented by wood as the temperature decreases over the winter period.

When residents of Zenzele were presented with various options of fuel types to choose from, in the questionnaire, there were instances where people chose more than one fuel. Residents explained that both coal and wood are commonly used fuels during winter, especially if a coal stove is owned. Both these fuels are burnt in larger coal stoves, in hand built stoves and even in imbaulas. When asked about which fuels were consumed at different times of the day, it was made clear that wood is generally burnt in the mornings if the need arises and, in the evening, coal and wood simultaneously, together in the same fire.

Figure 8. Average quantities of wood and coal consumed per day by all 15 households in Zenzele from May 2011 to September 2011.



The average amounts of wood and coal consumed per day during the morning and evening burning periods by the 15 households are illustrated in figure 8. The bottom and top caps of the error bars represent the standard deviation from the averages during each burning period, over that specific month. In most cases, an increase in the average consumption rates of both solid combustion fuels are seen during the colder months.

If there is only a limited supply of either fuel type, wood or coal, residents would prefer to utilise these stocks during the evening burning sessions. As most residents spend a limited amount of time in their homes in the morning before leaving for either school or work, the heat generated from a coal and/or wood fire would be wasted. For this reason, residents opt for other fuels that are more convenient to provide for their energy needs in the mornings. Once the cooking has been done and the fire has progressed through all the combustion stages, evening fires are generally rekindled to provide additional heat for warmth throughout the night.

Emission Estimates

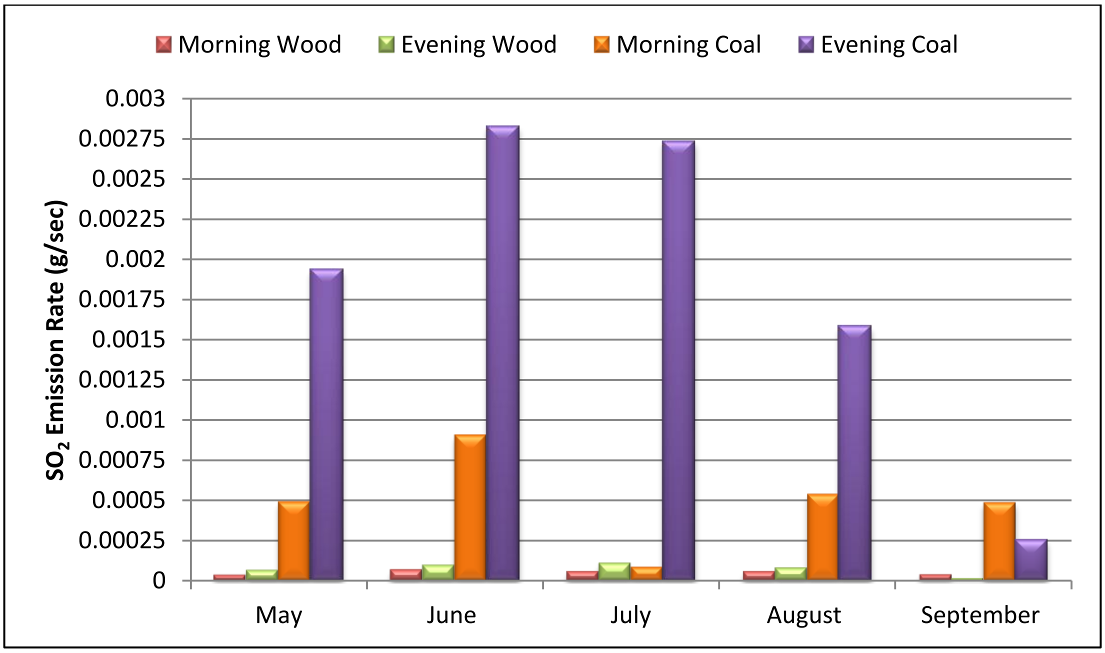
There is often a degree of uncertainty that arises when using emission factors that are not calculated within the study as they do not relate directly to the dataset being examined. For this reason, amongst some others, there is some uncertainty that, therefore, also exists within the emission estimates. Specifically, as was the case in this study, the most significant uncertainties in the emission estimates arose on account of human error. Using a set of emission factors adapted from the 2004 FRIDGE (Funds for Research into Industrial Development, Growth and Equity) Report, the data collected from the scale measurements were converted into emission estimates. The set of emission factors made use of in calculating the emission estimates are as follows: SO_2 for wood and coal and PM_{10} for wood and coal (Table 1).

Table 1. Emission factors used to calculate emission estimates (adapted from the FRIDGE Report, 2004)

	Units	SO_2	PM_{10}
Coal	g/kg	19	4.1
Wood	g/kg	0.18	15.7

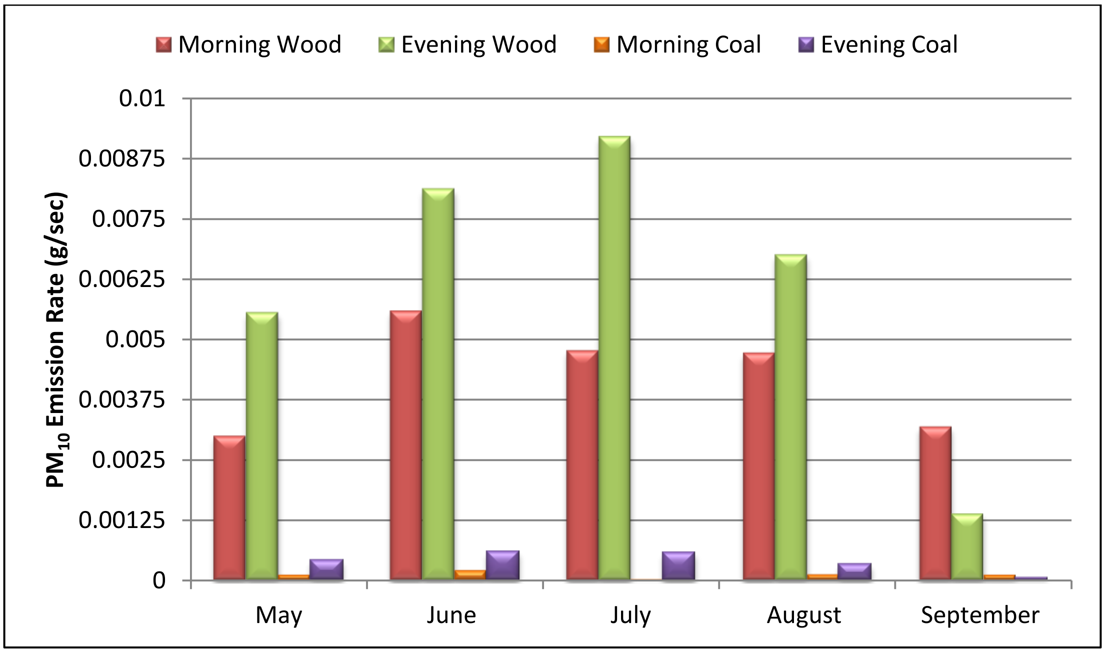
Figures 9 and 10 represent the average emission rates for all 15 households that correspond to the combustion of wood and coal during the morning and evening burning periods, for the two different pollutants under investigation. The emission factors associated with this set of pollutants are recorded on different scales and for this reason, although all the figures below apply the same base data, one graph will differ from the next. These emission estimates were calculated using a total burning period of 7 hours. It was assumed that the morning burning period lasts for 3 hours and the evening burning period lasts for 4 hours.

Figure 9. Average SO_2 emission rates per household in Zenzele from May 2011 to September 2011.



The average SO_2 emission rates that are associated with the 15 households are presented in figure 9. At 0.0028g/sec, the combustion of coal in the evening over the month of June has the highest emission rate for SO_2. The lowest SO_2 emission rate of 0.000016g/sec occurs in September during the evening combustion of wood. It has already been established and is evident in the consumption data that on average wood is consumed more frequently during both the morning and evening burning sessions. Figure 9, however, illustrates SO_2 emission rates for coal that are far higher than that of wood. This is attributed to the high emission factor associated with coal and SO_2; and therefore the greater amount of sulphur dioxide released when coal is burnt as opposed to wood.

Figure 10. Average PM_{10} emission rates per household in Zenzele from May 2011 to September 2011.



In figure 10, where the emission rates from wood combustion are more pronounced, the seasonal pattern associated with this type of combustion are evident. Generally the emission rates for both wood and coal are higher during the colder months. The highest emission rates occur during the evening combustion of wood from May to August but in September, however, the highest rate occurs during the morning combustion of wood. The emission rates for the evening combustion of wood peaks in July at 0.0092g/sec. As temperatures start to gradually increase, less fuel is required for space heating in the evenings and can therefore be used for other activities such as boiling water and cooking in the mornings. The highest PM_{10} emission rates that correspond with both the morning and evening burning sessions over this 5 month period are for wood.

Coal burnt in the mornings has the lowest emission rate, with a value of 0.000019g/sec being recorded in July. This is in line with the expected trend as the consumption of coal during the morning burning sessions is far less than that consumed during the evening burning session. Residents opt for creating labour and fuel intensive fires in the evenings so as to gain the maximum benefit of the heat generated. In addition, coal is utilised more in the evenings in a bid to save already limited funds, as the demand for this commodity drives prices up[17]. As a consequence of this increased demand, the supply and availability of both coal and wood can often also become a problem.

DISPERSION MODELLING

Predictions from CALPUFF

The time-averaged concentrations of SO_2 and PM_{10} as predicted by CALPUFF are presented in figures 11 to 13. The predicted maximum average hourly and daily concentrations of SO_2 and the maximum average daily concentrations of PM_{10} for Zenzele and Orange Farm were examined.

Figure 11. Maximum average hourly SO_2 concentrations in µg/m³ for Zenzele and Orange Farm from May 2011 to September 2011 for (a) the households that burn wood only, (b) the households that burn wood and coal simultaneously and (c) a combination of these two sources, representing all of the households.

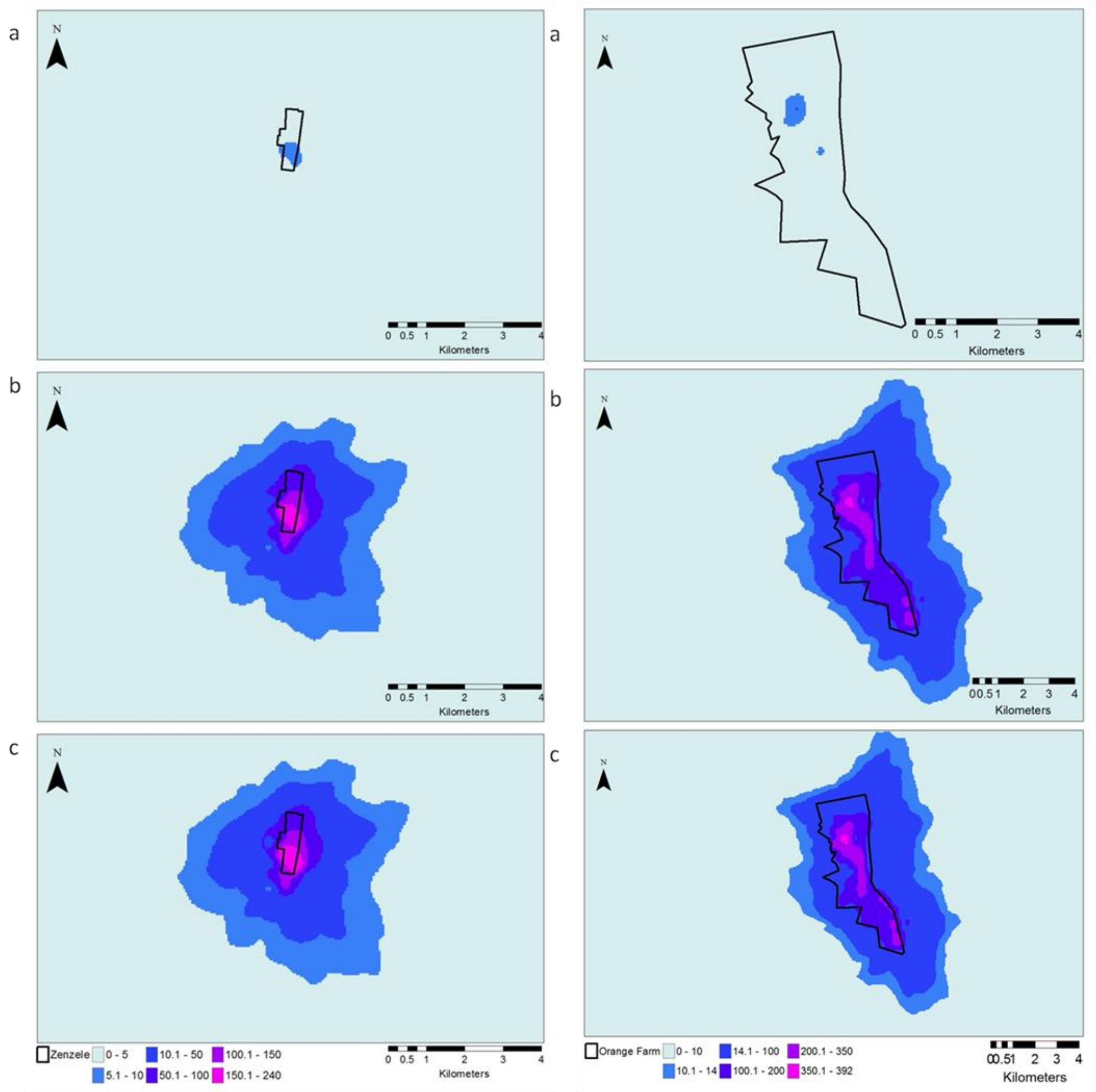
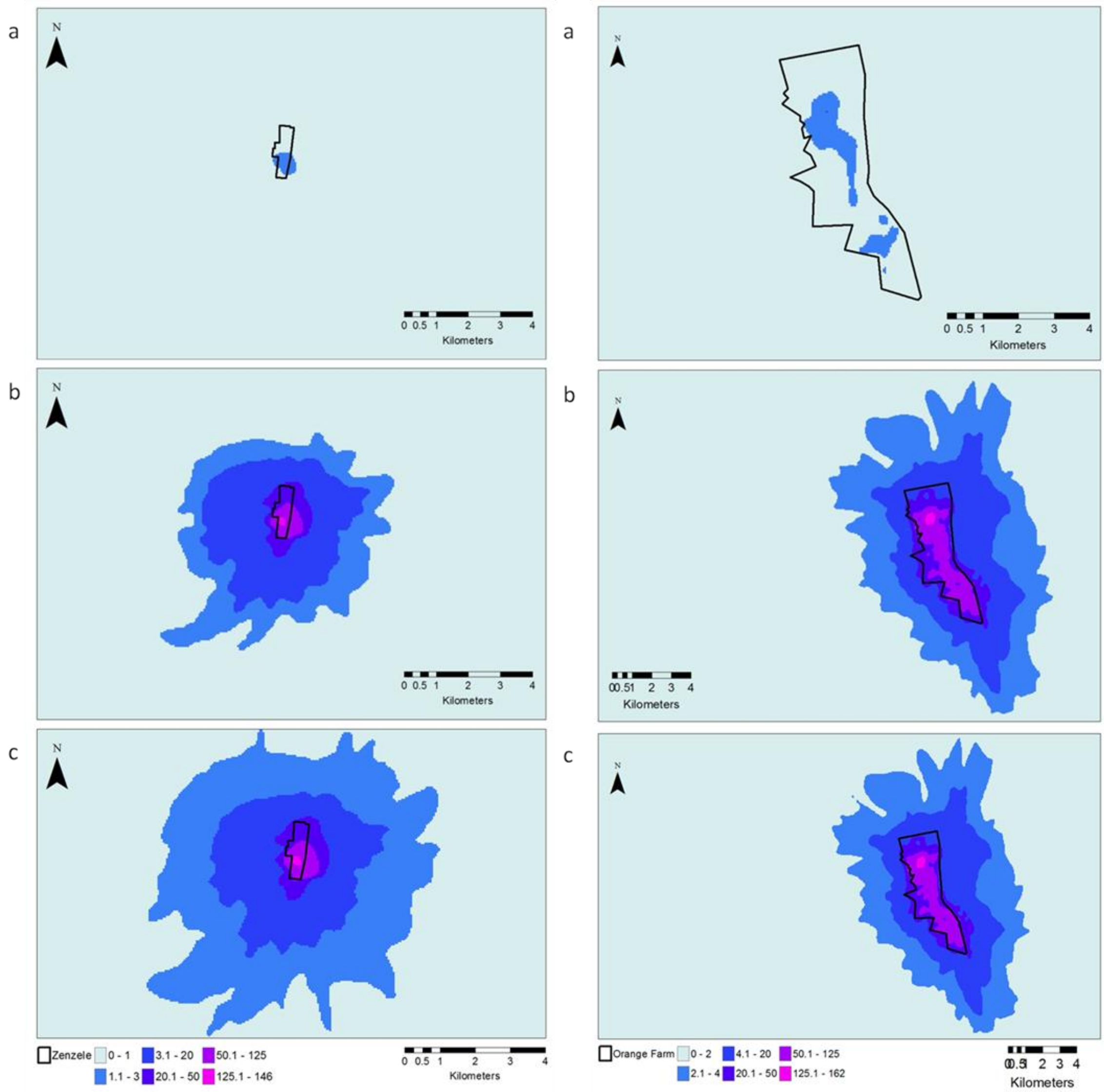


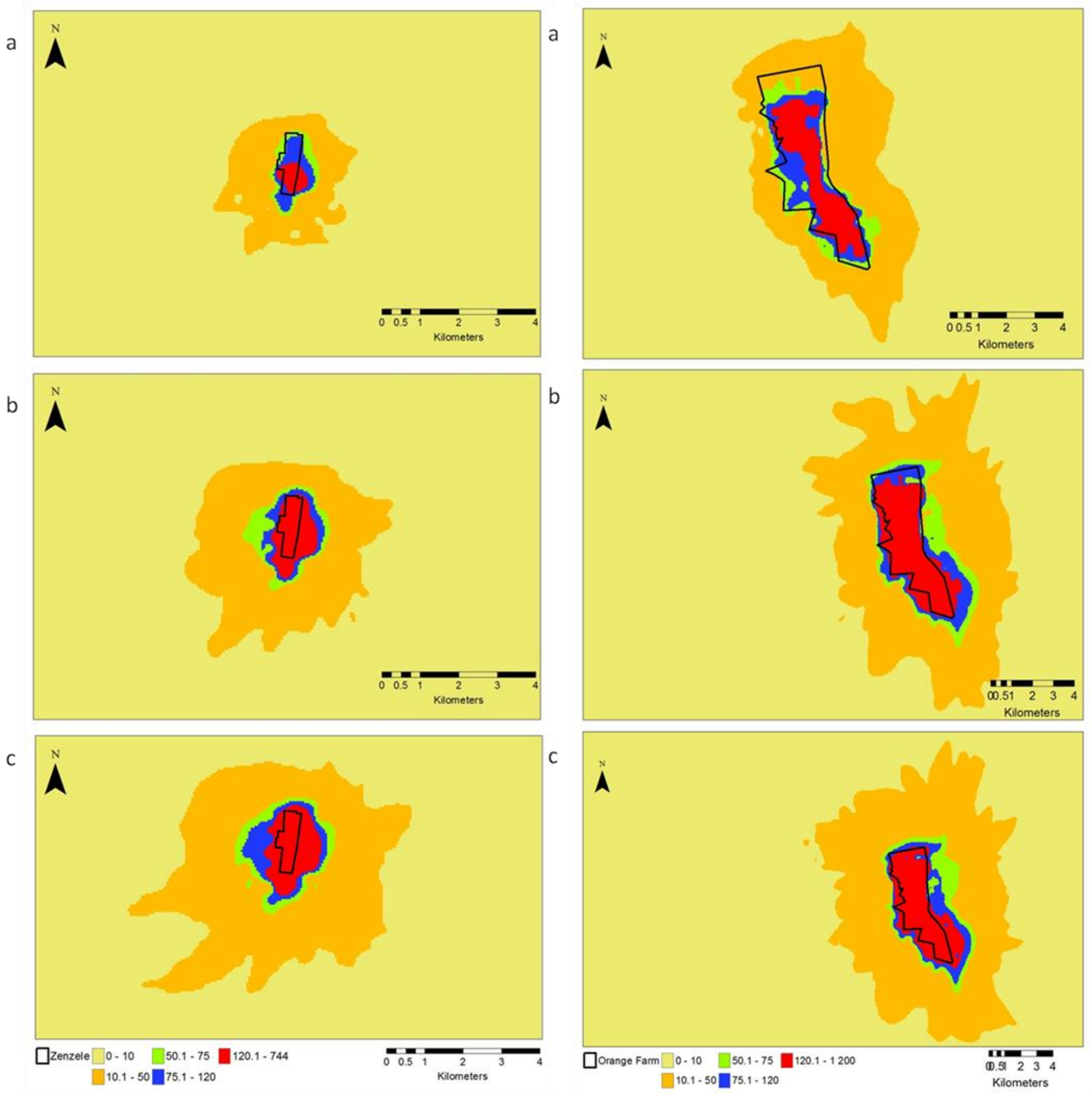
Figure 12. Maximum average daily SO_2 concentrations in µg/m³ for Zenzele and Orange Farm from May 2011 to September 2011 for (a) the households that burn wood only, (b) the households that burn wood and coal simultaneously and (c) a combination of these two sources, representing all of the households.



With reference to the maximum average hourly and maximum average daily concentrations of SO_2 in Zenzele and Orange Farm, figures 11 and 12 confirm that a significant portion of these SO_2 emissions are associated with the combustion of coal. This is in line with the calculated average emission rates for SO_2. The average SO_2 emission rates associated with coal were the most prominent because of the high emission factors, even though larger quantities of wood were consumed over the study period.

The current South African national ambient air quality standard (NAAQS) for the hourly and daily concentrations of SO_2 specifies limit values of 350µg/m³ and 125µg/m³ respectively. The maximum average hourly concentrations for Zenzele do not exceed this limit value but areas in Orange Farm that are highlighted in bright pink are in exceedence of this hourly limit value and have the potential to be in non-compliance with the South African NAAQS if this limit is exceeded more than the allowable frequency of exceedence. The maximum averages daily concentrations exceed the South African NAAQS limit value in both Zenzele and Orange Farm when the domestic combustion includes coal. The World Health Organisation stipulates a value of 20µg/m³ as the air quality guideline for daily concentrations of SO_2. The maximum average daily SO_2 concentrations that fall within the three highest classes, indicated by the purple, magenta and bright pink, all exceed this air quality guideline.

Figure 13. Maximum average daily PM_{10} concentrations in µg/m³ for Zenzele and Orange Farm from May 2011 to September 2011 for (a) the households that burn wood only, (b) the households that burn wood and coal simultaneously and (c) a combination of these two sources, representing all of the households.



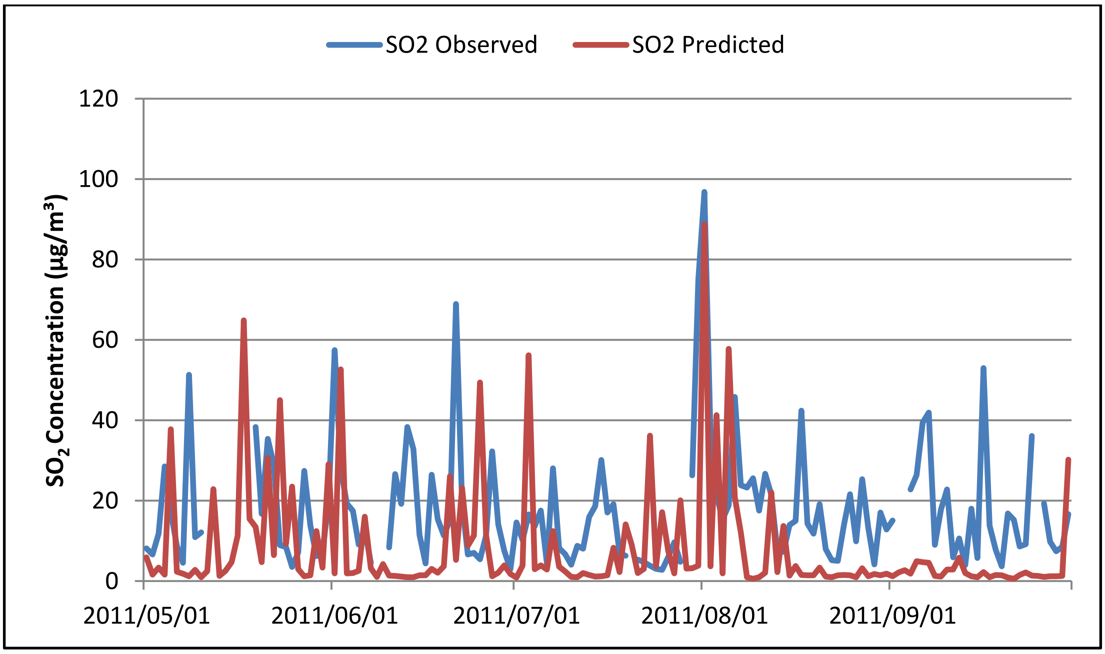
At the time of this study, the current and future South African national ambient air quality standards (NAAQS) associated with the daily concentrations of PM_{10} specified limit values of 120µg/m³ and 75µg/m³ respectively. Since then, the future NAAQS limit value has become the current one. It is evident in the panels of figure 13 that the current limit value of 75µg/m³ is being exceeded in Zenzele and Orange Farm. In fact, in both of the panels (b) and (c), the impact of the maximum average daily PM_{10} concentrations is noticeable over the entire outline of both settlements. Once again, the potential for exceedence of the current NAAQS is high.

The air quality guideline specified by the World Health Organisation (WHO) for daily concentrations of PM_{10} is 50µg/m³. Once again, this air quality guideline is exceeded in Zenzele and Orange Farm. Although this guideline is lower than South Africa's national standards, it is of great importance as it specifies the limit at which daily concentrations of PM_{10} become harmful to human health. With concentrations in all the panels of figure 13 significantly exceeding the WHO standard, the health impact on residents' of Zenzele and Orange Farm is of great concern.

Predicted and Observed Time-Series Comparison

The 24-hour average concentrations of SO_2 and PM_{10} that were predicted by CALPUFF for Orange Farm were compared with the average daily concentrations for the same two pollutants from data obtained from the City of Johannesburg's air quality monitoring station in Orange Farm.

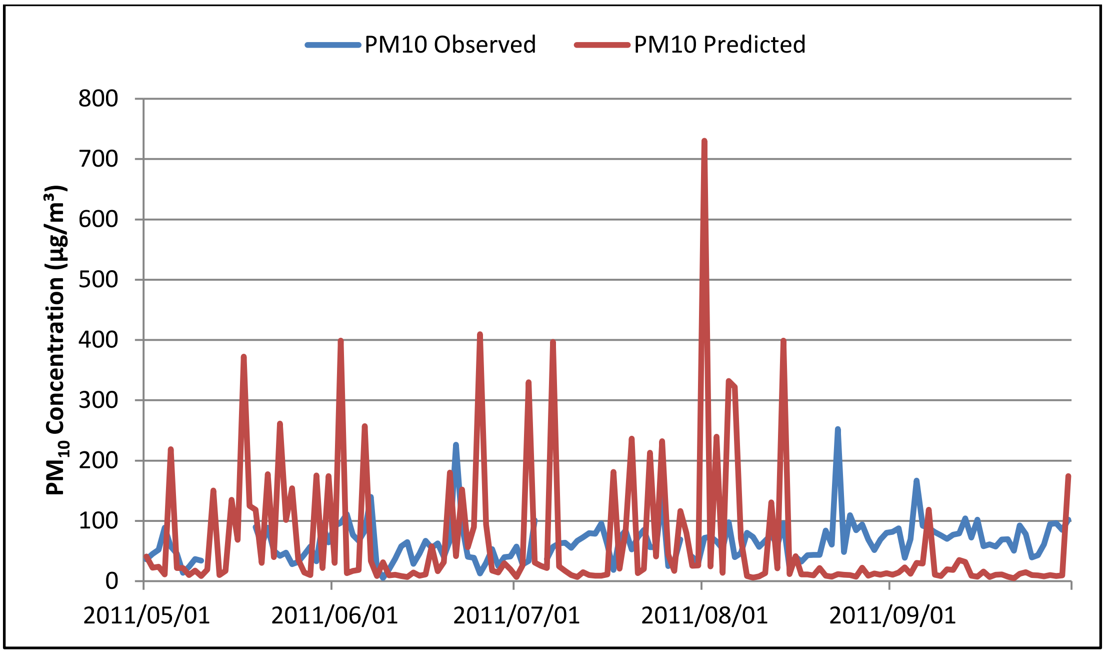
Figure 14. Observed and predicted 24-hour average concentrations of SO_2 in Orange Farm from May 2011 to September 2011.



In general, the model results for SO_2 compare well in magnitude with the measured data from the air quality monitoring station in Orange Farm (figure 14), indicating that the model setup was reasonable. Similar peaks are observed between the two datasets, the most striking of which, is the highest peak for the study period, occurring at the beginning of August 2011. Generally the base of the observed data tends to be a bit more elevated than that of the predicted data. This is to be expected as the time-series files created by CALPUFF for Orange Farm do not account for background concentrations of SO_2 that are captured at air quality monitoring stations, thereby under predicting the concentrations of SO_2. There are a number of other contributing sources of long-term ground level concentrations of SO_2 prevalent in the Vaal Priority Area that have an influence on the ambient concentrations of SO_2, including those measured at the City of Johannesburg's air quality monitoring station at Orange Farm. These sources include power generation, iron and steel processes as well as petrochemical processes.

CALPUFF also used a daily 7 hour burning period, where positive values were used to represent only the 7 hours of burning in a day and zero values were used to represent the non-burning hours. Ambient concentrations, however, that are measured at the monitoring station are done so throughout the day. These factors provide explanations for the discrepancies between the observed and predicted datasets such as the elevated base of the observed data.

Figure 15. Observed and predicted 24-hour average concentrations of PM_{10} in Orange Farm from May 2011 to September 2011.



Once again, in figure 15 the base of the observed data is elevated, highlighting the difference in the measurement periods and the presence of background concentrations of PM_{10} between CALPUFF and the Orange Farm air quality monitoring station. Common sources of long-term ground level concentrations of PM_{10} dominant in the Vaal Triangle Priority Area and specifically surrounding Orange Farm include smaller industries, iron and steel processes, power generation, mines, ferroalloy processes and petrochemical processes (DEAT, 2009). Data applied in CALPUFF were associated with a daily 7 hour burning period whereas the observed data cover measurements over a full 24 hour period. With that said, though, peaks in the predicted data tend to be higher than those of the observed data, indicating that the model is over predicting the concentrations.

The calculated ratio, used to differentiate between the households that burn wood only as opposed to those that burn wood and coal simultaneously, might not be accurately representative of Orange Farm and the emissions therefore overestimated. Although the section of Orange Farm used in the pilot study was un-electrified, large portions of Orange Farm are electrified. As discussed earlier, even if electrified households continue to use solid fuels, the convenience of using electricity can outweigh the savings gained when using solid fuels, thereby reducing the combustion of wood and coal. Large quantities of wood and coal are burnt in Zenzele as this settlement is completely un-electrified and residents do not have the option of using electricity. Model inputs used in CALPUFF for Orange Farm were based on the emissions data associated with Zenzele's solid fuel consumption and for this reason if households in Orange Farm consume less solid fuels, CALPUFF would over predict their emissions. As coal is more readily available to residents of Orange Farm, the settlement as a whole consumes more coal during domestic combustion than wood. This is evident in the lower PM_{10} concentrations present in the observed dataset. Smaller quantities of wood as opposed to coal suggest not only lower concentrations of PM_{10}, but also increased concentrations of SO_2 as highlighted in figure 14.

CONCLUSION

Faced with the option of different fuels, residents in Zenzele chose more than one fuel type, especially during winter, where wood is generally burnt in the mornings and coal and wood were used in the evenings simultaneously. In general the emission estimates for SO_2 and PM_{10} are higher during the colder winter months. They start to increase towards the end of May, and peak in July, followed by a gradual decrease during August and September. Factors such as seasonality, the price and the availability of fuels as well as cultural aspects all have major influences on the fuel type and the quantity consumed. From the above, it is clear that there are significant seasonal variations in both the types and amount of fuels consumed during domestic combustion in low-income settlements.

An additional component of this study was to determine whether the emission rates from one low-income settlement could potentially be used to quantify and further predict the emissions generated as a result of domestic combustion, from other low-income settlements that exhibit similar burning behaviours. This was done using the dispersion modelling tool, CALPUFF and comparing the predicted output concentrations to observed concentrations from an air quality monitoring station situated in the same area. Besides having a comprehensive understanding of each individual settlement's dynamics, an important limitation of this process; in trying to use one low-income settlement's emission rates to estimate the emissions of another low-income settlement, is that this process does not account for individual household's social and cultural aspects associated with domestic fuel combustion.

In spite of the uncertainties and limitations associated with the modelling process and the potential for the widespread application of one low-income settlement's emission rates, the results obtained from this study represent an important assessment of the components necessary in achieving an objective such as this. It is possible to apply the emission rates associated with one low-income settlement to another with a degree of uncertainty but this process will require more than just linking two different households, located in two different settlements, to each other using similarities in burning behaviours and the number of people that reside in a household.

Another important focus of this study was to shed some light on common domestic fuels, consumed in low-income settlements in Johannesburg. With reference to the responses of the questionnaires answered in Zenzele, Orange Farm and Soweto, it was discovered that within both electrified and un-electrified settlements large quantities of solid domestic fuels are still being consumed. Although not as widely used during the warmer months, wood and coal are common fuels burnt frequently in low-income settlements during the colder winter month. In identifying these common fuels and highlighting the patterns in which they are utilised, this study further provides a dataset on the consumption rates of these fuel types, and in so doing, attempts to address in some way the uncertainties associated with their consumption.

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KEYWORDS

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